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GEOLOGICAL SURVEY
Ground Water Branch

# GEOLOGY, HYDROLOGY, AND WATER SUPPLY OF EDWARDS AIR FORCE BASE, KERN COUNTY, CALIFORNIA

By
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## ABSTRACT

Edwards Air Force Base occupies the northern part of Antelope Valley, California. As a result of large-scale and increasing agricultural pumping in the valley, the net draft has exceeded the perennial supply since about 1930 and was about 170,000 acre-feet in 1951--at least three times the estimated yield. As a result, there has been a continuing depletion of ground water stored in all the unconsolidated deposits, including the principal aquifers contained in the younger and older alluvium.

The rate of depletion beneath the Air Force Base was about 7,000 acre-feet per year during the period 1940-52 and had increased to about 13,000 acre-feet in 1960. The amount of stored water as of 1952 in the upper 200 feet of saturated deposits beneath the Base was roughly 1,400,000 acre-feet, which at the 1960 rate of depletion would last about 100 years. However, continued increase in the rate and planned increase in Base pumpage from 4,500 acre-feet in 1959 to 8,000 acre-feet per year suggest that the supply might be depleted in 75 years. On the other hand, additional stored water is available at greater depth and in the nearby Chaffee area, where about 200,000 acre-feet of water is stored in the upper 200 feet of saturated deposits and where in 1960 only a minor amount of pumping occurred.

The prolonged overdraft in Antelope Valley has resulted in cessation of flowing wells, which in 1911 could be obtained in an area of about 240 square miles, and has created a valley-wide pumping depression centering around a point about 2 miles south of the Air Force Base. Approximately 70 percent of the total depletion in storage beneath the southern part of the Base is attributed to drainage of ground water toward this pumping depression. The effects of the pumping extend at least as far north as Rogers Lake barrier, an east-trending granitic-rock ridge buried beneath the central part of Rogers Lake. In 1959 water levels to the north were about 50 feet lower than those to the south. Water moves northward from the barrier across the northern part of Antelope Valley to Fremont Valley.

In the central part of Antelope Valley, two major water-bearing zones were identified--a principal water-bearing zone contained in the younger and older alluvium and an underlying deep zone contained in the older alluvium; they are separated by lacustrine clay of Pleistocene age. Irrigation wells tap both zones, but the Air Force obtains most of its supply from the deep zone. In general, the quality of water is satisfactory for irrigation and public supply.

# INTRODUCTION

## PURPOSE AND SCOPE OF THE INVESTIGATION

Edwards Air Force Base occupies parts of the alluviated floors of several intermontane valleys in the western part of the Mojave Desert region of California. The alluvial valley fill is partly saturated with fresh ground water, which is drawn upon for water supply for the Air Base and for intensive irrigation of agricultural areas outside the Base boundary. There is little natural recharge to this valuable ground-water resource; thus, any ground water that is withdrawn results in more or less permanent depletion of the total ground-water supply available. Therefore, it is desirable to know how much fresh ground water is available, where it occurs, and how long it will last at a given rate of depletion.

The investigation of the geology and the ground-water appraisal of Edwards Air Force Base and vicinity, California, was started by the U.S. Geological Survey in October 1950 at the request of the Department of the Air Force. Specifically, the Geological Survey was requested to make a study of the Air Base and adjacent areas to determine the adequacy of the ground-water resources to supply a potential maximum pumpage of approximately 7 million gallons per day (roughly 8,000 acre-feet per year), to determine whether this amount of ground water could be withdrawn annually without seriously lowering the water levels in the vicinity of the Base or in adjacent areas, and to suggest the most feasible areas for any future supply wells.

This report (1) describes the geology of Edwards Air Force Base and vicinity with particular reference to the water-bearing deposits; (2) outlines the occurrence, source, and movement of ground water; (3) describes the degree of hydraulic continuity between ground waters beneath the Base and those in Antelope Valley, which is a large farming area; (4) discusses the water-level fluctuations with particular reference to the amount of lowering of water levels in the vicinity of the supply wells on the Air Force Base, and comments on the probable accelerated lowering of levels if the pumpage were increased from the 1.6 million gallons per day in 1953 to the potential maximum of 7 million gallons per day; (5) describes the chemical quality of the ground water in several basins; and (6) estimates the ground-water-storage capacity of the Main Base area and North Muroc basin, and discusses the adequacy of the estimated ground water in storage in relation to the potential maximum pumpage of 7 million gallons per day.

In addition to the material contained in this report, all the data for wells on and near the Base were collected; these are presented in separate reports (Dutcher, 1959a; Dutcher, Bader, Hiltgen, and others, 1961; Kunkel and Dutcher, 1961).

The fieldwork was begun in August 1950 and was temporarily terminated in May 1953; was resumed in July 1956 and completed in January 1960. A continuing program at the Base was started in July 1957 to keep the Air Force advised of the status of the ground-water supply.

The investigation was made by the Geological Survey, U.S. Department of the Interior, starting under the general supervision of J. F. Poland, district geologist in charge of ground-water investigations in California. The final phases of the work were completed under the general supervision of H. D. Wilson, Jr., district engineer, and under the immediate supervision of Fred Kunkel, geologist in charge of the Long Beach subdistrict office. The fieldwork for this study was done mainly by R. S. Brown, R. L. Wait, and W. J. Hiltgen of the Long Beach office.

The geologic mapping of the consolidated rocks is largely after published and unpublished mapping by T. W. Dibblee, Jr., U.S. Geological Survey.

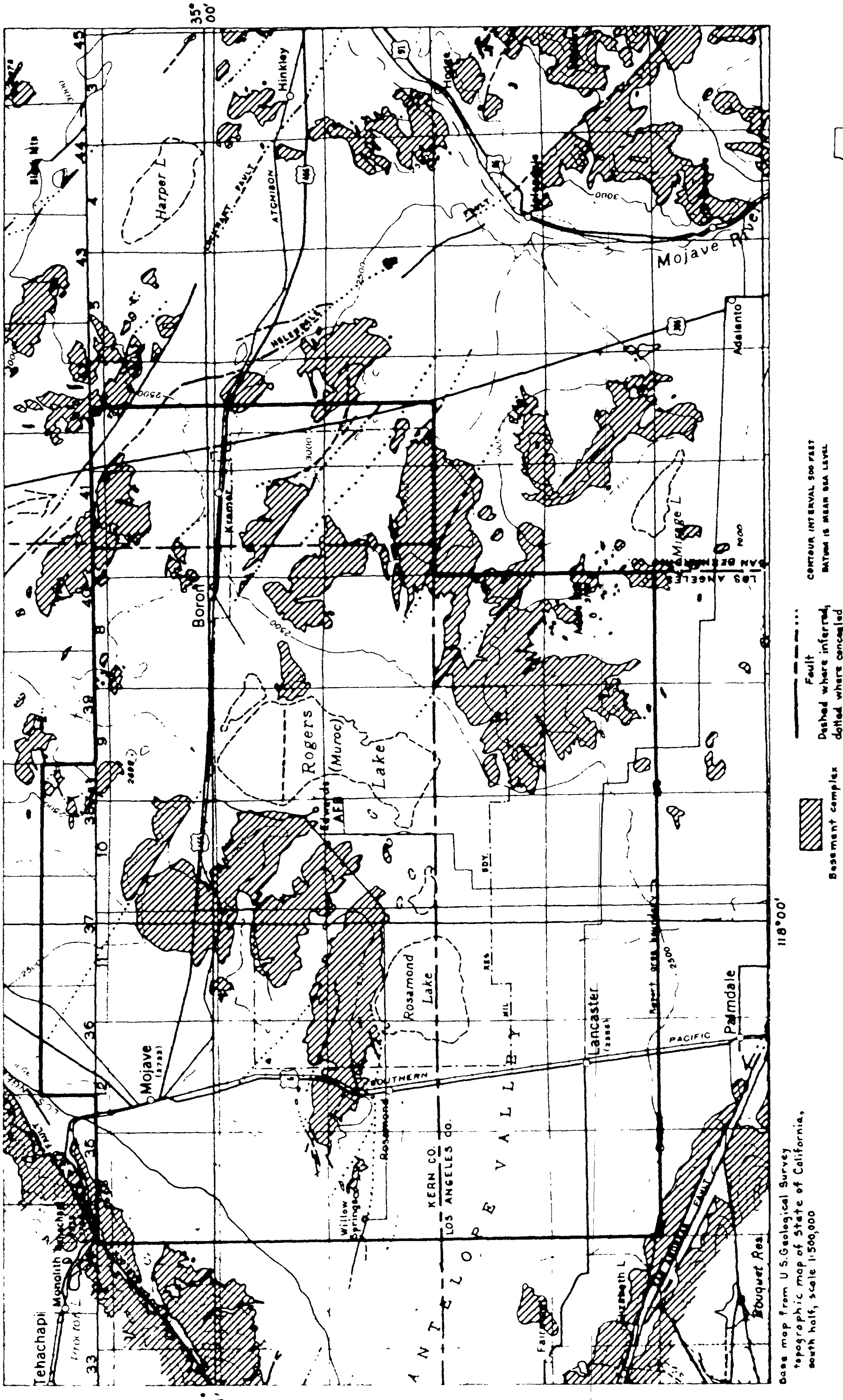
The initial investigation was supported by funds supplied by the Department of the Air Force. The report was revised for publication with funds supplied by the Geological Survey and the California Department of Water Resources.

## LOCATION AND GENERAL DESCRIPTION OF THE AREA

Edwards Air Force Base is in the south-central part of California near the western edge of the Mojave Desert region. Most of the Base is in the southeastern part of Kern County, and minor areas are in the western part of San Bernardino and northern part of Los Angeles Counties. It is about 60 miles north-northeast of Los Angeles in the northern part of Antelope Valley. The boundary of the Base shown on figure 1 covers an area of about 470 square miles and has a maximum east-west extent of 34.5 miles and a maximum north-south extent of 17 miles.

The area includes not only the Air Force Base but also an additional 700 square miles around the south, west, and north sides of the Base. The total area of investigation covers about 1,200 square miles and is included between 34°39' and 35°08' north latitude and 117°32' and 118°19' west longitude (figs. 1 and 1A).

The principal highways are U.S. Highway 6 (fig. 2), which traverses the western part of the area, U.S. Highway 395, which crosses the eastern edge of the Base, and U.S. Highway 466, which, except locally, bounds the northern edge of the Base. The Southern Pacific railroad parallels U.S. Highway 6, and the Atchison, Topeka, and Santa Fe Railway generally parallels U.S. Highway 466 (fig. 2).



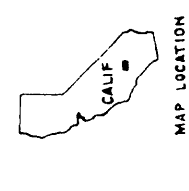




FIGURE 1.—Index map of part of southern California showing area described by this report

The area of investigation includes the northern half of the Antelope Valley drainage basin and the southern part of the Fremont Valley drainage basin. The results of this study show that the surface-drainage basin boundaries do not necessarily coincide with ground-water basin boundaries. The northern part of Antelope Valley includes Lancaster and North Muroc Basins, all the Gloster area, and the south half of the Chaffee area; the southern part of Fremont Valley includes the north half of the Chaffee area and the southern end of the Koehn Lake area. As is discussed in this report, these basins and areas are separated by bedrock hills, narrows, or ground-water barriers. In 1958 there was virtually no development of ground water in North Muroc basin, or in the Gloster and Chaffee areas.

The area of investigation is covered by the following topographic maps: U.S. Geological Survey maps at a scale of 1:24,000 include Adobe, Casa Desierta, Del Sur, Esperanza School, Hi Vista, Joshua, Lancaster, Lovejoy Springs, Oban, Roosevelt School, Tierra Bonita, West Alpine Butte, and Wilsona--all in Los Angeles County; Corps of Engineers, U.S. Army, maps at a scale of 1:24,000 include Bissell, Castle Butte SE, Desert Butte, Johannesburg SE, Johannesburg SW, Kramer, Kramer SW, Mojave, Mt. Mesa, Plano, Red Buttes, Redman School, Rich Rosamond, Rosamond Lake, and Soledad Mountain--mostly in Kern County; and Corps of Engineers, U.S. Army, maps at a scale of 1:62,500 include parts of Alpine Butte, Castle Butte, Mojave, Tehachapi, and Willow Springs--also mostly in Kern County.

## GEOGRAPHY

Antelope and Fremont Valleys are in the western part of the Mojave Desert region. The main geographic features of these valleys are shown on figure 1A. Each is a desert valley having interior surface-water drainage that terminates in a playa, or dry lake. Broad alluvial fans extend from the surrounding mountains to the playas. These two valleys adjoin within the area of investigation and northeast of Mojave are separated only by an indistinct drainage divide south of which (in Antelope Valley) infrequent runoff reaches either Rosamond or Rogers Lake and north of which infrequent runoff reaches Koehn Lake. The general area comprising these two valleys is roughly triangular in shape and is a structural basin that in general has been downdropped between the Garlock and San Andreas faults (fig. 1A).

On the south, the valley is bordered by the northwest-trending San Gabriel Mountains and their westward extension, Sawmill and Libre Mountains, and on the northwest by the northeast-trending Tehachapi Mountains. Less rugged hills border the area on the east. In the northwest part of the Air Force Base a group of low hills and ridges, herein called the Rosamond and Bissell Hills, extends westward from Edwards to near Willow Springs.

All streams entering the valley areas from the surrounding highlands are ephemeral; that is, they flow only for a few hours or days as the result of infrequent summer rainstorms or during winters when precipitation is large. Of these streams that flow from the San Gabriel Mountains into Antelope Valley, Rock and Little Rock Creeks are the largest and contribute the most runoff. The dry courses of typical streams abruptly widen from narrow channels in the mountains to indistinct washes half a mile or more in width downstream from the mountain fronts. Rock Creek wash extends into the valley as far north as Lovejoy and Alpine Buttes, whereas Little Rock Creek grades out onto the valley floor and is nearly indistinguishable beyond sec. 10, T. 7 N., R. 11 W.

Cottonwood Creek is the largest stream entering Antelope Valley from the Tehachapi Mountains on the west. This stream, similar to those entering the valley from the San Gabriel Mountains, has contributed to the deposition of a large alluvial fan extending toward the dry lakes from the mountain front. The course of Cottonwood Creek is traceable as a well-defined dry wash to the vicinity of Willow Springs beyond which it fans out into numerous minor distributaries.

Oak Creek (fig. 1A), which also flows into Antelope Valley from the Tehachapi Mountains, contributes some runoff to the valley. Thompson (1929, p. 299, pl. 19) states that floodwaters of this stream probably flow both southward into Antelope Valley and northward into Fremont Valley. However, more recent topographic maps show that no part of this stream is tributary to Fremont Valley and that the drainage divide between Antelope and Fremont Valleys is between Oak Creek and Cache Creek (fig. 2).

Numerous minor unnamed streams enter the valley from the east and southeast. Because they drain areas of relatively low precipitation, they contribute only small amounts of recharge to ground water. However, they have formed relatively large alluvial fans along the mountain fronts.

All major streams entering the southern part of Fremont Valley head in the Tehachapi Mountains, and infrequently during periods of large runoff, drain to Koehn Lake, which is about 25 miles northeast of Mojave. The largest of these streams is Cache Creek, which crosses the Chaffee area north of Mojave.

As shown on the topographic maps, the highest altitudes of the drainage divides are 9,389 feet above sea level in the highest part of the San Gabriel Mountains (North Baldy), 7,988 feet in the Tehachapi Mountains (Double Mountain), 3,203 feet along the northern margin in the Bissell Hills, and about 3,452 feet at Adobe Mountain along the eastern margin. The lowest altitudes in Antelope Valley are the surfaces of Rosamond and Rogers lakes, which are about 2,275 feet above sea level.

The lowest point in the drainage divide surrounding Antelope Valley is about 2,360 feet in the low pass between Desert and Castle Buttes (fig. 1). This low point was described by Thompson (1929, p. 304) and H. S. Gale (in Hubbs and Miller, 1945, p. 88) as probably being the former site of an ancestral stream wash which drained from Antelope Valley to Fremont Valley.

## CLIMATE

The climate of Antelope Valley and vicinity within the area of investigation is arid and temperate. U.S. Weather Bureau records collected at the Backus Ranch, between Lancaster and Mojave at an altitude of 2,620 feet, indicate that the mean annual temperature is $61\frac{1}{2}^{\circ}$F. Records are not available for confirmation, but elsewhere in the valley, at greater distances from the mountains and at lower elevations, the mean annual temperatures probably are somewhat higher. High temperatures of $110^{\circ}$ to $115^{\circ}$F are not uncommon during the summer months; temperatures as low as $15^{\circ}$F have been recorded infrequently during the winter. The mean annual temperature is comparable with areas in the coastal valleys to the south and west, but the daily range in temperature is usually much greater. Thompson (1929, p. 307) reports that temperature ranges between daily maximum and nightly minimum temperatures frequently amount to $30^{\circ}$ and sometimes to $45^{\circ}$F.

Precipitation, most of which occurs as rain during the winter months, is slight and in general decreases with lower altitude and distance from the mountains. The high mountains interrupt the course of moisture-laden air currents which in winter move inland from the Pacific Ocean, cause them to rise, and consequently precipitate most of their moisture as rain (snow at high altitudes) on the mountains. As a result, the precipitation on the desert to the northeast is considerably less than that required to support crops. Thundershowers occur infrequently during the summer months, and, although local in extent, a single storm sometimes may constitute a high percentage of total annual precipitation at any given locality. Occasionally some precipitation in the form of snow falls, even in the lowest part of the valley. However, it generally melts within a few hours. U.S. Weather Bureau records indicate that the annual precipitation at Mojave has ranged from a trace in 1883 to 12.09 inches in 1890. The average mean annual precipitation for the period of record 1877-1914 is 4.84 inches. The rainfall probably is somewhat less on playas where the altitude is lower and the distance from the mountains is greater.

The prevailing wind in Antelope and Fremont Valleys is from the southwest, and frequently is strong and carries sand and silt, which are deposited locally as dunes. U.S. Weather Bureau records collected at Backus Ranch, Calif., show that the wind movement and evaporation are greater during the summer than the winter. The average monthly wind movement for the period 1939-55 is 3.8 miles per hour and ranges from 1.9 miles per hour in December and January to 5 miles per hour in June.

The average annual evaporation (from standard U.S. Weather Bureau pan) for the period 1936-55 is 116.56 inches and ranges from 2.92 inches in December to 18.79 inches in July.

## PREVIOUS INVESTIGATIONS

### Ground-Water Investigations

Several publications contain data concerning occurrence and use of ground water for irrigation in Antelope Valley and vicinity. However, comparatively few contain data relative to the specific problems with which this report is concerned.

The first hydrologic work in the area was a reconnaissance investigation by Johnson (1911), which deals principally with occurrence of ground water in the central part of Lancaster Basin. A map showing the extent of flowing wells in 1908 is included, as well as a general discussion of various geologic features including the Rosamond fault (fig. 2).

The classic report by Thompson (1929, p. 201-223, and 289-371) on the Mojave Desert region contains a section on ground water in Antelope and Fremont Valleys. Plate 19 of Thompson has been modified for use as the area-location map for this report (fig. 1A). Thompson discusses the historical background, early development, and use of ground water, the general geology, the occurrence and movement of ground water, and the area of artesian flow in 1914 and 1919. The report includes some data on runoff for the period 1923-26. Also included is a similar discussion of the Fremont Valley area (Thompson, 1929, p. 201-223). That paper also includes an introductory section containing an excellent discussion of the historical and cultural background of the Mojave Desert region.

A report by the California Division (now Department) of Water Resources (1947) deals primarily with the pumping overdraft of Antelope Valley. That report contains maps showing principally the water-level contours in Antelope Valley for the autumn of 1946 and lines of equal specific yield of the deposits in the valley, changes in elevation of the water table from the end of the irrigation season in 1943 to the same period in 1945.

A second report by the California Division of Water Resources (1955) continues the pumping-overdraft study which began with the 1947 report. It contains maps showing water-level contours "in the pumping zone" for the spring of 1954, location of proposed Feather River project aqueduct, major distribution lines, and reservoirs, and contains pumpage data for the valley.

In a report by Snyder (1955) the pumping overdraft in Antelope Valley is discussed with particular regard to the economics of crop production by use of irrigation water pumped under conditions of large overdraft and continuously declining water levels. That report contains tables showing the consumptive use of various crops and estimates of typical annual irrigation applications, annual draft on ground water, consumptive use of ground water, costs of pumping installations, and prices received for agricultural products during the period 1920-51.

An unpublished hydrologic report on the area near Mojave was prepared in 1930 by Mr. Cyril Williams, Jr., Consulting Engineer for the Pacific Portland Cement Co. It deals with the occurrence and movement of ground water in the Gloster and Chaffee areas and the northern part of Lancaster Basin.

## Geologic and Mineral Investigations

The geology of Antelope Valley was first observed casually in the early 1840's by explorers seeking overland routes across the desert to southern California (Thompson, 1929, p. 11). Since that time several reports dealing with geology have been published. Principal among these are papers by Hershey (1902) on Tertiary stratigraphy, Simpson (1934), Wiese and Fine (1950) on geologic structures, Wiese (1950) on the geology of the Neenach quadrangle, Noble (1954) and Roberts (1951) on the geology of the Rosamond (and Bissell) Hills, and Gale (1946) on geology of the Kramer borate district.

## ACKNOWLEDGMENTS

During this investigation, a large amount of data was furnished by the Los Angeles office of the California Department of Water Resources. This material included 140 well logs and 82 records of water levels for wells within the area of investigation. The Los Angeles County Flood Control District supplied copies of well-location maps and well records. Additional well logs were supplied by well drillers and property owners. The collection of this material and other data on individual wells was greatly facilitated by the willing cooperation of numerous well drillers, private individuals, and property owners who freely supplied the information.

Mr. Cyril Williams, Jr., consulting engineer, San Francisco, Calif., kindly loaned to the Survey an unpublished consulting report on the hydrology of the Mojave area for use during the investigation. This report contains many water-level records which were freely drawn upon in the preparation of this report.

The Corps of Engineers, U.S. Army, also supplied data on water levels, well locations, well logs, and chemical analyses of water from old wells near Rogers Lake and from the existing Base supply wells.

## FIELD LOCATIONS OF WELLS

As part of the investigation of Edwards Air Force Base and vicinity, 1,102 wells were inventoried by the Geological Survey and their locations are shown on figure 2. Of this total, 345 are within the Base boundary and 757 are in the surrounding area. The principal purposes of the inventory were to measure water levels and well depths, assign well numbers to existing or destroyed wells, to ascertain the areal distribution and use of wells on and near the Base, to select representative wells for sampling for chemical analysis, and to select observation wells for periodic measurements of water levels. These data were used to construct water-level contour maps, geologic cross sections, and water-level profiles, chemcial-quality maps, and hydrographs, which in turn were used to interpret the geologic character and hydrologic features of the water-bearing deposits.

All descriptions of wells within the Base, together with well logs, water-level records, and chemical analyses, have been compiled in three data reports (Dutcher, 1959a; Dutcher, Bader, Hiltgen, and others, 1961; and Kunkel and Dutcher, 1961).

## WELL-NUMBERING SYSTEM

The well-numbering system used by the Geological Survey in the Edwards Air Force Base and vicinity area investigation conforms to that used in all recent ground-water investigations made by the Geological Survey in California. It has been adopted as official by the California Department of Water Resources and by the California Water Pollution Control Board.

The wells are assigned numbers according to their location in the rectangular system for the subdivision of public land. For example, in the number 8/11-35J2, the part of the number preceding the slash indicates the township (T. 8 N.), the part between the slash and the hyphen is the range (R. 11 W.), the number between the hyphen and the letter is the section (sec. 35), and the letter indicates the 40-acre subdivision of the section as shown in the accompanying diagram.

| | | | |
|---|---|---|---|
| D | C | B | A |
| E | F | G | H |
| M | L | K | J |
| N | P | Q | R |

Within each 40-acre tract the wells are numbered serially as indicated by the final digit. Thus, well 8/11-35J2 is the second well to be listed in the NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 35 (San Bernardino base and meridian).

Similarly, well 32/36-21Q1 is in the SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 21, T. 32 S., R. 36 E., Mt. Diablo base and meridian. Because all the wells in the Edwards Air Force Base and vicinity area are either in the northwest quadrant of the San Bernardino base and meridian lines or in the southeast quadrant of the Mt. Diablo base and meridian lines, the foregoing abbreviations of the township and range are sufficient.

For wells not field located by the Geological Survey, the 40-acre tract letter has been omitted and replaced with a letter "Z." Thus, 9/8-8Z1 indicates a well that was plotted on the map from an unverified location description, and the location is only approximate.

The well-numbering system is also used in modified form as a convenient means of locating a feature described in the text. For example, an area or feature within the NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 7, T. 9 N., R. 10 W., may be identified as 9/10-7M.

# GEOLOGY

## LANDFORMS

Antelope and Fremont Valleys are the topographic expression of the major structures in the bedrocks, as modified by stream erosion and deposition. Because the structural and climatic history of the valleys are complex, so too is the physiographic history. The results of this investigation and the findings in other parts of the Mojave Desert region strongly suggest that the existing major landforms were evolved during the Pleistocene epoch.

Edwards Air Force Base is in the western part of the Mojave Desert region in a depressed area between the San Gabriel and Tehachapi Mountains. On and near the Base the landforms are of three types: the low hills and buttes underlain in large part by consolidated sedimentary and igneous rocks; the alluvial fans extending outward from the hills; and lowland features comprising the dry lakes, or playas, the related old shorelines, and sand dunes.

## Hills and Buttes

### Rosamond and Bissell Hills

The Rosamond and Bissell Hills occupy the central part of the area covered by this report (fig. 2). They have been referred to by Johnson (1911, p. 20) as the Rosamond Buttes and by the California Division of Water Resources (1947, p. 3) as the Soledad upland. The Rosamond Hills of this report extend eastward from near Willow Springs to Rogers Lake and the Bissell Hills extend northward nearly to Desert Butte (fig. 1A). The hills rise to altitudes of 3,450 feet--nearly 1,200 feet above the surfaces of the adjacent dry lakes.

Along the south side the hills have been uplifted along the Willow Springs fault. Elsewhere, they may be a part of a general uplifted or upwarped block. In general the hills have been extensively eroded and are surrounded by alluvial fans which, in places, extend nearly to the crests of the ridges. The hills have been breached by streams in two places--one north of the town of Rosamond where a minor drainage extends south from the Gloster area and the other east of Bissell where a drainage discharges to Rogers Lake.

The consolidated rocks that form the Rosamond and Bissell Hills effectively separate the ground-water bodies in the Gloster and Chaffee areas from those in Lancaster and North Muroc basins.

## Hills on the East

A discontinuous range of unnamed hills extends north-northeast from Lovejoy and Saddleback Buttes along the east side of the area. The consolidated rocks that form the hills effectively separate the ground water in Lancaster and North Muroc basins from that in the Upper Mojave, Middle Mojave, and Harper Valleys.

## Isolated Hills and Buttes

South of the town of Mojave, the alluvial fans that slope generally eastward from the Tehachapi Mountains are interrupted by several prominent isolated hills, the largest of which is Soledad Mountain, which is probably an old volcanic vent, rising to an altitude of nearly 4,200 feet--about 1,500 feet above the surrounding alluvial fan. This mountain and the row of isolated hills extending eastward to the Bissell Hills form the discontinuous ground-water boundary between the Gloster and Chaffee areas.

Castle Butte and Desert Butte, at the north end of the area, are composed of volcanic and sedimentary rocks and are striking features which rise abruptly to heights of several hundred feet above the valley floor. Ground water discharges from North Muroc basin northwest into the Koehn Lake area through the alluvium between these two buttes.

Two elongate low hills, oriented nearly east-west and composed of granitic rocks, lie about 2 miles north of Buckhorn Springs near the southwest side of Rogers Lake. They are approximately a mile in length and nearly a quarter of a mile in width and rise as much as 75 feet above the surrounding land level. The surfaces of these hills are covered with coarse cobbles and boulders, probably the remnants of an old alluvium, suggesting that the hills were elevated by structural movement or are erosional outliers of the Rosamond Hills. A structural origin is suggested by the thick deposits of alluvium between the hills and the Rosamond Hills.

Another isolated hill (fig. 2), composed of a very coarse breccia of crystalline rocks, rises about 120 feet above the surface of Buckhorn Lake. The steep and linear north side suggests elevation along a fault--possibly one related to the Willow Springs fault.

## Alluvial Fans

The areas between the hills or mountains and the dry lakes are occupied by alluvial fans, ranging in extent from apex to toe from less than a mile to more than 25 miles. Locally, they are overlain by sand dunes (fig. 2). The fans of smallest extent surround the isolated hills and buttes and those of largest extent lie north of the San Gabriel Mountains and east of the Tehachapi Mountains. Characteristically, all simple fans have a profile which is concave upward with steep gradients at the apexes along the mountain front and flatter gradients at the toes where they either merge with others, usually near the central part of the valley, or terminate at the edges of dry lakes.

## Fans South of the Rosamond Hills

The alluvial fans extending outward from the San Gabriel and Tehachapi Mountains in the area south of the Rosamond Hills terminate at Rosamond, Buckhorn, and the south end of Rogers Lake. Typical of the fans along the front of the San Gabriel Mountains is the fan of Little Rock Creek, which in 20 miles descends from an alitutde of about 2,925 feet at its apex to about 2,275 feet at Rosamond Lake or has an average gradient of about 32 feet per mile. East of Lancaster the gradient is about 15 to 20 feet per mile and near the dry lake decreases to only 10 to 15 feet per mile.

Similarly, the fan of Cottonwood Creek is typical of the larger fans along the east side of the Tehachapi Mountains. The apex of the fan is at an altitude of about 4,000 feet and at its terminus at Rosamond Lake is 2,275 feet--a drop of about 1,700 feet in 24 miles, or an average gradient of about 70 feet per mile. The gradient is about 15 feet per mile near the lake and about 200 feet per mile near the apex of the fan.

## Fans North of the Rosamond Hills

In the Gloster and Chaffee areas, north of the Rosamond Hills, the alluvial fans of Oak and Cache Creeks, which drain eastward from the Tehachapi Mountains, are the predominant valley features (fig. 1A). The surfaces of these fans descend from altitudes of about 3,500 to 4,000 feet at their apexes to about 2,500 feet where they merge with small fans from the west slope of the Bissell Hills north and south of the way station of Bissell. Fans around the Rosamond and Bissell Hills and isolated hills and buttes are minor and merge with the two larger fans at short distances from the hills. To the north the fan of Cache Creek descends through Fremont Valley to Koehn Lake, which is at an altitude of about 1,900 feet.

### Fans Around Rogers Lake

The valley area south, east, and north of Rogers Lake constitutes the third extensive area of alluvial fans. Unlike the other two extensive areas of alluvial fans previously discussed, the fans here are local in extent and most of them grade imperceptibly into debris slopes that, in places, are known to be underlain at shallow depth by bedrock. The streams that drain and build the individual fans in this area are small and the drainage area of each is limited. For this reason and because the surrounding bedrock highlands are low in altitude, runoff is small, the slopes of the alluvial fans locally are relatively high, and the contained deposits are poorly sorted.

The low divide between Rogers Lake and the Koehn Lake area is about 7 miles north of Rogers Lake and is formed by coalescing fans built out from the adjacent hills and in part may be formed by uplift. This divide is at an altitude of about 2,360 feet--about 90 feet higher than Rogers Lake.

During Pleistocene time, surface drainage from Antelope Valley to Fremont Valley probably occurred through this reach. There is no direct physiographic evidence of such through drainage remaining, however, and if drainage occurred here during Recent time, all traces of old channels and related features have been eroded away or buried beneath more recent accumulations of detrital materials.

## Lowland Features

The lowland features comprise the dry lakes or playas, the sand dunes and sand hills, and the old shorelines (fig. 2). In large part, they are limited to the lowest part of Antelope Valley between altitudes of 2,275 and 2,350 feet. Locally the sand dunes extend to higher altitudes.

### Playas

The name "playa" is a Spanish word meaning shore or strand. It is a nearly level area that occupies the lowest part of a basin of interior drainage and is covered intermittently with water forming a temporary lake. Thus, the terms "lake" and "playa" can be used interchangeably. Rogers, Rosamond, and Buckhorn Lakes have altitudes of 2,270, 2,275, and 2,286 feet, respectively, and occupy a total area of about 65 square miles. At one time, Buckhorn Lake was much larger, and it is probable that the three lakes were one, but dune sand and old beach bars cover a relatively large part of the playa surfaces (fig. 2).

Rogers Lake, one of the largest playas in the Mojave Desert region, has an area of nearly 45 square miles. Shaped somewhat like a distorted hourglass, it is about 12 miles long and 5 miles wide at its widest point at the north end. The northeast edge of the playa is bordered by a well-developed beach bar. The surface of the playa is level, hard, smooth, and, when dry, is capable of supporting heavy vehicles and aircraft; it affords an excellent landing field. Deflation of the playa deposits by wind is suggested by low "islands" of playa deposits that remain as erosional remnants of playa deposits around the shore of the lake. The surfaces of the exposures are not more than 3 to 5 feet above the average level of the lake surface.

In the northeast part of Rogers Lake, where the water table is 30 to 60 feet below land surface, several "drain holes" or vents about half a foot to a foot in diameter were found. When water is on this part of the playa, it flows into these "drain holes" at moderate rates. These unusual features have been observed only at one other playa, Coyote Lake which is about 20 miles northeast of Barstow. These holes do not seem to become plugged with the fine materials that are carried into them by the water. Their origin is not known, but they may have developed along vertical tension joints in the playa deposits.

Rosamond Lake has an area of about 20 square miles, is the westernmost and second largest of the three playas, and is roughly oval in shape. Most of the playa is hard and relatively smooth, but a small part, where ground water is close to the surface and evaporation is taking place, is soft or puffy. Several wells on the playa are nearly concealed by low sand mounds, deposited by the wind, which rise 1 to 2 feet above the playa.

Buckhorn Lake covers an area of about 2 square miles, is the smallest of the three major playas, and is separated from Rosamond Lake by sand dunes. Both actively drifting and old stationary sand dunes surround the playa, and a part of it now is being buried beneath drifting sand. Consequently, the margins of the playa are extremely irregular and constantly changing.

## Old Lake Features

Physiographic features related to deposition near the margins of old lakes, which were more extensive than the playa surfaces now remaining, are shown on the geologic map (fig. 2). These comprise cut terraces, beaches, bars, and spits which were formed in lakes probably in late Pleistocene time. The most pronounced of these is a large beach bar or shingle beach across the northeast end of Rogers Lake which rises to a height of 25 to 35 feet above the present playa and is surfaced with a veneer of waterworn pebbles. This beach bar is continuous for a distance of 6 miles. During periods when water is on the playa and when a southwest wind is blowing, the lower part of the bar may be considered an active beach. Another old beach lies northwest of Muroc at an altitude of 2,300 to 2,310 feet--about 25 to 40 feet above the playa. It extends southward for about 4 miles and continues from that point as a well-defined recurved spit, terminating about half a mile west of Muroc.

Two "islands" of granitic rock protrude through the playa of Rogers Lake. One was in 10/9-20R and was nearly indiscernible from an automobile because it was so low. It covered an area of about 10 acres and, before removal by the Air Force, rose only 3 to 5 feet above the playa. Its surface was worn by waves and abraded by windblown sand. The other rock island is in 10/9-24L, and rises about 50 feet above the playa. It has one well-defined row of holes which resemble wave-eroded features at a level about 30 to 40 feet above the playa and other less well-defined holes at lower levels. Some of the holes may have been caused by windblown sand, but the holes high above the playa more likely were waterworn.

Numerous small beach bars nearly concealed by windblown sand extend discontinuously along the south and west margins of Rosamond Lake. These features are at approximately the same altitude as the old lake features developed near the margins of Rogers Lake. In addition, small beach bars extend between the two bedrock hills northeast of Buckhorn Lake and between the two hills composed of old fan deposits in 9/11-25, northwest of Buckhorn Lake.

As shown on the geologic map, several discontinuous cut shorelines are present in the area surrounding the three major playas. Cut shorelines were observed at three altitudes surrounding the playas and are believed to have been formed during the highest stage of the lake or lakes and at intermediate levels during a recessional period near the close of the last pluvial period (time of relatively great precipitation) in Pleistocene time. The most pronounced cut shorelines were observed near the south margin of the Rosamond Hills east of U.S. Highway 6, just south of well 9/11-22K1, and near the southeast corner of 10/10-13. Elsewhere, the cut shorelines shown on the geologic map are mainly after work by T. W. Dibblee, Jr. (personal communication, 1958), U.S. Geological Survey, who mapped these features on aerial photographs.

## Sand Dunes

The lowland area around the playas in Lancaster Basin contains approximately 75 square miles of sand dunes and sandhills, the most prominent areas of which are shown on figure 2. They vary from small widely spaced gently rolling dunes less than 2 or 3 feet in height to large hills, the crests of which locally are as much as 40 feet above the general land surface.

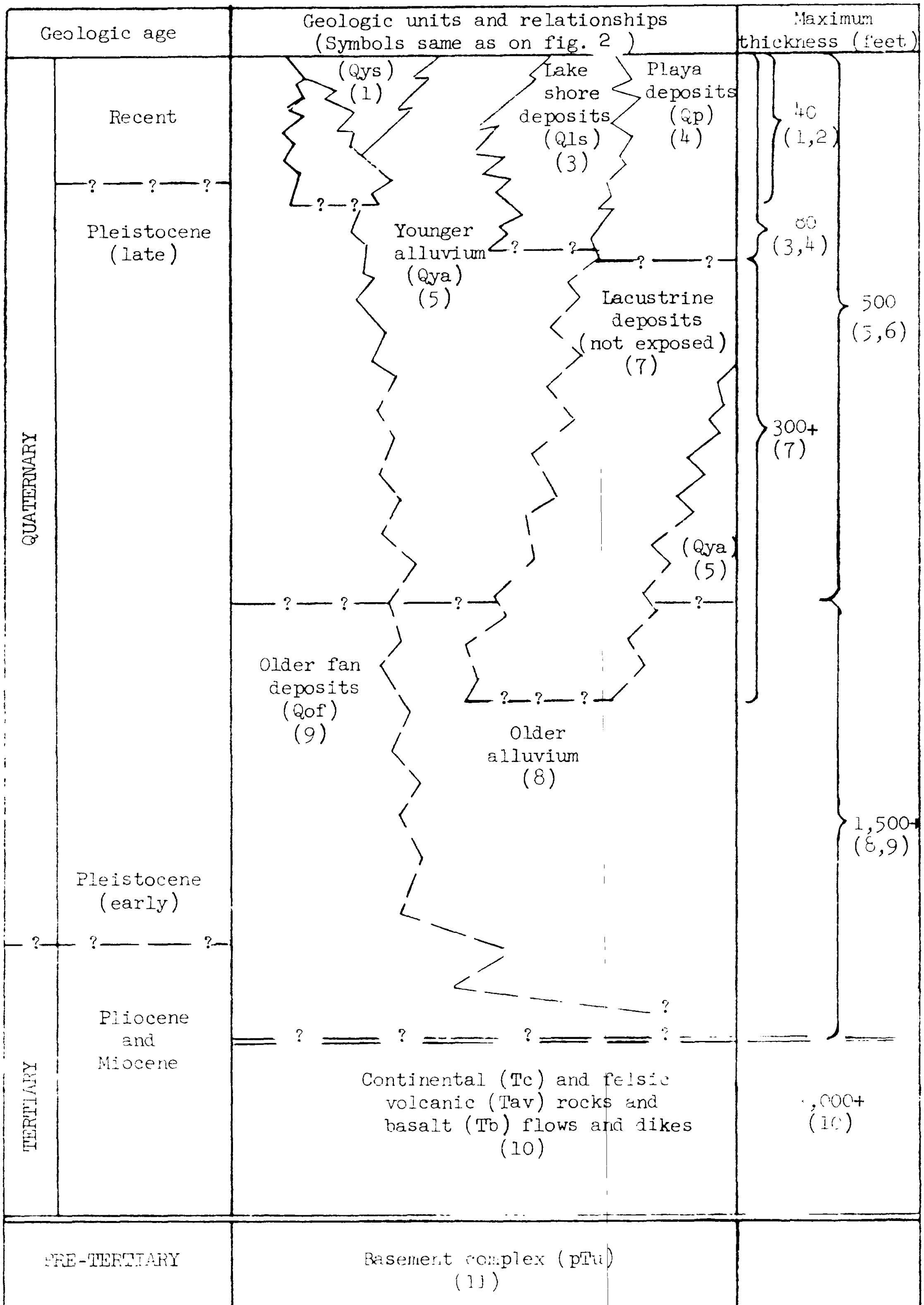
A part of the sand in this area is now actively drifting, but most of the dunes are either anchored by vegetation indigenous to the desert environment or, in the case of those immediately northwest of the large playas, are moderately indurated. Owing to the abrasive action of windblown sand, these poorly cemented dunes locally are carved into badlands topography typical of areas where wind erosion is active; many small steep-sided hills exist where excellent examples of the original crossbedding can be observed.

The drifting sand is accumulating on the windward (west) sides of the playas and poses a continual problem to ranchers where the sand drifts onto the fields, and, during periods of high winds, sandblasts windows, paint, and other exposed objects. Ranch access roads and, infrequently, highways temporarily are blocked by drifting sand.

## CHARACTER AND WATER-BEARING PROPERTIES OF THE DEPOSITS AND ROCKS

Based on their capacity to contain and yield ground water, the deposits and rocks in the Edwards Air Force Base area are divided into two classes: (1) those that are consolidated and yield water only from fractures or are tightly cemented and yield water to wells in such small quantity that the drilling of wells in these rocks is not oridnarily feasible; and (2) those that are unconsolidated and have connected interstices which may yield appreciable quantities of water to wells.

Table 1 summarizes the stratigraphic units and outlines their sequence, general lithologic character, and water-bearing properties, and the geologic map (fig. 2) shows their areal distribution. The major stratigraphic relations and the general lithologic character of the units are shown diagramatically on the cross sections (figs. 3, 4, and 5), which have been compiled from logs of water wells contained in the reports by Dutcher (1959a); Dutcher, Bader, Hiltgen, and others (1961); and Kunkel and Dutcher (1961).



Geologic age
Geologic units and relationships (Symbols same as on fig. 2 )
Maximum thickness (feet)
QUATERNARY
Recent
Pleistocene (late)
Pleistocene (early)
TERTIARY
Pliocene and Miocene
PRE-TERTIARY
(Qys) (1)
Lake shore deposits (Qls) (3)
Playa deposits (Qp) (4)
Younger alluvium (Qya) (5)
Lacustrine deposits (not exposed) (7)
(Qya) (5)
Older fan deposits (Qof) (9)
Older alluvium (8)
Continental (Tc) and felsic volcanic (Tav) rocks and basalt (Tb) flows and dikes (10)
Basement complex (pTu) (11)
40 (1,2)
60 (3,4)
300+ (7)
500 (5,6)
1,500+ (8,9)
,000+

Table 1.--Geologic units of Edwards Air Force Base and vicinity, California

| General lithologic character | Water-bearing properties |
|---|---|
| 1. Young windblown sand (Qys) derived from younger alluvium in western part of the valley and deposited in the central and east part of the valley as dune sand, sand veneer, and sand ridges, locally includes areas of small interdune playas; dunes range in height from 6 to 40 feet; in small part anchored by vegetation but in large part actively drifting. | 1. Unconsolidated and generally above the water table; locally contains perched water where underlain by clay; yields water in small quantities to wells. |
| 2. Old windblown sand (Qos) derived mainly from younger alluvium but in part from playa deposits; crossbedded and poorly to moderately indurated, locally subject to intense wind erosion and carved into badlands topography. | 2. Unconsolidated to moderately indurated and generally above the water table; not penetrated by wells. |
| 3. Lakeshore deposits (Qls) occur as beach deposits and spits along the margins of Rogers and Rosamond Lakes; consist of gravel and sand containing much intermixed silt, locally crossbedded. | 3. Unconsolidated and occurs above the water table. |
| 4. Playa deposits (Qp) consist principally of clay with some silt and silty clay, interbedded with lenses of silty sand; underlie the "dry lakes." | 4. Unconsolidated; where saturated the permeability of these deposits is very low and the total dissolved solids of the water generally is high. |
| 5. Younger alluvium (Qya) consists of moderately well-sorted gravel, sand, silt, and clay occurring mainly in discontinuous lenses beneath the central valley areas. | 5. Unconsolidated; in Lancaster Basin contains most of the shallow water-bearing zone and yields water to wells at moderate rates; largely unsaturated in the other basins. |
| 6. Younger fan deposits (Qyf) consist of poorly sorted arkosic gravel and sand and intermixed mudflow debris derived mainly from local exposures of consolidated rocks. | 6. Unconsolidated; generally occurs above the water table; locally yields small quantities of somewhat inferior quality water to wells. |
| 7. Lacustrine deposits (not exposed) consist of clay, silt, and silty sand; composed of a relatively continuous and uniform blue clay beneath the central and northern parts of Lancaster Basin and a brown clay containing silt and sandy silt beneath the eastern part of Lancaster Basin. Ground water is confined in the underlying alluvium and these deposits seperate the deep water-bearing zone from the principal water-bearing zone in Lancaster Basin; not identified elsewhere | 7. Unconsolidated; generally of very low permeability, a few sand zones in the brown-clay member may yield moderate quantities of water to wells. |
| 8. Older alluvium (Qoa) composed of moderately well-sorted, slightly to moderately deformed lenses of gravel, sand, silt, and clay; locally contains coarse boulder beds composed predominantly of volcanic rocks. | 8. Unconsolidated where saturated; contains most of the deep and part of the principal water-bearing zones in Lancaster Basin and locally yields water to wells at rates up to 1,500 gpm; yields of wells in North Muroc basin and the Gloster and Chaffee areas are considerably less. |
| 9. Older fan deposits (Qof) is a fanglomerate consisting of boulders, cobbles, gravel, and talus breccia mainly of granitic origin; very poorly sorted, angular to subrounded, and commonly indurated. | 9. Moderately to highly indurated in exposures; where penetrated by wells is of very low permeability. |
| 10. Continental sedimentary rocks of Tertiary age (Tc) comprise undifferentiated fluviatile and lacustrine conglomerate, sandstone, siltstone, clay, shale, limestone, dolomite; waterlaid volcanic tuff and agglomerate.<br>Felsic volcanic rocks of Tertiary age (Tav) comprise undifferentiated intrusive and extrusive felsite, latite, andesite, rhyolite, and dacite.<br>Basalt of Tertiary age (Tb) comprises undifferentiated extrusive amygdaloidal olivine basalt and intrusive diabasic basalt.<br>Quartz basalt of Tertiary age (Ttrb) comprises dark-colored largely extrusive quartz basalt. | 10. Consolidated; generally of low permeability; yields water from fractures and from sandstone and tuff beds at rates up to 15 gpm. |
| 11. Basement complex (pTu) consolidated undifferentiated igneous and metamorphic rocks; locally the granitic rocks are deeply weathered. | 11. Consolidated but locally unconcolidated residuum; locally yields small quantities of water to wells from fractures or from the residuum. |

## Consolidated Rocks

The consolidated virtually nonwater-bearing rocks exposed in the area covered by figure 2 have been grouped into two main units. In order of discussion from oldest to youngest they consist of granitic intrusive and metamorphic rocks which form the basement complex of the area, and a complex series of indurated continental deposits interbedded with volcanic flows, which together are cut locally by dikes and volcanic vents.

### Basement Complex

The basement complex, which is exposed extensively in the area and which underlies and forms the bottoms of most of the ground-water basins, is composed principally of granitic rocks and in small part of metamorphic rocks. It includes also a few extensive northwest-trending pegmatite dikes which form prominent ridges in the Rosamond and Bissell Hills. The granitic rocks include quartz monzonite and associated plutonic rocks ranging in type from granite to diorite (Simpson, 1934). The metamorphic rocks, which are exposed in the northeastern part of the area near Boron, include schist, gneiss, and metavolcanic rocks briefly described by Gale (1946, p. 357-358). They have been intruded by the granitic rocks. The age of the metamorphic rocks probably ranges from Precambrian to Triassic, and the plutonic granitic rocks probably are of Jurassic or early Cretaceous age.

The basement complex in the Rosamond and Bissell Hills and in the unnamed hills east of Lancaster Basin has long been subject to periodic uplift and erosion. Because of long periods of exposure, the rocks are deeply weathered, and the arkosic residuum locally attains a thickness of more than 100 feet. The development of the residuum involves the decomposition of the feldspar grains to a kaolinitic clay, which fills most of the interstices between the resistant quartz crystals.

The residuum, where saturated, supplies minor amounts of water to wells, commonly in quantities sufficient only for limited domestic and stock use. The unweathered and unfractured basement complex yields no water to wells, but, where fractured below the water table, it may yield relatively small quantities of water to wells. The basement complex is not sufficiently productive to warrant exploration as a major source of supply.

## Continental and Volcanic Rocks of Tertiary Age

The rocks of Tertiary age exposed in the Edwards Air Force Base and vicinity rest unconformably on the basement complex and locally are folded and faulted. Also, these rocks locally form the bottoms of the ground-water basins. Where exposed discontinuously in the area north of the Willow Springs fault and west of R. 10 W., they were named the Rosamond series by Hershey (1902, p. 365-370) and, where exposed in the area west of U.S. Highway 6, were called the upper and lower Rosamond by Simpson (1934, p. 384). The Tertiary continental rocks east of about R. 11 W. were called the Ricardo formation by Gale (1946, p. 338-350).

In general, these rocks include sedimentary rocks and locally interbedded volcanic rocks of several types, and were assigned a Miocene or Pliocene age by Hershey, Simpson, and Gale. To make a detailed study of these rocks was beyond the scope of this report, and, therefore, they are shown on the geologic map (fig. 2) and described in the following paragraphs, as follows: continental rocks, felsic volcanic rocks, and basalt, all of Tertiary age.

Continental rocks of Tertiary age.-- In their upper part, the continental rocks of Tertiary age include undifferentiated fluvial and lacustrine conglomerate, sandstone, siltstone, and shale. In their lower part, they contain green and blue shale, some limestone, dolomite, and water-laid agglomerate, volcanic tuff, tuffaceous sandstone, gray-green tuff-breccia, and conglomerate. The larger fragments consist of monzonite, dacite, basalt, rhyolite, latite, and a few waterworn granitic pebbles.

The rocks exposed in the Rosamond Hills reportedly attain a total thickness of about 3,000 feet. Along the north side of the Willow Springs fault the strata dip southward $20^{\circ}$ to $30^{\circ}$ and their exposures are terminated by the fault. They have been downdropped south of the fault and might be encountered at depth in Lancaster Basin. However, the cuttings from oil-test well 8/11-9D1, drilled to a depth of more than 5,000 feet on Rosamond Lake, do not indicate the presence of any lava rocks, such as are commonly associated with the continental rocks of Tertiary age; the fragmental rocks could not be distinguished in well cuttings from those in the older fan deposits and alluvium.

The continental rocks of Tertiary age probably underlie at depth a large part of the Edwards Air Force Base area, but they are known to have been encountered in wells only in the northeastern part of the Chaffee area. In North Muroc basin, north of U.S. Highway 466, drillers and owners report encountering basalt in the wells. The basalt may be interbedded with the upper part of the continental deposits or may underlie the basalt. Therefore, only the uppermost part of the Tertiary continental rocks may have been penetrated by the wells.

No fossils were found in the continental rocks. However, they have been assigned to the Miocene and Pliocene age by others, principally on the basis of stratigraphic position and lithologic similarity to rocks in other areas where the age of the rocks has been determined.

The continental rocks for the most part yield only very small quantities of water to wells. They generally are poorly sorted and well cemented, and where attempts have been made to develop wells in them in the area northeast of Kramer (fig. 1), yields of only 5 to 15 gpm (gallons per minute) with large drawdowns are common. Mine operators in Soledad Mountain report encountering some water in shafts at a depth of about 200 feet below the level of the surrounding desert floor, which is about the depth to ground water in the adjacent alluvium. However, the yield of the watered shafts is relatively small--only about 15 gpm, or 20,000 gallons per day. In North Muroc basin some wells tap basalt and tuff beds in, or associated with, the so-called Ricardo formation (G· le, 1946), and the yields are reportedly between 50 and 100 gpm with moderate to large drawdowns. However, much of this yield may be supplied from the overlying alluvium. Thus, the continental sedimentary rocks of Tertiary age are not sufficiently productive to warrant exploration as a source of large supplies of ground water.

Felsic volcanic rocks of Tertiary age.--Where exposed discontinuously in the area of the Rosamond Hills and northward to the Tehachapi Mountains, the felsic volcanic rocks include undifferentiated intrusive and extrusive felsite, latite, andesite, rhyolite, and dacite; one outcrop of basalt is present in the Soledad Mountains, but elsewhere in the western part of the area the volcanic rocks are of the felsic type. Volcanic vents, plugs, and dikes were observed along the road 2 miles east of Rosamond, at Desert Butte, and at Soledad Mountain, which probably was a former site of extensive volcanic extrusion.

The Tertiary felsic volcanic rocks locally are interbedded with or protrude through the continental rocks of Tertiary age where these have been assigned a Miocene age. Therefore, the felsic volcanic rocks also have been assigned a Miocene age.

The volcanic rocks are nearly impermeable and yield virtually no water to wells.

Basalt of Tertiary age.--Where exposed in the eastern part of the area, principally north and northeast of Rogers Lake, the basalt of Tertiary age includes undifferentiated extrusive amygdaloidal olivine basalt and intrusive diabasic basalt. It has been assigned a Pliocene age by most workers in the area; a few have considered that locally the basalt may be early Pleistocene in age. The present authors, however, consider the basalt to be not younger than late Pliocene. A few small outcrops of quartz basalt have been mapped by Dibblee (1960, pl. 8) in the southeast corner of the area. He considers this material to be of Miocene(?) to Pliocene(?) age.

Except locally, the basaltic rocks are nearly impermeable and where penetrated by wells in North Muroc basin yield only minor amounts of water. Although not penetrated by wells elsewhere in the area, it is believed that the basalt is not sufficiently productive to warrant exploration as a source of large supply of ground water.

## Unconsolidated Deposits

The unconsolidated to moderately indurated deposits on and near Edwards Air Force Base include, from oldest to youngest, the older fan deposits and older alluvium of Pliocene and Pleistocene age, the lacustrine deposits (not exposed) of Pleistocene age, the younger fan deposits and younger alluvium of Pleistocene and Recent age, the playa and lakeshore deposits and the old windblown sand of late Pleistocene and Recent age, and the windblown sand of Recent age.

The playa and lakeshore deposits and windblown sand are considered equivalent in age and stratigraphic position to the upper parts of the younger alluvium and fan deposits. The lacustrine deposits, which were identified from the study of well logs in Lancaster Basin, for the most part are considered equivalent in age to and interfinger with the lower part of the younger alluvium, but in the lowermost part may interfinger with the upper part of the older alluvium. Similarly, the older fan deposits are considered equivalent in age to the older alluvium. These relations are discussed in more detail in the following pages and are shown diagrammatically on table 1.

## Older Fan Deposits

The older fan deposits comprise old moderately to highly indurated red to brown fanglomerate and stream-channel deposits that have been subjected to considerable warping, faulting, and uplifting. They may range in age from late Pliocene to early or middle Pleistocene. Surface exposures of these deposits are limited to a few outcrops; the only two outcrops of sufficient size to be shown at the scale of figure 2 are those near Buckhorn Lake and near Bissell in the Bissell Hills. The subsurface extent of these deposits beneath the valley floors could not be determined, but it is believed to be large in the northern part of the area. The old fan deposits were encountered in test wells in the Gloster area and North Muroc basin (figs. 3 and 5). They rest unconformably on the rocks of Tertiary age or the basement complex. The relation of the older fan deposits to the older alluvium was not determined, but they are believed to occupy similar stratigraphic positions--the older fan deposits near the margins of the major valleys and the older alluvium in the central valley areas. At the north edge of Rogers Lake semi-contolidated materials, believed to be old fan deposits or continental rocks of Tertiary age, underlie the older alluvium at well 10/9-4D1 and were penetrated throughout the interval between 433 and 502 feet.

The older fan deposits have a wide range in lithology. Near Buckhorn Lake a "hill" of indurated fanglomerate crops out (fig. 2) and is composed of igneous and metamorphic cobbles and boulders. This outcrop probably is related to subsidiary faulting associated with the Rosamond fault, but no geologic or hydrologic evidence of faulting was observed. The older fan deposits in the Bissell Hills, near Bissell, and in the other isolated areas of very limited areal extent, are composed of angular to subrounded cobbles and boulders, composed principally of granitic rocks and some metamorphic and volcanic rocks. Most of the fragments of granitic rocks are highly weathered and, in the several places where they overlie granitic rocks of the basement complex, are difficult to distinguish from the underlying granitic residuum.

The maximum observed thickness of the fanglomerate is about 100 feet, but locally beneath North Muroc basin the deposit may greatly exceed that thickness.

The poor sorting and the moderate to high induration as observed in outcrops suggest that the older fan deposits would yield little water to wells. Where penetrated by wells in the Gloster area and North Muroc basin, the old fanglomerate is poorly permeable and yields practically no water.

## Older Alluvium

The older alluvium of this report is defined as the moderately permeable, coarse-grained, weathered, and moderately well-sorted alluvial deposits underlying the valley areas beneath the younger alluvium and occupying about the same stratigraphic position in the central valley areas that the older fan deposits are believed to occupy near the valley margins. The older alluvium and older fan deposits probably interfinger. Except where outcrops of limited extent could be observed, principally near the valley margins, well logs and well yields were used to distinguish the older alluvium from the older fan deposits and the younger alluvium.

The older alluvium in the Edwards Air Force Base and vicinity represents an extensive cycle of alluviation prior to the development of the present landforms and drainage systems. It locally has been warped and faulted, and in the upland areas it has been nearly eroded away. Beneath the valley floors it probably has been subjected to some erosion but for the most part has been covered by the younger deposits.

Areal extent and stratigraphic position.--Where exposed, the older alluvium is limited to a few small outcrops near the south margin of the Rosamond Hills, a few larger areas where outcrops are discontinuously exposed north and east of Rogers Lake, between the Los Angeles aqueduct and the Tehachapi Mountains, and one locality south of U.S. Highway 466 in the Bissell Hills (fig. 2). At depth in the several ground-water basins the extent is great (figs. 3, 4, and 5).

In the northeastern part of Lancaster Basin, where the supply wells for the Main Base of Edwards Air Force Base are located, the older alluvium is encountered at relatively shallow depth beneath the playa and lacustrine deposits (fig. 3). The uppermost part of the alluvial deposits is younger alluvium, but the bulk of the deposits beneath is older alluvium.

In the central part of Lancaster Basin the older alluvium includes all the alluvial deposits that extend downward from the lacustrine deposits to the undetermined contact with the Tertiary continental rocks or other consolidated rocks of the area. In the other basins it underlies the younger alluvium and extends downward either to the basement complex or to the Tertiary rocks and probably rests unconformably on the older rocks. Wells 9/8-6H1 and 6H2, on the east side of Rogers Lake, penetrated coarse sand and gravel to depths of 467 and 354 feet, respectively, and the deposits below a depth of about 100 feet are believed to be older alluvium.

In the Gloster area and the southern part of the Chaffee area the contact between the younger and the older alluvium could not be determined (fig. 5). However, the contact between the younger and the older alluvium is believed to be at a depth of about 35 feet at test well 10/12-22J1, about 21 feet at test well 10/12-23C1, and only about 12 feet at test well 10/12-13H1.

After the well canvass was completed, several wells were drilled during 1955 in sec. 36, T. 11 N., R. 9 W., in North Muroc basin and are not shown on the well-location map (fig. 2). The depths of these wells have a wide range, but at least one was drilled to a depth greater than 600 feet. The logs of several of the wells suggest that the base of the older alluvium is about 486 feet below land surface at a well in 11/9-36A, about 407 feet below land surface at a well in 11/9-36C, about 370 feet at a well in 11/9-36D, and perhaps only about 250 feet at a well in 11/9-36H1. Wells 10/9-7A1 and 7A2 probably encountered older alluvium below the playa deposits at a depth of about 80 feet. The log of test well 10/9-4D1 suggests that the older alluvium extends from about 142 feet to about 433 feet below land surface.

Lithology.--Beneath the valley areas where the older alluvium is concealed, the well logs reveal the general character of the deposits. In Lancaster basin the older alluvium is tapped by the wells above and beneath the lacustrine deposits (fig. 3). The logs and well cuttings in this area show that the older alluvium generally is similar to the younger alluvium and is composed of gray, brown, and buff clay, clay and gravel, clay and sand, sand, and gravel mainly of granitic origin. Local zones of caliche, hardpan, and cemented gravel, sand, and sand and silt are reported by drillers. Some of the fragments are of volcanic rock. In general, the deposits are more compacted and indurated, somewhat coarser grained, more weathered, and more poorly sorted than the younger alluvium.

In North Muroc basin the few available well logs and cuttings from wells show that the material is poorly sorted, highly weathered arkosic gravel and sand locally containing calcareous cement.

In general, coarser and cleaner materials are reported in wells in the Chaffee area than in the Gloster area. Moreover, the logs indicate that the materials are lenses of gravel, sand, and clay. Owners and drillers report that the deeper materials are indurated, that the sand and gravel beds contain considerable silt or clay, and that the larger pieces of granitic rocks commonly are weathered.

Old stream-channel deposits are contained in exposures of the older alluvium and were deposited along the former courses of major streams. These channel deposits in the older alluvium, best exposed in the outcrops in the hills southeast and northeast of Rogers Lake, are composed of moderately well-sorted and well-rounded boulders, cobbles, gravel, sand, and some silt and clay. These deposits have not been recognized in wells beneath the valley floor.

Thickness.--In Lancaster basin the thickness of the older alluvium ranges from a few feet to 1,500 feet or more in the central part of the basin. Oil-test well 8/11-9D1 penetrated more than 5,000 feet of unconsolidated alluvial deposits and reportedly bottomed in these materials at a depth of 5,576 feet. An examination of the poorly preserved suite of washed cuttings from the well revealed little change in the character of the samples below the blue clay of the lacustrine deposits to the bottom of the hole. The cuttings consist of poorly sorted arkosic sand and an occasional fragment of volcanic rock. The cuttings were of no assistance in determining the possible contact between the older alluvium and the Tertiary continental rocks, if present. Similarly, elsewhere in Lancaster basin the base of the older alluvium, and consequently, the thickness could not be determined from logs of deep wells. Well 8/11-35J1, which is 1,536 feet deep, reportedly encountered no marked change in the character of the materials below the blue clay. Thus, the thickness of the older alluvium locally is at least 1,000 feet in Lancaster basin and may be considerably more than 1,500 feet.

The thickness of the alluvium south of Rogers Lake barrier (fig. 2) is unknown, but wells 9/10-24C1 and 24G1 were each drilled to depths of 750 feet and did not encounter bedrock. The electric logs for the wells suggest that below about 700 feet the deposits are fine grained and may contain water of marginal to poor quality, which suggests that the older alluvium extends to a depth of about 700 feet and that the thickness of the older alluvium in this area may be about 500 feet.

The thickness of the older alluvium in the Gloster area may be only a few hundred feet. During the period March 1 to May 20, 1956, test wells 10/12-22J1, 23C1, and 13H1 were drilled to depths of 242, 249, and 175 feet, respectively (table 11). Each penetrated the complete thickness of alluvium and encountered older fan deposits which were indurated and virtually nonwater bearing at depths of 234, 178, and 159 feet, respectively. Before the test wells were drilled, wells reportedly had been constructed to depths of as much as 500 feet in the basin through alluvial materials; data from incomplete logs of wells and the diaries of long-time residents of the area, however, indicate that most of the existing deeper wells probably bottomed in granitic rocks, continental rocks of Tertiary age, or older fan deposits.

In the northwest part of the Chaffee area, well 32/36-21Q1 reportedly was drilled to a depth of 1,356 feet and encountered "decomposed granitic rock" at a depth of 1,323 feet (Kunkel and Dutcher, 1961). According to an oral report from the driller, however, what are probably consolidated Tertiary continental rocks were penetrated at a depth of about 750 to 805 feet. Five deep test wells drilled in the central and eastern parts of the Chaffee area during 1956 penetrated the full thickness of the older alluvium. Data collected by the Geological Survey during drilling suggest that the older alluvium is about 400 to 500 feet thick in the northeast part of the Chaffee area, where underlain by the virtually nonwater-bearing Tertiary continental rocks and that it ranges in thickness from a few feet to about 300 feet in the southern and southeastern parts of the area, where it is underlain by crystalline rocks of the basement complex (fig. 5).

Age.--The age of the older alluvium is uncertain because no fossils were found in the deposit. The stratigraphic position, thickness, areal extent, lithology, and degree of structural disturbance suggest that the older alluvium is of late Pliocene and early Pleistocene age. In addition, the warping and faulting probably were associated with the so-called mid-Pleistocene orogeny of southern California, and therefore the bulk of the older alluvium is believed to be older than middle Pleistocene age.

Water-bearing character.--The deep water-bearing zone in the central and northern parts of Lancaster basin is almost wholly within the older alluvium. Locally, south of Rogers Lake barrier, the uppermost part of the deep zone may be within the younger alluvium.

With regard to the yield of the older alluvium, deep wells in the central part of Lancaster basin, wells 9/10-24F1 and 24G1, and 9/9-6H2 and 6H1 yield water at rates between 500 and 1,500 gpm (gallons per minute) with drawdowns of 10 to 30 feet. The average specific capacity is about 50 gpm per foot of drawdown. Although this approximate specific capacity is greater than that of wells in the younger alluvium, the thickness of older alluvium tapped is greater than that tapped by the younger alluvium. The unit yield per foot of aquifer penetrated is, therefore, less for the older alluvium. The former irrigation wells in sec. 16, T. 9 N., R. 10 W., probably obtained their supply from beds of coarse gravel and sand in the older alluvium. Wells 9/10-16C2, 16N1, and 16P1 were tested by the Air Force during February 1956, and were reported to yield 1,080, 720, and 1,120 gpm, respectively; the specific capacities were about 20, 12, and 20 gpm per foot, respectively.

Wells 9/9-6A1, 6C1, 6E1, 6L1, and 6M1, which encountered the bedrock materials of the Rogers Lake barrier at shallow depth (fig. 3), yield water at rates of 150 to 300 gpm with drawdowns of 10 to 15 feet and have an average specific capacity of about 20 gpm per foot. Considering the relative thinness of the deposits tapped, the specific capacity suggests moderate permeability. However, the quality of water in the wells is poor, as is discussed beyond.

In North Muroc basin, wells 10/9-7A1 and 7A2 yield 50 and 100 gpm with drawdowns of 9 and 8 feet, respectively, indicating an average specific capacity of about 10 gpm per foot. These are small-diameter wells and are only 200 feet deep. Based on the production of test well 10/9-4D1 in North Muroc basin, which yielded about 440 gpm with a drawdown of about 20 feet, the specific capacities of properly constructed and developed large-diameter deep wells penetrating the full thickness of older alluvium in North Muroc basin should average at least 20 gpm per foot.

Three wells in 11/9-36C, which were drilled after the completion of the fieldwork and which penetrate the full thickness of older alluvium in North Muroc basin, yield water at rates up to 1,300 gpm and have specific capacities of about 20 to 40 gpm per foot. A comprehensive $8\frac{1}{2}$-day pumping test was made by the owner of these three wells. The excellent field data indicate that the coefficient of transmissibility[1/] of the older alluvium in this area is about 90,000 gpd per foot and that the coefficient of storage[2/] is about 0.13. As the coefficient of storage under water-table conditions is practically equal to the specific yield, the specific yield of the deposits dewatered during the test is also about 13 percent. On the basis of a saturated thickness of about 300 feet at the time of the test, it is estimated that the permeability[3/] of the older alluvium at the site is about 300 gpd per square foot.

1/ The coefficient of transmissibility may be defined as the number of gallons of water, at the prevailing water temperature, that will move in 1 day through a vertical strip of the aquifer 1 foot wide, having a height equal to the full thickness of the aquifer, under a hydraulic gradient of 100 percent (1 foot per foot); it is generally expressed as "gallons per day per foot."

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

3/ The transmissibility divided by the saturated thickness of the deposits, in feet, is the average field coefficient of permeability, in gallons per day per square foot.

Four former irrigation wells in the Gloster area reportedly penetrated only the upper 100 to 200 feet of saturated older alluvium and had yields of 75 to 350 gpm with drawdowns of between 30 and 90 feet. These data suggested an average specific capacity of about 4 gpm per foot. Because the wells are shallow, because the reported yields and drawdowns could not be confirmed, and because little was known about the construction and development of the wells, it was believed that the apparent low value for specific capacity might not be representative of the yield of the older alluvium in that area. Accordingly, test wells were drilled by the U.S. Air Force to determine the yield and to aid in determining the amount of ground water in storage. Test wells 10/12-13H1, 22J1, and 23C1 were drilled during the period February to June 1956. The wells were not test pumped because bailing tests after completion showed the yields to be very small. The water levels in all three wells declined to within a few feet of the bottom after bailing a few minutes at rates of about 20 to 60 gpm. Although it was not possible to determine accurately the yield and drawdown by this method, it is estimated that the wells would produce only 20 to 30 gpm with excessive drawdown; the specific capacity of each is much less than 1. Therefore, the development of the Gloster area as a principal source of ground-water supply is not considered feasible. However, the supply is sufficient to meet the needs of domestic and stock wells.

In the Chaffee area, well 11/12-26J2 reportedly has a yield of about 800 gpm with a drawdown of 60 feet, suggesting a specific capacity of about 13 gpm per foot of drawdown. This well is 361 feet deep and probably obtains all of its supply from the older alluvium. Well 32/36-21Q1, which was completed to a depth of 805 feet and which probably obtains its supply wholly from the older alluvium, reportedly has a yield of 260 gpm and a drawdown of only 2.3 feet--a suggested specific capacity of more than 100 gpm per foot of drawdown. Six test wells were drilled in 1956 and 1957 by the U.S. Marine Corps in the eastern part of the Chaffee area, and the yields range from 90 to 1,900 gpm; the specific capacities range from about 2 to 22 gpm per foot.

## Lacustrine Deposits

The lacustrine deposits are composed of fine-grained materials that accumulated in a relatively large lake or marsh. Although the deposits are not exposed, they are encountered at depth in wells only in Lancaster basin. They consist mainly of two thick layers of clay--one blue silty clay and the other brown clay, containing silty sand and sand beds, which are present especially near the margins of the deposit. The subsurface extent of the deposits is shown on figures 3 and 4; their southernmost extent in Lancaster basin is not known. The lacustrine deposits underlie the playa deposits beneath Rosamond Lake, Buckhorn Lake, and the south end of Rogers Lake at a depth of 80 to 100 feet below land surface and southward become progressively deeper until near the south ends of sections A-A' and B-B' (figs. 3 and 4) they are about 700 feet. The buried surface of the lacustrine beds dips south to southeast about $1^{\circ}$.

The lacustrine deposits are believed to be transgressive from south to north, lapping northward onto the older alluvium and in turn being overlapped from the south by the older and younger alluviums. Accordingly, the lacustrine deposits underlie the younger alluvium and part of the older alluvium south of Rosamond Lake (figs. 3 and 4).

The blue silty clay is relatively extensive beneath the central and eastern parts of Lancaster basin. The brown clay, which is less extensive and contains considerable silt, sandy silt, and sand, is penetrated by wells, principally in the northeastern part of the basin, although a few wells encountered brown clay south of Rosamond Lake (fig. 4). For the most part, the brown clay overlies the blue clay and apparently represents a change in depositional environment; that is, a change from deposition in relatively deep water characterized by the unoxidized blue clay to deposition in shallow to intermittent lake conditions characterized by the oxidized brown clay and presence of coarser elements in the deposits.

The thickness of the lacustrine deposits as penetrated by any one well is as much as 300 feet. Beneath Rosamond Lake, the thickness is on the order of 300 feet, and beneath the southwest side of Rogers Lake it is about 100 to 150 feet. The stratigraphic position of the lacustrine deposits suggests that the probable age of the deposits is late Pleistocene (table 1).

The lacustrine deposits yield very little water to wells; the blue clay yields virtually no water to wells, but the sandy phases of the brown clay and silt beds locally supply some water to wells.

The blue clay effectively separates the principal water-bearing zone from the deep water-bearing zone in the central part of Lancaster basin (fig. 3). However, the brown clay, principally in the area southwest of Rogers Lake, is not sufficiently impermeable to prevent exchange of ground water between the principal and deep water-bearing zones. Because most deep wells are gravel packed and the perforations extend above and below the lacustrine deposits, it was not possible to determine whether the blue clay is sufficiently impermeable to prevent pumping from a deep well, perforated only opposite water-bearing zones beneath that unit, from causing a drawdown in nearby shallow wells perforated only opposite water-bearing zones above the blue clay.

## Younger Fan Deposits

The younger fan deposits are the relatively poorly sorted material and alluvial veneers around the margins of the valley areas between the younger alluvium and isolated hills, buttes, and mountains (fig. 2). They include also the pediments, which locally are discontinuously exposed as rock fans or are thinly buried by fan debris. The surface gradients on these fans are as much as 200 feet per mile.

Origin.--The fan deposits around the hills and buttes consist largely of mudflow and slope-wash debris which was and is carried out from the higher areas during brief periods of large and concentrated runoff following cloudburst-type precipitation. In some areas these deposits are actively aggrading, such as along the Willow Springs fault near Rosamond Lake; in other areas the fans are somewhat dissected.

Areal extent and stratigraphic position.--Around the margins of the Rosamond and Bissell Hills and locally around the hills east of Rogers Lake, deeply weathered rock fans or exposed pediments composed of granitic rock, commonly covered with a veneer of residuum and locally derived clasts, were mapped and are shown in figure 2 as younger fan deposits. These rock fans extend outward 1 to 2 miles from the mountain fronts.

The fan deposits in large part rest unconformably on the basement complex and the Tertiary continental and volcanic rocks and locally rest on the older alluvium and older fan deposits.

Lithology.--Where exposed, the younger fan deposits commonly are composed of very poorly sorted boulders, gravel, sand, silt, and clay and, unlike the younger alluvium, are composed of locally derived materials from the nearby hills or mountains. Along the east side of Lancaster basin the unnamed hills are granitic and supply granitic material to the surrounding fans. The fragments weather relatively rapidly and the pores in the poorly sorted materials are plugged with clay minerals, the result of weathering. On the other hand, around the hills composed of volcanic rocks the fan deposits are composed of volcanic rock fragments which do not weather quickly and the deposits are relatively porous, but are very poorly sorted. Near the heads of the fans the deposits commonly contain large angular boulders and cobbles in a matrix of sand, silt, and some clay. Downslope the degree of sorting improves and the range in grain size decreases.

Thickness.--Throughout the extensive areas of pediments the younger fan deposits are mainly a thin veneer of slope-wash debris overlying bedrock; where the pediments extend about 2 miles from the bedrock outcrops, the fan deposits may be only 2 to 10 feet thick, and locally they are absent and bare rock forms the surface of the fan. In other areas, such as in the southeast part of Lancaster basin, the deposits probably are more than 100 feet thick. Fan deposits of Recent age occur along the south margin of the Rosamond Hills south of the Willow Springs fault and are on the order of 25 feet in thickness. Near the isolated hills and buttes the thickness of the fan deposits may be about equal to the thickness of the younger alluvium which underlies the valleys.

Age.--As explained in the section on younger alluvium, the younger fan deposits interfinger with and are equivalent in age to the younger alluvium, and therefore are considered to range in age from late Pleistocene to Recent.

Water-bearing character.--In areas of extensive rock fans and locally around the small hills and buttes the fan deposits are above the zone of ground-water saturation. In areas where the fan deposits are composed almost wholly of granitic debris and in part are saturated, the yields of wells are small. For example, the deposits along the unnamed hills east of Lancaster basin have been drilled for water, but the yields were extremely low and most were abandoned. The eastern limit of wells in Lancaster basin coincides remarkably well with the contact between the younger alluvium and fan deposits--to the east of the contact there are few wells; to the west the well concentration is dense (fig. 2). Similarly, in the Gloster area unsuccessful attempts to obtain water from the fan deposits are indicated by the unused and destroyed wells. Thus, most wells drilled in the younger fan deposits can be expected to yield little water. Also, there is evidence that the water contained in the deposits is somewhat inferior in quality to that from the alluvium; the dissolved solids content is usually greater and the chloride content somewhat higher. Therefore, the drilling of prospective water wells within the area of the younger fan deposits shown on the geologic map (fig. 2) should be avoided.

## Younger Alluvium

The younger alluvium of this report is defined as the relatively well-sorted deposits underlying the valley areas between the fine-grained playa deposits and the poorly sorted and locally derived younger fan deposits (fig. 2), which stratigraphically are equivalent to and interfinger with the younger alluvium. The contact between the younger alluvium and younger fan deposits commonly is distinct around isolated hills and buttes, such as Soledad Mountain, but is somewhat indistinct near the larger upland areas, such as the Rosamond and Bissell Hills and the hills southeast of Rogers Lake. In addition to the physiographic and surficial geologic evidence, data such as well logs and well yields were used to distinguish the areas underlain by the two units.

Areal extent and stratigraphic position.--The younger alluvium extends into the area of investigation principally from the San Gabriel Mountains on the south and the Tehachapi Mountains on the west and northwest and to a lesser extent from the bordering bedrock hills on the east. The entire central valley area is underlain by younger alluvium.

The younger alluvium in general rests with local unconformity on the older alluvium and the lacustrine deposits; it is also interbedded with the lakeshore deposits and, as explained above, with the younger fan and playa deposits.

The base of the younger alluvium in North Muroc basin is arbitrarily selected as being in the same stratigraphic position as that of the playa deposits, which near well 10/9-4D1 may be about 100 feet below land surface (fig. 3). However, in Lancaster basin, where the accumulation of materials from the San Gabriel Mountains has been large, the base may be much deeper. The younger alluvium is transgressive from south to north over the lacustrine deposits.

Lithology.--Where exposed in excavations, road cuts, and channel banks the younger alluvium is composed predominantly of sand and gravel and some lenses of silt and clay. The clasts consist of crystalline and metamorphic rocks derived from the surrounding mountains; clasts of volcanic rocks are uncommon but locally are present in the Gloster and Chaffee areas and North Muroc basin. These deposits, in general, are unweathered and appear porous.

For the most part the deposits are coarse near the source areas at the contact with the younger fan deposits, and the grain size decreases downstream and is finest near the playas. The younger alluvium in Lancaster basin, which was derived principally from the San Gabriel Mountains, is coarser, more porous, and contains less fine material in the interstices of the sand and gravel than it does in the Gloster and Chaffee areas and North Muroc basin where runoff is smaller and more "flashy" in character.

Thickness.--The maximum thickness of the younger alluvium ranges from about 100 feet in North Muroc basin to possibly 150 feet in Lancaster basin, where the contact with underlying older alluvium was not distinguished (figs. 3 and 4). In the Gloster area, logs of test wells 10/12-13H1, 22J1, and 23C1 suggest that the thickness of the younger alluvium does not exceed 35 feet. In the Chaffee area, the thickness is not known but may be as much as 100 feet in the central and northern parts of the area southwest of the Muroc fault.

Age.--The uppermost part of the deposits are nearly everywhere actively aggrading whenever there is stream runoff or sheetflooding, and therefore the materials are Recent in age. At depth the age is not known but probably is late Pleistocene.

Water-bearing character.--Prior to about 1945, the younger alluvium was a principal source of ground-water supply in Lancaster basin. However, since that time it has been substantially dewatered and in 1960 probably yielded little water to wells. In the Gloster area it is thin and above the zone of saturation; in North Muroc basin and the Chaffee area it is relatively thick but also largely above the zone of saturation.

The logs of wells show that the deposits are composed of discontinuous lenses of gravel, sand, silt, and clay. None of the lenses are sufficiently extensive to be recognizable from well to well. However, in Lancaster basin the upper part of the unit contains numerous clay beds that collectively form a discontinuous confining cap over the underlying materials which constitute the principal water-bearing zone (figs. 3 and 4). The upper part of the deposit consists of discontinuous lenses of permeable material locally containing semiperched water bodies which in 1959 had a higher head than the water in the principal water-bearing zone in the older alluvium. No clear-cut horizon, bed, or group of beds within the younger alluvium was discovered that separates the principal water-bearing zone from the overlying semiperched water bodies.

The younger and older alluviums in Lancaster basin contain most of the principal water body, as shown on figures 3 and 4, and have supplied the bulk of the water for irrigation north and east of the town of Lancaster. The yields of the wells range from about 300 to more than 1,000 gpm and probably average about 700 gpm. The specific capacities of the wells average about 25 gpm per foot of drawdown, which indicates that the deposits are moderately permeable.

## Playa Deposits

The playa deposits are clay, silt, sandy silt, and some sand beds that were deposited in intermittent playa lakes. The deposits underlie the larger dry lakes in the topographically low parts of the valleys.

Origin, areal extent, and stratigraphic position.--The surficial playa deposits are active in that they are accumulated during periods when the lakes are flooded and are subject to deflation during periods when the lakes are dry.

The playa deposits underlie Rogers, Rosamond, Buckhorn Lakes, and several small unnamed lakes (fig. 2) and locally underlie the windblown sand. They are interbedded near the lake margins with the younger alluvium and lakeshore deposits.

Beneath Rosamond and Buckhorn Lakes, and possibly the south end of Rogers Lake, the playa deposits rest on or grade downward into the lacustrine deposits (figs. 3 and 4). Elsewhere, they rest unconformably on the older alluvium, older fan deposits, continental deposits of Tertiary age, and basement complex (fig. 3).

Lithology, thickness, and age.--The deposits are composed of light-yellow to light-gray silty and, locally, sandy clay. Hamilton (1951, p. 147) in his work on Rosamond Lake determined that 70 percent of the clay particles are finer than 1 micron (1/1,024 inch) in diameter and that 40 percent are finer than half a micron. Locally, however, beds up to 20 feet thick and composed mainly of sand and silt are present within the sequence of playa deposits.

Beneath Rogers Lake the playa deposits are about 80 feet thick; the thickness of the playa deposits beneath Rosamond and Buckhorn Lakes was not determined but is presumed to be about the same as that beneath Rogers Lake and is so shown on figure 4.

Based on the stratigraphic relationships and on the probable geologic history of the area, the playa deposits are believed to range in age from late Pleistocene to Recent.

The playa deposits yield virtually no water to wells. Because of their overall fine-grained character, they confine ground water in the principal water-bearing zone beneath the southern part of Rogers Lake and beneath the northern part of Lancaster basin. The extent of the confining beds, formed by the playa deposits and the interfingered fine-grained upper part of the younger alluvium, and the area of artesian flow in 1908 are shown on figures 3, 4, and 6.

## Lakeshore Deposits

The lakeshore deposits consist of sand and gravel and form the beach deposits and spits (fig. 2). The beach bars, shingle beaches, and spits are not differentiated on the geologic map, but they occur principally as beach bars near Rosamond Lake and as beach bars and shingle beaches along the north and northwest sides of Rogers Lake. On the west side of Rogers Lake the beach features are terminated at their southern end by a well-defined recurved spit. In addition to the lakeshore deposits shown on the map, younger lakeshore deposits are also present near the northeast margins of most of the large and small playas. Beaches, bars, and spits are actively being formed during periods when the lakes contain water. They range in thickness from a few inches to several feet, range in length from a few tens of feet to several hundred feet, and commonly are not more than a few tens of feet wide. The exposures of younger beach deposits are too small to be distinguished on the geologic map, and hence are included with the older lakeshore deposits.

Origin, areal extent, and stratigraphic position.--At an earlier time, probably in late Pleistocene when the lowland area now occupied by Rosamond and Rogers Lakes was flooded perennially, strong southwest winds induced currents and waves on the lake. These currents and waves carried coarse-grained materials, deposited in the lake or reworked from the younger alluvium, to the lake margins where the lakeshore deposits were laid down. At present, whenever Rogers Lake is flooded, the strong southwest winds continue to drive water against the beach deposits, and the deposits close to the playa are actively reworked.

Lakeshore deposits are exposed in a nearly continuous 12-mile band around the north end of Rogers Lake, near the west and south margins of Rosamond Lake, and locally near hills between those two lakes. Across the northeast end of Rogers Lake a prominent ridge composed of beach deposits rises 25 to 35 feet above the surface of the playa. Along the northwest side of Rogers Lake, relatively thin beach deposits rest on the older fan deposits and the basement complex and are at an altitude of about 2,300 feet--about 25 feet above the playa. West of the town of Muroc (now abandoned), these deposits merge with a well-defined spit which is about 1 mile in length; at one excavation, since covered, excellent exposures of crossbedding were observed. Lakeshore deposits are discontinuously exposed in small narrow bars or ridges near the south and west margins of Rosamond Lake. In the area between Rogers and Rosamond Lakes the lakeshore deposits, if present, are concealed by actively drifting windblown sand or by old windblown sand.

No exposures are available to show the relationships between the lakeshore deposits, the younger alluvium, and the playa deposits. It appears, however, that the younger alluvium is actively covering the beach deposits; the lakeshore and playa deposits appear to be interbedded; the old windblown sand locally overlies lakeshore deposits; the active windblown sand locally is covering the beach deposits. These relations are shown diagrammatically on figures 3 and 4.

Lithology, thickness, age, and water-bearing character.--The lakeshore deposits consist of cobbles, gravel, sand, and silt. The individual beach bars and spits locally show excellent crossbedding where excavations in the deposits have been made. The dissected surface of the extensive beach bar along the northwest margin of Rogers Lake is sparsely to densely covered with a veneer of cobbles up to 2 inches in the large dimension.

The thickness of the lakeshore deposits is known principally at excavations where the maximum observed thickness was about 25 feet; the entire vertical extent of the deposits may be as much as the playa deposits, or on the order of 80 feet. Test well 10/9-4D1 was drilled through the Rogers Lake beach bar near its west extent and penetrated 34 feet of coarse gravel and sand before encountering the playa deposits (fig. 3). Thus, 34 feet is the maximum known thickness of the lakeshore deposits.

According to early residents of the valley, the fossil bones of a large mammal were recovered from a pit near the southeast end of Rogers Lake beach bar in the relatively fine-grained materials, presumably along or near the contact of the beach and playa deposits. Because the bones reportedly were very large, possibly those of a mammoth, it appears possible that the lower part of the lakeshore deposits is Pleistocene in age. In view of the meagerness of this information and because the surface is aggraded during periods when the lake is flooded, the age of the lakeshore deposits can be defined no more closely than probable late Pleistocene and Recent.

The lakeshore deposits appear permeable, but they are above the zone of ground-water saturation.

## Old Windblown Sand

The old windblown sand consists of moderately dissected and indurated dunes composed of very coarse sand east of Rogers Lake. East of Rosamond Lake it consists of dissected dunes of interbedded silt and sand.

Origin, areal extent, and stratigraphic position.--The old windblown sand in the dunes east of Rogers Lake is very coarse grained; the dunes in that area are mainly of the transverse type--that is, strike northwest, normal to the direction of the prevailing southwest wind. The coarseness of the sand and the shape and crossbedded nature of the dunes are believed to result from a strong prevailing wind blowing over a sandy lakeshore surface which afforded a limited supply of coarse sand. Because the old windblown sand locally consists of alternating layers of sand and clayey silt along the east side of Rosamond Lake, these dune materials are believed to result from alternate changes in the source material available on the lake.

Sand probably was carried periodically into Rosamond Lake by streams and, when the water evaporated, the sand was blown by the wind and deposited as dune sand along the west margin of the lake. As deposition of material by wind continued, the supply of sand is believed to have been exhausted periodically and the clayey materials of the playa deposits were blown away and also deposited on the dunes to the east of Rosamond Lake. Because some of the old windblown sand is highly indurated, it is inferred that at intervals the dunes may have been surrounded by or submerged beneath lake water.

In the lowlands surrounding the playas, extensive areas are covered by moderately indurated dunes of old windblown sand which presently are being eroded by wind action; locally the old dunes are carved into badlands topography as a result of abrasion by blowing sand.

The old windblown sand overlies unconformably and locally is interbedded with the upper parts of the playa deposits, younger alluvium, and younger fan deposits. It is overlain locally by young windblown sand.

Lithology, thickness, age, and water-bearing character.--In the area east of Rogers Lake most of the old windblown sand is coarse grained; grain sizes up to 3 millimeters are common and locally the grain size of much of the deposit exceeds 1.5 millimeters. In that area, as elsewhere, there are excellent exposures of aeolian crossbedding.

In the area east of Rosamond Lake most of the old windblown sand forms dunes which are also being eroded by wind action. The exposures show alternating layers of crossbedded coarse sand and silty clay.

The maximum thickness of the old windblown sand is believed to be about 40 feet; where active wind erosion has occurred locally the deposit ranges in thickness from a thin veneer to about 10 feet.

The stratigraphic position, degree of induration and dissection, and the lithology of the old windblown sand suggest that it was deposited during and immediately after the latter stages of the last perennial lake that existed in Antelope Valley. Accordingly, the age of the old windblown sand is believed to be very late Pleistocene and Recent.

The old windblown sand is above the regional water table and does not contain significant quantities of ground water; in the Buckhorn Lake area it locally contains water of inferior quality perched on the playa deposits.

## Dune Sand

Dune sand comprises both large and small sand dunes. Between the small dunes, minor areas of playa deposits and younger alluvium are exposed. Areas completely covered by sand and those small areas only partly covered are not differentiated on the geologic map (fig. 2).

In Antelope Valley the prevailing wind from the southwest picks up and carries large quantities of sand and finer particles from the alluvial deposits and playas and redeposits the coarser material as dune sand and sand veneer on other formations. Some fine material is blown out of the basin. With respect to the prevailing wind direction the dunes in the area generally are either transverse or longitudinal; locally both exist in the same small area.

The lowland area of Antelope Valley, extending northward from Lancaster to the Rosamond Hills and eastward from Rosamond to about 3 miles east of Rogers Lake, is extensively covered by deposits of windblown sand. Locally, it is absent and some of the land is farmed, but where the windblown sand is absent in only small areas the land is unsuitable for farming because these areas are undrained and are periodically occupied by very small lakes after heavy rains. These features are too small to distinguish on figure 2.

The dune sand overlies unconformably and locally is interbedded with the playa deposits, younger alluvium, and younger fan deposits. Locally it overlies the old windblown sand.

The maximum thickness of the dune sand is believed to be about 40 feet, but in general it ranges from a veneer to about 10 feet.

In many sand dunes grain sizes of 1 to 3 millimeters are common; in a few of the dunes observed, nearly all the grains approach 3 millimeters in size. The coarser material is fairly well-sorted crossbedded arkosic sand.

Where the dune sand rests on playa deposits or on the younger alluvium and contains perched ground water, it formerly yielded small quantities of water of inferior quality to wells used for domestic purposes. Because the wells tapping these perched water bodies are no longer in use and because the quantity of water contained is small, the dune sand is not considered to be a source of ground-water supply.

# GEOLOGIC STRUCTURE

## Regional Structural Features

Antelope and Fremont Valleys are part of the Basin and Range province of the western United States (Fenneman, 1930) and are characterized by fault-block mountains and basins. The Tehachapi and San Gabriel Mountains comprise the major elevated fault blocks and the adjacent desert area is a depressed block, which itself contains local complex structural features. The principal displacement has been along the Garlock and San Andreas faults (fig. 1A). The Garlock fault is a major arcuate structural feature extending from the south end of Death Valley westward to the Tehachapi Mountains, trending southwestward along the southeast side of the Tehachapi Mountains, and joining the San Andreas fault in Tejon Pass.

The San Andreas fault is the most widely known and longest fault in California. It borders Antelope Valley on the south and extends along the northern margin of the San Gabriel Mountains from the southeast corner of the area shown on figure 1A to and beyond the Tehachapi Mountains. The somewhat dissected escarpment of this feature forms the southern boundary of the Mojave Desert region (fig. 1).

Structural Features Related to Ground Water

Within the relatively depressed downfaulted area between the San Gabriel and Tehachapi Mountains, smaller structural features are present. Some of these greatly influence the occurrence and movement of ground water in the unconsolidated materials that partly fill the major structural depression of Antelope Valley. Within this area are at least two major faults and one minor fault, which serve to subdivide the area into separate ground-water basins. These basins are established on the basis of hydrologic continuity and a nearly uniform gradient in the ground-water body in the separate ground-water basins. On the basis of natural subdivisions, the area of this investigation overlies parts of Lancaster and North Muroc basins and the Gloster and Chaffee areas and the southern end of the Koehn Lake area (figs. 2 and 6). The principal faults and ground-water barriers are discussed below.

## Willow Springs Fault

The Willow Springs fault (formerly called Rosamond fault) strikes eastward across Antelope Valley from the area west of Willow Springs to about as far as Buckhorn Lake. It passes north of the town of Rosamond and, although its location is imperfectly known, the dissected escarpment of this feature forms the boundary between the consolidated rocks of the Rosamond Hills on the north and Lancaster basin on the south (fig. 2). An escarpment in the alluvium west of Willow Springs locally marks the location of the fault where it separates Lancaster basin from the Willow Springs area, which is not included in this investigation (fig. 1).

The consolidated rocks along the south flank of the Rosamond Hills locally are greatly disturbed by faults believed to be associated with the Willow Springs fault zone (fig. 2). The total displacement along this fault is unknown. However, the log of well 8/11-9D1 (Dutcher, Bader, Hiltgen, and others, 1961) suggests that the total vertical displacement may be more than 5,000 feet.

The Willow Springs fault and the uplifted Rosamond Hills together form the greater part of the northern boundary of Lancaster basin. The position of the fault in its eastern extent is inferred as shown on the geologic map (fig. 2).

One of the principal purposes of the study was to determine whether a barrier to ground-water movement existed between the Air Force well field at Rogers Lake and the agricultural area to the southwest. In 1951 electrical-resistivity profiles were made across the south end of Rogers Lake to determine whether the Willow Springs fault extended eastward beneath the lake; the resistivity profiles showed no disparity in this area. Furthermore, the fluctuations of water levels and the water-level contours (fig. 6) show no discontinuity in the ground-water bodies tapped by wells. Accordingly, it is concluded that the Willow Springs fault probably does not extend as far east as Rogers Lake, but if it does, it has not yet become an effective barrier to ground-water movement.

## Muroc Fault

The Muroc fault is another major geologic structure related to the occurrence and movement of ground water in the area of investigation. The fault is exposed in the granitic rocks near the northeast margin of the Bissell Hills (fig. 2) and strikes northwest across the alluvial plain northeast of the town of Mojave; it may extend as far as the Garlock fault along the southeast flank of the Tehachapi Mountains. It forms the common boundary between the Chaffee and Koehn Lake areas. As shown on figure 5, the Muroc fault impedes northward movement of ground water and has resulted in a displacement in water level of nearly 300 feet. Movement along the fault probably has displaced beds in the older alluvium and the resulting shear zone has become cemented and (or) is filled with clayey impermeable fault gouge forming a barrier similar to other well-known barrier features elsewhere in southern California.

The feature is not known to extend southeast into North Muroc basin, but it is possible that the buried bedrock barrier beneath the northeast part of Rogers Lake may be related in part to structural movements along a southeast extension of the Muroc fault (fig. 3).

Little is known about the relative movement along the Muroc fault or the total displacement involved. Cache Creek, which emerges from its canyon in the mountains northwest of Mojave, follows the south side of the fault nearly to the Bissell Hills before crossing the fault into the Koehn Lake area. This suggests that the most recent movement may have been relative uplift on the north side, but geologic data indicate that the north side of the fault is down relative to the south (fig. 5). In the uppermost deposits, the Muroc fault does not form a complete barrier to ground-water movement from the Chaffee area to the Koehn Lake area, because no ground water is discharged at land surface on the upstream (south) side.

## Gloster Fault

The Gloster fault is a minor geologic structure that affects somewhat the occurrence and movement of ground water in the Gloster area (fig. 2). It divides the area approximately in the middle into two subareas herein called the east and west parts of the Gloster area. The fault is poorly exposed in the alluvial fans bordering the Rosamond Hills on the south (fig. 2) and strikes northwest across the alluvial plain and probably passes along the northeast margin of Soledad Mountain. As shown on figures 5 and 6 the Gloster fault impedes northeastward movement of ground water.

Little is known about the relative movement along the fault; test wells drilled in the Gloster area penetrated the full thickness of alluvial materials on both sides of the fault, and it was found that the older rocks are not markedly higher on one side of the fault than on the other (fig. 5). Exposures of granitic rock southwest of the fault in the valley area suggest that minor uplift has occurred on the southwest side.

## Rogers Lake Barrier

The imperfectly determined structural feature which forms the gradational boundary between Lancaster and North Muroc basins is termed Rogers Lake barrier. On figure 2 the barrier symbol shows the approximate centerline of the barrier. Limited geologic and hydrologic evidence indicate that the barrier is several miles in width (south to north) and extends from Muroc eastward across the lake as a nearly completely buried irregular bedrock ridge that probably is nowhere more than several hundred feet below land surface (fig. 3). On the lake in the southwest corner of sec. 20, T. 10 N., R. 9 W., about 20 acres of basement complex was exposed (now leveled and covered by the Air Force in connection with runway construction). The extension of the Muroc fault into North Muroc basin along the north side of Rogers Lake barrier may limit the northern extent of this feature.

The hydrologic evidence for the position of the barrier is discussed in the section on the limits of North Muroc basin. Because the barrier feature underlies a part of the surface of Rogers Lake, which is extensively used as a runway for experimental aircraft by the Air Force, it was not possible to undertake exploratory drilling to determine more about the character and extent of the barrier feature.

Because of the reduction in cross-sectional area of the water-bearing deposits, the barrier impedes the flow of ground water out of Lancaster basin. As shown by the water-level contours on figures 6 and 6A and the water-level profile on figure 3, the gradient across the barrier is relatively steep compared to the gradients to the north and south. In 1958 the water level to the north was about 40 feet lower than that to the south.

## Other Structural Features

Several other structural features are shown on the geologic map (fig. 2), but they are not known to affect the occurrence and movement of ground water. Several imperfectly exposed northwest-trending faults are inferred to cut the consolidated rocks in the hills east of Rogers Lake. These features, which were first noted on aerial photographs, were studied to determine whether they formed barriers along their possible extensions beneath the alluvium. Because no barrier effect could be determined, it is assumed that these are old features that either have been inactive since the deposition of the alluvial materials or do not extend far beyond the areas where the basement complex is exposed.

An unnamed fault south of and nearly parallel to the Gloster fault is exposed in the Rosamond Hills and strikes northwest toward the Gloster area, but its effect on ground-water movement could not be determined. Numerous minor faults cut the Tertiary continental and volcanic rocks, but none seem to extend into the ground-water basins.

# GEOLOGIC HISTORY

## Regional History

That this area was the site of marine deposition during Paleozoic time has been shown by the work of Hulin (1925) and Wiese (1950). In his work on the Randsburg quadrangle, Hulin states that a series of marine sediments, believed to be Paleozoic in age, crop out over a large portion of the El Paso Mountains north of this area, and the total thickness of this sequence originally is believed to have been 15,000 to 16,000 feet (Hulin, 1925, p. 31). Wiese (1950) mapped a metasedimentary series in the southwestern part of Antelope Valley which he assigned tentatively to the Paleozoic, because the rocks were lithologically similar to Paleozoic rocks in the Inyo Range and the Randsburg quadrangle, and were intruded by plutonic rocks thought to be of Jurassic age.

So far as is known, only a few fossils have been found in these rocks, and according to Hulin they were very indistinct. George H. Girty (Hulin, 1925, p. 33) believed that one specimen was possibly a Paleozoic coral or sponge probably not younger than Carboniferous age. Accordingly, this area may have been one of marine deposition during Paleozoic time, although only isolated remnants or roof pendants now remain of these once extensive deposits. Later, probably during Jurassic time, a series of volcanic flows and tuff beds accumulated over a part of the area. These were subsequently metamorphosed and are locally exposed in the hills near Boron.

It was into the marine and the pre-Tertiary volcanic rocks that the presently extensively exposed bedrock--mainly quartz monzonite and granite--was later injected. This intrusion is believed to be of late Jurassic or early Cretaceous age (Hulin, 1925, p. 42) and is thought to be a part of, or closely associated with, the Sierra Nevada batholith. There is no further sedimentary record preserved until Miocene time. During the interval from late Jurassic or early Cretaceous to late Miocene time, not only the Paleozoic strata and the metavolcanics but also great thicknesses of the pre-Tertiary granitic intrusives were removed and transported out of the area. The process of degradation apparently continued until a land surface of moderate relief was formed. Reed (1933, p. 184) states that of the land areas of California that existed through early Miocene time, "Mohavia" was not merely the largest but also by far the most active contributor of detritus to the ocean.

During late Miocene time, Antelope Valley once again received sediments but depositional conditions were different from those of Paleozoic time and the area received both continental and littoral sediments, as shown by the presence of the Santa Margarita formation (late Miocene) of littoral origin near the western margin of the valley (Wiese, 1950, p. 32 and 34). Whether marine or littoral deposits exist beneath the entire valley floor is not known, but Wiese postulates that the beds in the Neenach basin (fig. 1A) were deposited near the eastern limit of the late Miocene sea. This was suggested by Wiese as an explanation of the local derivation of the detritus of which they are composed, their coarseness and shallow-water character, and the apparent gradation to continental beds between the outcrop and Liebre Ranch. He further suggests that the volcanic material which centers near the Liebre Ranch may well have been the obstacle that prevented a farther landward transgression of the sea.

This deposition was interrupted by volcanic activity in late Miocene time. The volcanism is believed to have been of local rather than regional extent. Many of the source areas or vents, such as Soledad Mountain, Rosamond Hill, and Red Hill north of Rosamond Lake, supplied the flows, tuffs, and agglomerates now present in the area. Some of the flows issued from fissures, indicating that much local faulting probably occurred at that time.

This volcanic activity was followed by renewed local uplift and probably more vigorous erosion because the uppermost part of the deposits of late Miocene age contain a boulder conglomerate, as described by Simpson (1934, p. 399).

Gale (1946, p. 335) considered the borate beds in the area near Boron to be of Pliocene age. However, owing to lack of fossil evidence, correlation by Gale was based on lithology; he assigned the Kramer borate deposits in North Muroc basin to the Ricardo formation of early Pliocene age.

## History of the Ground-Water Basins

Antelope Valley has existed as a structural valley and has intermittently received detritus from the surrounding highlands since about late Pliocene time. A core collected from a depth of about 1,100 feet in oil-test well 8/11-9D1 contained a few fragments of dacitic rocks, which probably were derived from beds of Miocene or Pliocene age. The valley probably acquired approximately its present configuration in late Pliocene time, and the rate at which the detrital materials accumulated was dependent to a large extent upon the elevation of the surrounding mountains in relation to the valley area and on climatic conditions which changed from time to time as deposition continued. From late Pliocene to about middle Pleistocene time a considerable volume of alluvial deposits accumulated, as evidenced by the great thickness of older alluvium and older fan deposits. Intermittent structural activity probably accounted for the local deposition of the old fanglomerate, but, in general, structural activity probably was limited mainly to long-continuing elevation of the surrounding mountains and depression of the valley areas.

In about middle Pleistocene time the period of older alluviation was disrupted by marked structural activity. The present major physiographic features of the valley area probably date from that time. Movement along the principal faults probably caused downwarping of the basins and major uplift of the mountains, resulting in disruption of the established drainage pattern and locally in the formation of basins of interior drainage. Since middle Pleistocene time, the following geologic history of the area is postulated:

A pluvial period, or time of relatively heavy precipitation, produced considerable runoff and large lakes in which the blue-clay member of the lacustrine deposits began to form in Lancaster basin. Deposition of the older alluvium probably continued around the margins of the lake and was followed by deposition of the younger alluvium. However, no clear subsurface contact between younger and older alluvium could be determined. No remnants of old shorelines of this age exist, but the outflow probably was northward into Fremont Valley and thence eastward. Areas where the lake overflowed and the depth of the lake are not known. The large volume of alluvial debris supplied from the San Gabriel Mountains encroached upon the lake in Lancaster basin, forcing it northward and resulting in the transgression of the alluvial sequence northward over the lake clays, which in turn were deposited over older alluvium at the present site of the south end of Rogers Lake. Alluviation in the other basins continued. Erosion of the elevated older fan deposits and older alluvium also occurred.

An interpluvial period, or time of relative aridity, followed the pluvial period, the lakes probably became intermittent, and deposition of the younger alluvium and fan deposits continued at a greatly reduced rate. Possibly part of the brown-clay member of the lacustrine deposits was deposited in the shallow intermittent lakes. Minor crustal warping and faulting probably occurred during this period.

A second pluvial period rejuvenated the lake, which covered the sites of Rogers, Rosamond, and Buckhorn Lakes and probably extended considerably farther. This large perennial lake was probably the Lake Thompson, named by Miller (1946). The deposits laid down probably comprise the uppermost part of the lacustrine deposits and a large part of the playa deposits. The lakeshore deposits and old shore features cut in the basement complex and elsewhere probably were formed and now remain as remnants at altitudes between about 2,275 and 2,350 feet; the most prominent features are at an altitude of about 2,300 feet. This altitude is about 60 feet lower than the present divide between Desert and Castle Buttes (fig. 1), which during the previous pluvial period probably was the outlet from Antelope Valley to Fremont Valley and which now is concealed beneath the younger alluvium and fan deposits. The bulk of the younger alluvium and fan deposits probably was deposited during this period.

The end of the second pluvial period probably was marked by the return to arid climatic conditions which have continued to the present. Perennial Lake Thompson gradually decreased in size and became ephemeral. Deposition of the younger alluvium, younger fan deposits, and playa deposits continued at a much slower rate, and the intermittent dry lakes took on their present appearance and character. The return to drier climatic conditions was accompanied by an increase in the deposition of windblown sand, which covers parts of Rosamond, Buckhorn, and Rogers Lakes and a considerable part of the adjacent younger alluvium and fan deposits.

The relation of the climatic cycles of the Pleistocene and Recent epochs to the sedimentation in the Mojave Desert region is not presumed to have been solved during this investigation. Rather, the probable sequence of events discussed above is presented as a logical chronological development in the light of the evidence at hand for the limited area of Antelope Valley with the expectation that as additional data accumulate, a more accurate chronology for the geomorphic, sedimentary, and structural history of the region will be attained.

## GENERAL FEATURES OF RUNOFF AND RECHARGE

Runoff from the San Gabriel and Tehachapi Mountains discharges onto the alluvial fans, crosses the valley alluvium, and infrequently reaches the playas where it ponds and evaporates. The perennial low flow of the streams seldom extends far beyond the foot of the mountains, and it is only during infrequent winter storms or summer cloudbursts that sufficient runoff occurs to reach the playas. Because the average precipitation on the valley floor ranges only from 5 to 10 inches a year, very little runoff occurs and probably very little rain penetrates below the root zones. Flood flows from the mountains, however, lose water by seepage into the younger fan deposits and alluvium, and therefore runoff is the principal source of recharge to the ground-water basins.

Unfortunately, only a few of the streams are gaged and none have gages on the lower courses (near the playas) to measure the seepage loss. It was beyond the scope of this investigation to estimate the runoff from the mountains or the seepage losses in the valley areas. However, estimates have been made by others. Thompson (1929, p. 322) estimated that the total runoff in Antelope Valley averages about 75,000 acre-feet a year and believed that possibly 50,000 acre-feet percolated to ground water. The California Division of Water Resources (1947, p. 10, and table 1) estimated that the total runoff averages about 66,000 acre-feet a year; the estimates are shown in table 2. The California Division of Water Resources also estimated that of the 66,000 acre-feet about 5 percent is lost by evaporation and transpiration, leaving 63,000 acre-feet per year for direct diversion and for percolation to ground water.

Table 2.--Estimated total average annual runoff to Antelope Valley[1/]

| Watershed area | Area (acres) | Runoff[2/] (acre-feet) |
|---|---|---|
| San Gabriel Mountains, including Rock, Little Rock, Leonis Valley-Amargosa, and several small creeks | 186,240 | 44,000 |
| Sawmill, Liebre, and Tehachapi Mountains (not including Oak, Cottonwood, and a few other small creeks) | 128,000 | 18,000 |
| Tehachapi Mountains, including flow from Oak, Cottonwood, Minetos, and other small creeks | 42,880 | 4,000 |
| Totals | 357,000 | 66,000 |

1/ From California Division of Water Resources, 1947, table 1.

2/ Rounded to the nearest thousand acre-feet by the authors.

The two principal streams draining the north side of the San Gabriel Mountains are Rock Creek and Little Rock Creek (fig. 1). Troxell (1956, p. 42) estimates that the mean annual runoff in these two streams, based on the period 1920-50, is about 13,000 acre-feet for Rock Creek (near Valyermo) and about 14,000 acre-feet for Little Rock Creek (near Little Rock), or a total of 27,000 acre-feet. This estimate is roughly 60 percent of the totals estimated by the California Division of Water Resources (1947).

## GROUND-WATER HYDROLOGY

This appraisal of the principal ground-water basins in and near Edwards Air Force Base is developed through successive treatment of the occurrence, source, and movement of ground water. It includes critical analyses of (1) the barrier features which impede movement and delimit the basins; (2) the nature and relative magnitude of the recharge and discharge; (3) water-level fluctuations and their relation to the ground-water supply; (4) the general quality of water; and finally, (5) the estimates of ground-water storage capacity in areas critical to the water supply in the vicinity of the Air Force Base and an analysis of the data with respect to the potential requirements of the Air Force Base.

# LANCASTER BASIN

## Limits of the Basin

Lancaster basin is about 35 miles long and 24 miles wide and covers an area of about 800 square miles (fig. 1A), of which about 360 square miles is considered in this report and is shown on figure 2. It extends from Buttes basin and the San Gabriel Mountains on the south to Willow Springs fault and Rogers Lake barrier on the north, and from Neenach basin on the west to the unnamed hills on the east. As herein considered, the basin is about the same as that defined by the California Division of Water Resources (1947, pl. 2).

No known barriers exist within the basin that would impede the movement of ground water. Hence, although several water-bearing zones are known to occur, Lancaster basin is a single hydrologic unit.

## Occurrence of Ground Water

There are two major and three minor ground-water bodies in Lancaster basin. The two major bodies, the principal and the deep, supply nearly all the water pumped from wells in the basin.

## Principal and Deep Water Bodies

The principal and deep water bodies in Lancaster basin extend continuously from Buttes and Neenach basins (fig. 1) on the south and west to the Rosamond Hills and North Muroc basin on the north and northeast. They are contained in the younger and older alluvium and the younger and older fan deposits which fill the major structural basin of Antelope Valley, and they are separated vertically by the lacustrine deposits (figs. 3 and 4). The bottom of the basin is considered to be at the base of the older alluvium. In the deeper parts of the basin below the depth range penetrated by water wells, however, the water may be of poor chemical quality.

The thickness of the two water bodies varies from place to place with the depth to water below land surface and the depth below land surface of the old granitic surface or other nonwater-bearing rocks. In the area adjacent to granitic outcrops, such as Alpine Buttes and Piute Butte, near the southeast corner of the basin (fig. 1), the granitic floor is buried under only 300 to 400 feet of alluvium, but on Rosamond Lake oil-test well 8/11-9D1 was drilled to a depth of 5,576 feet and reportedly did not encounter bedrock (Dutcher, Bader, Hiltgen, and others, 1961, table 6). Wells north of Roosevelt School reportedly have been drilled to depths of 1,500 feet and have not encountered bedrock. Well 8/11-35J1 bottomed in unconsolidated materials at a depth of 1,536 feet, as did well 8/11-25R2 at 1,301 feet and well 8/11-36H2 at 1,050 feet. On the east side of the basin, well 9/10-24G1 was drilled to a depth of 750 feet in unconsolidated deposits, and on the west side, well 8/12-30Q1 is reported to have been drilled through unconsolidated alluvial deposits to a depth of more than 500 feet. Although many wells have been drilled in the basin, only a few near outcrops of bedrock, such as wells 9/9-6A1, 6C1, 6E1, 6L1, and 6M1, are known to have penetrated fully the water-bearing deposits.

The depth to water below land surface in Lancaster basin varies from place to place, but in general is greatest along the south and west sides. Near the Buttes basin boundary on the southwest the depth to water below land surface ranged from 240 to 300 feet and on the southwest side of the basin the depth to water exceeded 300 feet in 1952. As of March 1952 the depth to water decreased from the south edge of the basin toward the north and east, and in the vicinity of the southwest corner of Rosamond Lake there was an area of about 3 square miles where the heads in wells were above land surface. The area of flowing wells did not extend farther to the north and east to Buckhorn and Rogers Dry Lakes, as the water levels there were generally 20 to 50 feet below land surface. In the center of the pumping depression in sec. 26, T. 8 N., R. 11 W. (fig. 6), the depth to water was about 150 feet below land surface. By March 1958 the center of the pumping depression had moved about a mile southeast and was about 25 feet deeper than in 1952 (fig. 6A, and Dutcher, 1959b).

In the area around the south end of Rogers Lake, the depth to water varies according to the location of the well in relation to topographic features. Those wells on the alluvial slopes near the bedrock hills, or on sand dunes or knolls have a greater depth to water than those near the playa. In December 1951 the depth to water at well 9/9-20G1 on Rogers Lake was about 6 feet below land surface and at well 9/8-6H1 on the fan to the northeast it was about 115 feet below land surface.

Most wells penetrate not more than a few hundred feet into the saturated deposits; these wells locally disclose differences in the hydrostatic head within that range of penetration. Because the lacustrine deposits in the central part of the basin (figs. 3 and 4) effectively confine ground water in the permeable materials below, certain deep wells there and shallower wells along the northern margin penetrate into the older alluvial deposits that contain ground water at a head generally higher than in the alluvium above the lacustrine deposits. This is illustrated on figure 7 by the hydrographs for closely spaced wells 7/10-5M1, 5N3, and 7B1, which are shallow, intermediate, and deep, respectively.

Underlying an area of about 240 square miles in the central part of the basin, the ground water is considered to be confined beneath the lacustrine deposits, the playa deposits, and local clay beds at shallow depth in the younger alluvium. The original area of flowing wells, as determined by Johnson (1911), is reproduced on figure 6 for comparison with the area of flowing wells in March 1952. In the few deep wells, perforated only opposite older alluvium beneath the lacustrine deposits, water levels in the spring months are generally a few feet to as much as 12 feet higher than in shallower wells tapping only materials above the lacustrine deposits. (See hydrographs for wells 7/10-5N3 and 8/10-19N4, figs. 7 and 8.)

Accordingly, the geologic and hydrologic data indicate two generally distinct water-bearing zones separated by the lacustrine deposits. The permeable materials of the younger alluvium and probably part of the older alluvium above the lacustrine deposits constitute the principal water-bearing zone, and the permeable materials of the old alluvium below the lacustrine deposits constitute the deep water-bearing zone. The degree of hydraulic interconnection between them is not known, but the wells tapping the deep zone generally had a somewhat higher head in 1952 and therefore were not used for control in constructing the water-level contours (fig. 6).

The extent of the area of flowing wells has decreased continuously from more than 240 square miles in 1911 (Johnson, 1911) (fig. 6), to about 200 square miles in 1920 (Thompson, 1929, pl. 19), and to about 3 square miles in March 1952 (fig. 6). In 1960 no flowing wells existed in Lancaster basin. In March 1952 artesian flow was noted at five wells in the area outlined, but flow occurred for a short time, only during the spring when there were no large withdrawals of ground water. The artesian flow occurred after large withdrawals had stopped and the subsequent transmission of pressure effects caused the water levels to recover partially from the low levels of the previous irrigation season.

The northeastern boundary of the confined water beneath Rogers Lake is imperfectly known. It is believed to extend about to the southern edge of Rogers Lake barrier as shown on figure 3. This position is deduced mainly from reports that certain wells in the area formerly flowed; it also is based on reports of the northernmost occurrence of springs in 9/9-8 and 10/9-36. A northeast-trending line between these two points may represent the northernmost limit of original artesian flow.

## Minor Water Bodies

Several shallow semiperched water bodies occur in the uppermost part of the younger alluvium and playa deposits. These overlie and have a higher head than the water in the underlying principal and deep water bodies. Under native conditions the shallow bodies had a lower head than the deeper bodies and were fed by upward leakage. Now that the head in the deeper zones has been reduced substantially by pumping, the converse is true and the shallow water in large part has become semiperched to perched and supplies some water to the deeper zones by downward leakage. This relationship is clearly demonstrated by the hydrographs (fig. 7), which show that the water level prior to about 1940 in well 7/10-5N1 (intermediate depth) was above that in well 7/10-7B1 (depth 81.6 feet) and that the water level after about 1940 in well 7/10-5M1 (depth 387 feet) was below the level in well 7B1. These graphs show that originally the levels in deep wells tapping the principal water-bearing zone were higher than those in shallow wells tapping the shallow deposits because water levels in most of the deeper wells were above land surface prior to about 1920. The presence of shallow water bodies was not detected in the area of the large pumping depression (fig. 6), where shallow observation wells are lacking and where sufficient time has elapsed since regional drawdown began to cause the water in the upper zones in large part to drain to the deeper and more heavily pumped zones.

Minor amounts of water are withdrawn from the shallow water bodies mainly for domestic use. However, the declines shown in the hydrographs indicate that water is draining slowly from the semiperched water bodies through the separating clay lenses into the deeper zones below. As was pointed out, the shallow zones are believed to have received recharge initially from the main confined water body, but at present (1959) are believed to be independent of that source and to receive only recharge from infiltration of irrigation-return water and possibly very minor amounts from streams.

No clear-cut base for the vertical extent of the semiperched water bodies was discovered; it appears likely that they are present discontinuously within the upper part of the younger alluvium and playa deposits and no definite horizon within the deposits separates the semiperched water bodies from the principal water body. Also, semiperched water bodies probably will become more extensive both areally and at increasing depth as the head in the deeper zone continues to decline. Accordingly, these shallow semiperched water bodies may be considered a discontinuous and transient "shallow water-bearing zone," which is not identified on the maps or cross sections.

Discontinuous perched water bodies are contained in the dune sand that rests on the playa deposits. They are perched above and separated from the principal water body by the generally fine-grained playa deposits and formerly supplied water locally to shallow domestic wells. They also are separated from the semiperched water bodies in the alluvium and playa deposits. Recharge is extremely small and is presumed to be wholly from infiltration of rain falling on the dune sand. A large part of the ground water evaporates from the margins of the dunes and a very small part percolates downward through the playa deposits to other water bodies. These perched water bodies are too small to identify on the maps and cross sections, and wells tapping them were not used for control in constructing the water-level contours for the principal water-bearing zone.

A relatively thin water body locally overlies the bedrock in the pediments and occurs in the fan deposits which surround the bedrock highlands. Water in the fan deposits rests on bedrock, which is at comparatively shallow depth, particularly along the south flank of the Rosamond Hills. Water-level altitudes in wells penetrating these water bodies were not used in constructing the water-level contours (figs. 6 and 6A). Wells that derive their supply from this source are sufficient only for limited domestic supply or stock needs, principally wells 9/11-18L1, 9/11-22K1, and 9/10-8P1, near the north margin of Lancaster basin. Water not intercepted by wells for these purposes moves valleyward and eventually reaches the shallow or the principal and deep water bodies. (See section on quality of water.)

## Source and Movement of Ground Water

### General Features

Ground water, like water in streams, moves from points of high head to lower head, though, of course, it moves much more slowly. In the past, ground water in Antelope Valley moved from the surrounding mountains on the south and west toward Rosamond and Buckhorn Lakes, where it was evaporated from the surface of the playas or used by plants, and northward beneath Rogers Lake, where it moved across the Rogers Lake barrier to North Muroc basin, and thence out of the valley between Desert Butte and Castle Butte, as described by Thompson (1929, p. 325). In 1952, however, owing to the large withdrawals by pumping, the direction of ground-water flow had been modified extensively from that under native conditions. The water-level contours (fig. 6), based on water-level measurements made March 3 to 8, 1952, show that in Lancaster basin the water level was lowest, 2,220 feet above sea level, in the pumping depression centering around 8/11-26, where irrigation wells are most numerous. Extending away from this pumping depression in all directions, the water levels were progressively higher in altitude, indicating that ground water was moving from a large surrounding area toward the area of heavy pumping. Another smaller ground-water depression in 1952, caused by heavy pumping during the period, was in 9/10-16 and 20. Here water levels in wells locally were more than 115 feet below land surface in September 1951 (Dutcher, Bader, Hiltgen, and others, 1961). A minor depression also centered about 8/13-14 and 15.

By March 1958, the low point of the main pumping depression had moved slightly southwestward to 8/11-34, and the water level had been drawn down to about 1,995 feet above sea level (fig. 6A). A lesser pumping depression had developed to the southeast, centered around 7/10-30, where the deepest water level was about 2,220 feet above sea level. The pumping depression centered around 9/10-16 had extended laterally for several square miles, particularly toward the southeast, but the deepest water levels were a few feet higher than in 1952. A smaller pumping depression had developed to the east, centered about 9/10-24, caused by increased pumping in that area.

In March 1952 the 2,260-foot contour line surrounding the main pumping depression was elongated in the northeast direction and extended from 7/11-19 to 9/10-35. At the close of the pumping season in November 1951, however, the 2,260-foot contour line did not close around the pumping depression but extended completely across Rogers Lake on the south and to the margin of the basin along the north side of the playa. In November 1951 a low ground-water divide was present in the vicinity of the southern part of Rogers Lake, and ground water was moving away from the divide to the northeast toward Rogers Lake barrier and into North Muroc basin, and to the southwest toward the large pumping depression. The gradient is steepest toward the southwest, and in 1960 the major movement of water still occurred in that direction.

The result of the reverse in direction of flow due to pumping will in time cause substantial ground-water movement out of, and hence depletion of storage in the vicinity of, the well field at the Air Force Base. As long as withdrawals continue to increase annually, or even if they are maintained at the average rate for 1950-55, in Lancaster basin, the cone of depression will continue to enlarge and more water will move from the area of the Air Force well field toward the pumping depression. This depletion of storage due to pumping outside the base boundary is discussed in the section on ground-water storage capacity.

Hydrographs compiled from continuous water-level recorders, which were operated on three Air Force wells, are plotted on figure 9. The comparative water-level altitudes of these graphs substantiate the conclusions derived from the water-level contours that since 1952 ground-water movement during most of each year is from the Air Force Base toward the pumping depression. The seasonal pumping effects in the agricultural season can be identified readily in these graphs. They show that, during the early part of 1951, there was a decrease in head from southwest to northeast--from the vicinity of well 8/10-4G1 toward wells 9/10-24P1 and 12R1. During the pumping season in the agricultural areas to the southwest, however, the head relations were reversed. From about June 1951 to January 1952, the decrease in head was from the vicinity of well 9/10-12R1 toward wells 9/10-24P1 and 8/10-4G1--that is, from northeast to southwest. During 1952 this cycle was repeated, but the head decline toward the southwest during the summer months was somewhat greater, as evidence by the increased separation between the graphs for the individual wells. If the large agricultural withdrawals are continued, it can be expected that in time ground water as far north as Rogers Lake barrier will be moving southwest toward the pumping depression, thereby depleting the supply beneath the Air Force Base.

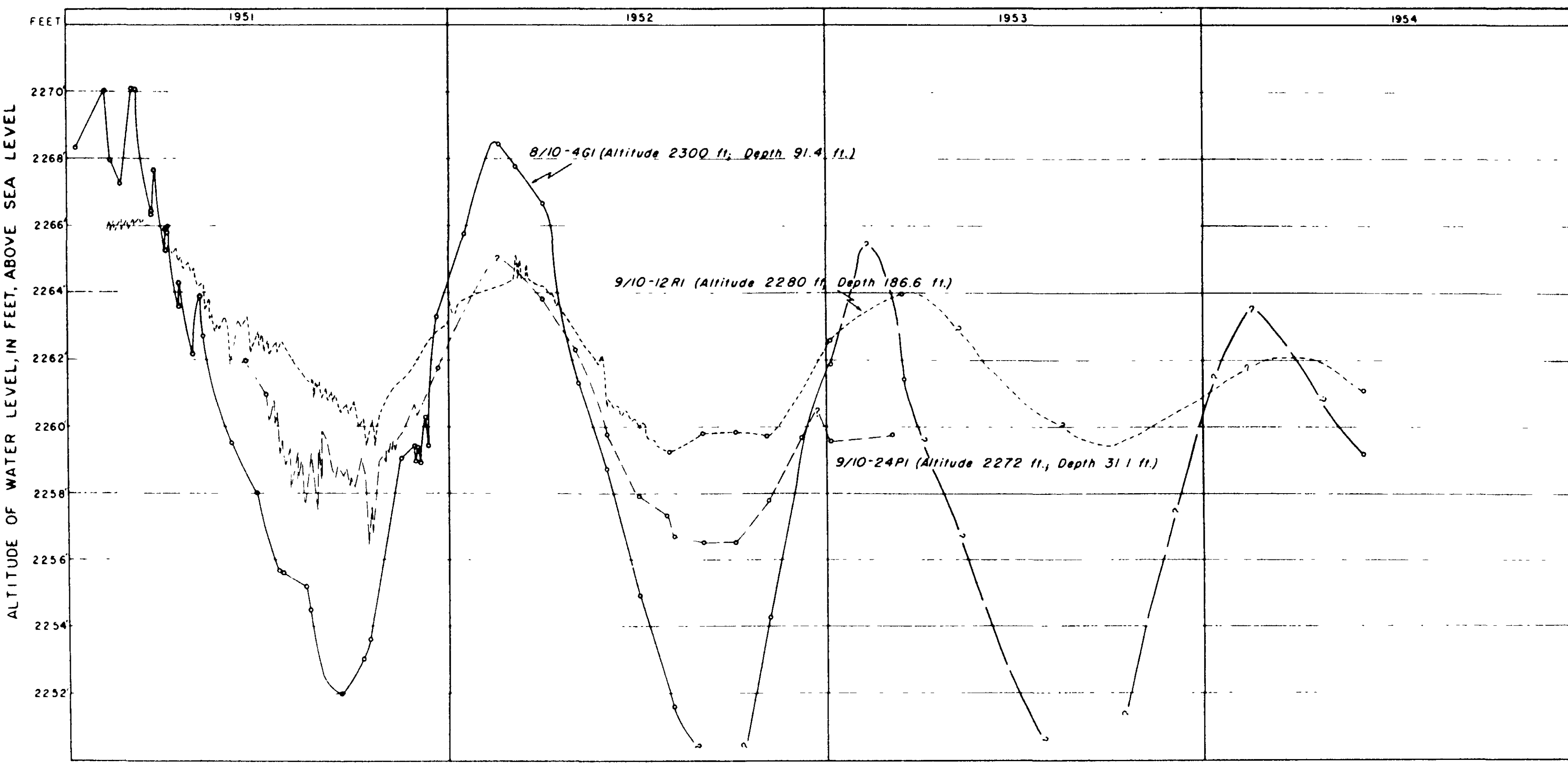



FIGURE 9. SHORT-TERM HYDROGRAPHS FOR THREE WELLS SHOWING SEASONAL PUMPING EFFECTS IN THE WEST ROGERS STORAGE UNIT

## Principal Sources of Recharge

The main source of recharge to Lancaster basin is underflow from Neenach and Buttes basin which adjoin Lancaster basin on the west and south. A second and minor source of ground-water recharge may enter Lancaster basin as underflow from two sources: from beneath the large alluvial fan southeast of Rogers Lake, and from the Cottonwood Creek alluvial fan across the Willow Springs fault west of the Rosamond Hills.

The ultimate source of the water is from rainfall and melting snow. This water collects in streams as runoff and percolates from the streambeds to the ground-water body in the adjoining ground-water basins. After it becomes a part of the ground-water bodies near the mountains it moves slowly toward the heavily pumped area near the center of Lancaster basin. The rate at which the water moves was not determined in this study. Measurements made by Lippincott and reported by Thompson (1929, p. 321) indicate a velocity of about 3.4 miles a year in 1896 in the highly permeable material present in the vicinity of Little Rock Creek where the hydraulic gradient was relatively high. However, that rate is much greater than the average velocity for the area and would not be applicable to Lancaster basin where the deposits have much lower pemerability and where the gradient is much less. Some direct recharge to ground water occurs when floodwaters occasionally enter the basin in Rock Creek and Little Rock Creek washes.

As pointed out in the section on runoff and recharge to Antelope Valley, the probable magnitude of the average annual recharge has been estimated by Thompson (1929, p. 322) and the California Division of Water Resources (1947, p. 19) as 50,000 to about 63,000 acre-feet per year. In addition, estimates of annual recharge for the period 1924-51 were made by Snyder (1955) and are shown in table 3. Under natural conditions practically all this recharge entered Lancaster basin, from which it was discharged by natural processes. Now that there is substantial pumping in the adjoining basins in Antelope Valley, a part of this recharge is intercepted; so the recharge to Lancaster basin has been reduced. Moreover, within the basin, most of the recharge is intercepted by pumping south of Rosamond and Rogers Lakes before it reaches the Air Force Base.

The only recharge now reaching the well field at the Air Force Base is the minor amount contributed from infrequent and generally small runoff on the alluvial fans east and west of Rogers Lake and south of Rogers Lake barrier. Thus, the supply available at the Air Force Base in this basin is limited almost wholly to the ground water in storage, and even this supply is draining slowly southwestward toward the large area of pumping for irrigation and northward to North Muroc basin.

## Principal Types of Discharge

There are two principal types of ground-water discharge from Lancaster basin: discharge by natural means and discharge by artificial means. The natural discharge at present includes underflow into North Muroc basin and a small amount of transpiration by native plants that depend on ground water for their supply. Natural discharge formerly included also discharge by springs and losses by evaporation from bare soil surfaces where ground water was at shallow depth. Artificial discharge of ground water is here defined as pumping for agricultural and other uses.

Pumping for irrigation.--In Antelope Valley the use of ground water for agricultural purposes dates back to the early 1880's, when it was discovered that wells drilled in the lower part of the valley to depths of 200 to 500 feet yielded flowing water in quantities sufficient for irrigation. According to Thompson (1929, p. 20), Hinton reported that in 1890 about 100 wells were in use in the valley. Johnson (1911, pl. 6) showed the location of 353 wells in 1908, a large part of which were within the area of artesian flow. Thompson (1929, p. 326), at the completion of his fieldwork in about 1920, reported data for 171 key water wells in Antelope Valley and estimated the pumpage for the irrigation of about 11,960 acres to be about 38,000 acre-feet per year. In that part of Antelope Valley shown on figure 2 about 1,000 water wells of all types were inventoried in 1950-52.

The drilling of new wells and the use of ground water for irrigation in Antelope Valley has increased steadily since 1890. The California Division of Water Resources (1947, p. 16) estimated the pumpage in 1945 to be 109,000 acre-feet for the irrigation of about 44,500 acres, which exceeded their estimate of average annual recharge (63,000 acre-feet) by about 45,000 acre-feet. New lands were and are being developed each year, and it is reported (California Division of Water Resources, 1947, p. 17) that between 1945 and May 1947 roughly 8,000 acres were added to the area irrigated, thereby increasing the annual overdraft to about 60,000 acre-feet per year. Using Thompson's estimate of 11,960 acres under irrigation in 1920 and the State's estimate of about 44,500 acres under irrigation in 1945, the average annual irrigated acreage increase was about 1,300 acres. However, as discussed above, the yearly increase in lands put under irrigation during recent years has greatly exceeded the 25-year average of 1,300 acres per year for the period 1920-45. Hurley (1950) reports that 54,900 acres were under irrigation in Antelope Valley in 1949, most of it in Lancaster basin. Snyder (1955, p. 62) reports that 70,900 acres were under irrigation in Antelope Valley in 1951. In 1959 Antelope Valley was one of the largest irrigated areas in the Mojave Desert region.

Because the area under irrigation increased from about 44,500 acres in 1945 to about 70,000 acres in 1951, it probably was still larger in 1959, and therefore, the total quantity of water pumped for irrigation also was greater than in 1951. Snyder (1955, p. 87) estimated that the net draft of ground water--total pumpage less return to the water table by infiltration--in Antelope Valley during 1951 was about 168,000 acre-feet.

As the land most suitable for irrigation in the central part of Lancaster basin is still being developed, the demand for water is increasing and many new wells are being drilled each year. Large ground-water withdrawals have depleted substantially the amount of ground water in storage and have caused the water levels to decline at an accelerated rate. This, in many cases, has made it necessary for the users to drill new wells or deepen old wells in order to continue to obtain an adequate supply. Increased annual use of water in this area only tends to increase the overdraft that now exists.

Data compiled by Snyder (1955, p. 87) and presented in table 3 indicate that annual overdraft in Antelope Valley, mainly the result of pumping for irrigation in Lancaster basin, has existed at least since the early 1920's, and that the yield of about 60,000 acre-feet a year has been exceeded since about 1928. The estimates by Snyder show that the cumulative overdraft for the period 1924-51 was more than 1.8 million acre-feet as of 1951, probably greater than that in any other ground-water basin in the desert of southern California.

Table 3.--Ground-water inventory and overdraft, Antelope Valley, 1924-51

(after Snyder, 1955, table 5.1)

| Year | Estimated net draft on ground water (acre-feet) | Estimated recharge to ground water (acre-feet) | Overdraft on ground water (acre-feet) | |
|---|---|---|---|---|
| | | | Annual | Cumulative[1] |
| 1924 | 27,000 | 9,000 | 18,000 | 518,000 |
| 1925 | 32,000 | 6,000 | 26,000 | 544,000 |
| 1926 | 41,000 | 43,000 | -2,000 | 542,000 |
| 1927 | 49,000 | 35,000 | 14,000 | 556,000 |
| 1928 | 64,000 | 5,000 | 59,000 | 615,000 |
| 1929 | 81,000 | 8,000 | 73,000 | 688,000 |
| 1930 | 86,000 | 12,000 | 74,000 | 762,000 |
| 1931 | 79,000 | 13,000 | 66,000 | 828,000 |
| 1932 | 55,000 | 44,000 | 11,000 | 839,000 |
| 1933 | 48,000 | 7,000 | 41,000 | 880,000 |
| 1934 | 60,000 | 11,000 | 49,000 | 929,000 |
| 1935 | 56,000 | 50,000 | 6,000 | 935,000 |
| 1936 | 66,000 | 10,000 | 56,000 | 991,000 |
| 1937 | 64,000 | 75,000 | -11,000 | 980,000 |
| 1938 | 65,000 | 102,000 | -37,000 | 943,000 |
| 1939 | 69,000 | 31,000 | 38,000 | 981,000 |
| 1940 | 82,000 | 11,000 | 71,000 | 1,052,000 |
| 1941 | 58,000 | 167,000 | -109,000 | 943,000 |
| 1942 | 79,000 | 10,000 | 69,000 | 1,012,000 |
| 1943 | 82,000 | 99,000 | -17,000 | 995,000 |

Table 3.--Ground-water inventory and overdraft, Antelope Valley, 1924-51--Continued

(after Snyder, 1955, table 5.1)

| Year | Estimated net draft on ground water (acre-feet) | Estimated recharge to ground water (acre-feet) | Overdraft on ground water (acre-feet) | |
|---|---|---|---|---|
| | | | Annual | Cumulative 1/ |
| 1944 | 86,000 | 69,000 | 17,000 | 1,012,000 |
| 1945 | 98,000 | 24,000 | 74,000 | 1,086,000 |
| 1946 | 115,000 | 23,000 | 92,000 | 1,178,000 |
| 1947 | 123,000 | 29,000 | 94,000 | 1,272,000 |
| 1948 | 137,000 | 1,000 | 136,000 | 1,408,000 |
| 1949 | 142,000 | 3,000 | 139,000 | 1,547,000 |
| 1950 | 150,000 | 6,000 | 144,000 | 1,692,000 |
| 1951 | 168,000 | (a) | 168,000 | 1,860,000 |

1/ "Cumulative overdraft should include the waste and overdraft which occurred before adequate records became available; an allowance of 500,000 acre-feet is made for this volume."

a. "Less than 1,000 acre-feet."

In 1952 some discharge was still taking place in the area of flowing wells. However, these uncapped wells flowed for less than 6 months a year, as indicated by measurements taken in 1951-52 at well 8/12-12Q1, where the water level was 3.06 feet below land surface in December 1951, but was above land surface and flowed from February 1, 1952, until about June 5, 1952 (Dutcher, Bader, Hiltgen, and others, 1961). The water level in this well was 1.47 feet below the top of casing on July 3, 1952. The discharge from uncapped flowing wells as of 1952 was negligible, and it had stopped altogether by 1957.

Pumping for Edwards Air Force Base.--The Air Force has drilled new wells from time to time to supply the increasing demands for water at Edwards Air Force Base. In connection with the water supply at the Base, the Corps of Engineers, U.S. Army, was consulted by the Air Force at various times after the problem of declining water levels in Antelope Valley became serious. It was realized that, if the trend of increased agricultural development in that area continued and a national emergency necessitated increased water usage at the Base, a ground-water shortage, considered to be of serious nature by all users, might develop. In this connection the magnitude of the pumpage by the Base is a critical factor.

Records of total ground water pumped from the wells at Edwards Air Force Base were supplied by the Air Force for the period July 1, 1947, to February 1, 1954, and from August 1, 1955, through 1959. Yearly totals, in part estimated for the 13-year period 1947-59, are shown in table 4.

Table 4.--Pumpage from wells at Edwards Air Force Base, 1947-59

| Year | Pumpage (acre-feet) | Year | Pumpage (acre-feet) |
|---|---|---|---|
| 1947 | a600 | 1954 | a2,000 |
| 1948 | 670 | 1955 | a2,200 |
| 1949 | 640 | 1956 | a2,400 |
| 1950 | 650 | 1957 | a2,800 |
| 1951 | 810 | 1958 | a4,100 |
| 1952 | 1,000 | 1959 | a4,500 |
| 1953 | 1,800 | | |

a. In part estimated by the Geological Survey.

Except for a small amount of Base pumpage from North Muroc basin, which has been about 100 acre-feet a year or less, all the supply for the Base is derived from Lancaster basin. The total pumpage for the 13-year period of record has increased sevenfold. The pumpage of 4,500 acre-feet in 1959 is about 55 percent of the ultimate requirements, estimated by the Air Force to be about 8,000 acre-feet per year. Even if this ultimate amount were to be withdrawn wholly from Lancaster basin, it would be equivalent to only about 3 percent of the net draft at the 1951 rate (table 3).

Natural discharge.--Under natural conditions the discharge from Lancaster basin over a long period of time equaled the recharge to the basin. Because of heavy pumping and overdraft, however, natural discharge in 1959 was substantially reduced. Originally, natural discharge occurred in three known ways, which are discussed separately below:

1. In past years some ground water was discharged by means of springs that flowed the year round. Some of the more prominent springs are discussed by Johnson (1911, p. 47) and by Waring (1915, p. 376-377). Buckhorn Springs in 9/10-27M reportedly ceased to flow in 1944, but in 1911 reportedly had a total flow of about 180 gpm. Indian Springs, in the SE$\frac{1}{4}$ of 9/12-14, also has stopped flowing but was reported by Waring to flow about 3 gpm in 1915. Willow Springs, in 9/13-7Q and 7R, had a combined flow large enough to irrigate about 33 acres in 1911, according to Johnson (1911, p. 47). Waring reported the flow at 35 gpm.

Charles Anderson, a long-time resident of Antelope Valley, reported that a spring existed in 1891 on Rogers Lake in the center of 9/9-8. A clump of mesquite grew around this natural discharge point, and although the spring was dry 1952, dead mesquite still remained on several earth mounds in that area in 1952. He also reported a spring, dry in 1952, in 10/9-36.

2. Under natural conditions a large amount of ground water was discharged by plants through the process of transpiration and evaporated from moist soil surfaces in the lowlands area where ground-water levels were at shallow depth. No quantitative data are available on the amount of such discharge, but based on data from similar areas, the amount of ground water originally discharged in this manner was probably a large proportion of the total natural discharge.

In 1959 relatively minor amounts of water were used annually by mesquite trees, salt grass, and other phreatophytes that are indigenous to this area and that depend upon ground water for their supply. In 1957 some evaporation of ground water took place for short periods directly from bare soil surfaces in very small areas where the water level was locally less than about 8 feet below land surface--principally at the southeast edge of Rogers Lake.

3. Some ground water is discharged from Lancaster basin to North Muroc basin as subsurface outflow through the alluvial and possibly through the playa deposits which overlie the Rogers Lake barrier (fig. 3). Water-level contours for January 1948, March 1952 (fig. 6), and March 1958 (fig. 6A) show that at least since 1948 all outflow to North Muroc basin has been derived from the depletion of ground water in storage in the vicinity of the south half of Rogers Lake. This outflow will continue at a diminishing rate until the water levels south of Rogers Lake barrier decline below the lowest altitude of the barrier or until the axis of the ground-water divide shifts northward to North Muroc basin. If and when the outflow stops, all ground-water movement south of the barrier feature will be toward the central part of Lancaster basin. Because no data on transmissibility of the deposits overlying Rogers Lake barrier could be obtained, no estimates of outflow to North Muroc basin could be made.

As mentioned in the section on the Willow Springs fault, none of the water-level contours or profiles (figs. 3 and 6) show any discontinuity between Rogers Lake barrier and the agricultural area of Lancaster basin. Accordingly, it is concluded that hydraulic continuity exists between the two areas and that no ground-water barrier is present. The data collected on the transmission of pumping effects from well to well on the Air Force Base also indicate that no barrier passes between the Air Force well field and the central part of Lancaster basin.

Although wells in the central part of the basin derive their supply from both the principal and deep water-bearing zones, and although the Main Base wells appear to derive their supply wholly from the deep zone (fig. 3), the lacustrine deposits have not formed an effective barrier to the southwestward movement of ground water from the deep zone in the Main Base area to the principal zone to the southwest.

## Water-Level Fluctuations

### Scope and Utility of Records

In Lancaster basin periodic depth-to-water measurements have been made in more than 150 observation wells within the area of study (figs. 1 and 2). The agencies making these measurements and their span of record to date are the Los Angeles County Flood Control District, beginning in 1941; the U.S. Geological Survey, beginning in 1950 and continuing intermittently to date; and the California Department of Water Resources, beginning in about 1930. The Geological Survey and State Department of Water Resources publish measurements annually. The volumes containing water-level measurements published by the two agencies and the year or years of record contained each are listed in table 5.

Table 5.--Available records of water-level measurements in Antelope Valley, Los Angeles and Kern Counties, Calif.

| Year | USGS Water-Supply Paper | Year | California Division of Water Resources Bulletin [1] |
|---|---|---|---|
| 1908-09 | 278 | 1941 | 39-J |
| 1915-22 | 578 | 1942 | 39-K |
| 1915-43 | 991 | 1943 | 39-L |
| 1944 | 1021 | 1944 | 39-M |
| 1945 | 1028 | 1945 | 39-N |
| 1946 | 1076 | 1946 | 39-O |
| 1947 | 1101 | 1947 | 39-P |
| 1948 | 1131 | 1948 | 39-Q |
| 1949 | 1161 | 1949 | 39-R |
| 1950 | 1170 | 1950 | 39-S |
| 1951 | 1196 | 1951 | 39-T |
| 1952 | 1226 | 1952 | 39-U |
| 1953 | 1270 | 1953 | 39-V |
| 1954 | 1326 | 1954 | 39-W |
| 1955 | 1409 | 1955 | 39-55 |
| | | 1956 | 39-56 |
| | | 1957 | 39-57 |

1. California Division of Water Resources, 1944, Bull. 39-J, p. 375-468, and annual supplements thereafter. California Department of Water Resources since July 1956.

In addition to those in the published reports, numerous water-level measurements are given in table 5 of Dutcher, Bader, Hiltgen, and others (1961), and miscellaneous water-level measurements made in individual wells are included as a part of the well data in table 1 of the same report. Nearly all these measurements were made between October 1950 and March 1960.

In Lancaster basin, as elsewhere, records of water-level fluctuations in wells are necessary for the interpretation of past and present hydrologic conditions. The records collected showed several types of fluctuations pertaining to the conditions or forces at work in the several water bodies. The fluctuations are mainly related to seasonal pumping effects and to long-term ground-water depletion of the basin. The fluctuations in the various depth zones and areas of large overdraft are discussed in the following pages.

The rise and fall of the water level can be shown by plotting the altitude of the water level above mean sea level against time. These hydrographs (figs. 7 to 10) show that the ground-water fluctuations in the water-bearing zones are of two general types: (1) an overall year-to-year decline since the beginning of record, and (2) seasonal fluctuations of water levels in wells resulting from variations in pumping rates.

## Fluctuations in the Principal Water-Bearing Zone

Long-term fluctuations.--The overall ground-water trend in Antelope Valley is one of decline. Long-term hydrographs for seven wells penetrating the principal water-bearing zone in Lancaster basin (figs. 7 and 8) show that the rate of decline, as well as the total amount of decline for the period of record, depends largely on the geographic location of the well in relation to the concentrated area of pumping (centering around the pumping depression) in the central part of the basin (figs. 6 and 6A). The available composite records for wells 7/10-5N1, 5M1, and 5N3 (fig. 7), which are near the eastern margin of the pumping depression, and are 198, 240, and 387 feet deep, respectively, indicate an overall decline of about 150 feet for the 37-year period 1921-58. The record for destroyed well 7/10-5N1 is plotted with well 7/10-5M1 to make the record more complete. Because of seasonal fluctuations, the highest water levels in the spring are selected for computing yearly and long-term net declines. A total water-level decline of about 150 feet in wells near the margin of the pumping depression for the 37-year period 1921-58 averaged 4 feet per year. However, the average yearly decline since 1945 was more nearly 7 feet per year.

Well 7/11-24C1 (fig. 7), depth 210 feet, is along the southern margin of the pumping depression, and the record shows a water-level decline of about 100 feet from 1933 to 1953, or an average of about 5 feet per year. However, the average yearly decline for 1943-53 was about 7 feet per year. Although well 7/10-12H1 (fig. 7) is sufficiently far from the area of concentrated pumping that seasonal fluctuations are almost completely lacking, the annual decline after 1944 also exceeded 5 feet per year.

The record for well 7/12-34H1, depth 124.2 feet (fig. 8), shows a decline of about 65 feet from spring 1922 to spring 1947, or about 2.6 feet per year. From 1940 until the well went dry in 1947, however, the annual decline averaged more than 3 feet. The graphs for wells 8/12-22D1, 9/12-21D1, 21D3, and 21D4, which penetrate the principal water-bearing zone west of Rosamond Lake and 10 to 12 miles west and northwest of the large pumping depression, and wells 8/10-8R3, 8R4, and 9P1, about 5 miles northeast of the large pumping depression, show that the general ground-water decline is much less in the areas away from the vicinity of heavy pumping and has averaged less than 1.0 foot per year.

Seasonal fluctuations.--In addition to the overall decline of ground-water levels due to depletion of storage in certain areas, a marked seasonal decline of water level occurs during the spring, summer, and autumn when pumping is large, followed by a rise in the winter when pumping is reduced. As a result, the hydrographs of wells in the areas of heavy withdrawal show annual fluctuations which may exceed 40 feet. Each spring, usually in March, water levels in most wells penetrating the principal and deep water-bearing zones in the vicinity of the pumping depression begin to decline as pumping for irrigation begins. The response to pumping is greatest where the withdrawals are heaviest in the irrigated areas, and the decline is progressively less away from the center.

Thus, as shown on figures 7 and 8, wells 8/10-19N4 and 7/10-5M1 and 5N1 of intermediate depth, which penetrate the principal water-bearing zone nearest the center of heavy seasonal pumping, show relatively large seasonal fluctuations of about 30 to 40 feet. Well 7/11-24C1 (fig. 7), farther from the center of heavy pumping, shows a fluctuation of about 10 to 15 feet, and well 7/10-12H1 still farther shows little or no seasonal fluctuation.

Fluctuations in the West Rogers storage unit.--Seasonal water-level fluctuations in wells penetrating the water bodies in the West Rogers storage unit (fig. 12) are shown on figure 10. Hydrographs for wells 8/10-4G1, 9/10-12R1, and 9/10-24R1 show marked seasonal fluctuations due to pumping. The fluctuation is greatest at well 8/10-4G1, nearest to the large pumping depression in the agricultural area in Lancaster basin. Of all the records plotted on figure 10, only that for well 9/9-24H1 does not show marked seasonal pumping effects; rather, it shows a gradual decline of about 4 feet from August 1948 to March 1953.

Well 9/10-16M1 (fig. 10) penetrates the principal water-bearing zone in the center of a residual pumping depression in an area of former heavy draft (fig. 6). In contrast to wells 8/10-4G1, 9/10-12R1, and 9/10-28H1, the hydrograph of this well shows a continuous rise in water level, starting in 1951 and totaling about 27 feet by December 1959. The recovery at this well is due to the cessation of pumping in the immediate vicinity after the land was purchased by the Air Force.

However, the levels in well 9/10-16C1 (Dutcher, Bader, Hiltgen, and others, 1961, table 5), which penetrates a shallow water body, declined 15 feet from June 1952 to May 1954, indicating that the principal water body was being recharged by downward percolation from the shallow body. In October 1953 the head in well 9/10-16C1 was about 75 feet higher than the head in the deeper wells, but in May 1954 the head differential between the two water bodies had decreased to about 56 feet.

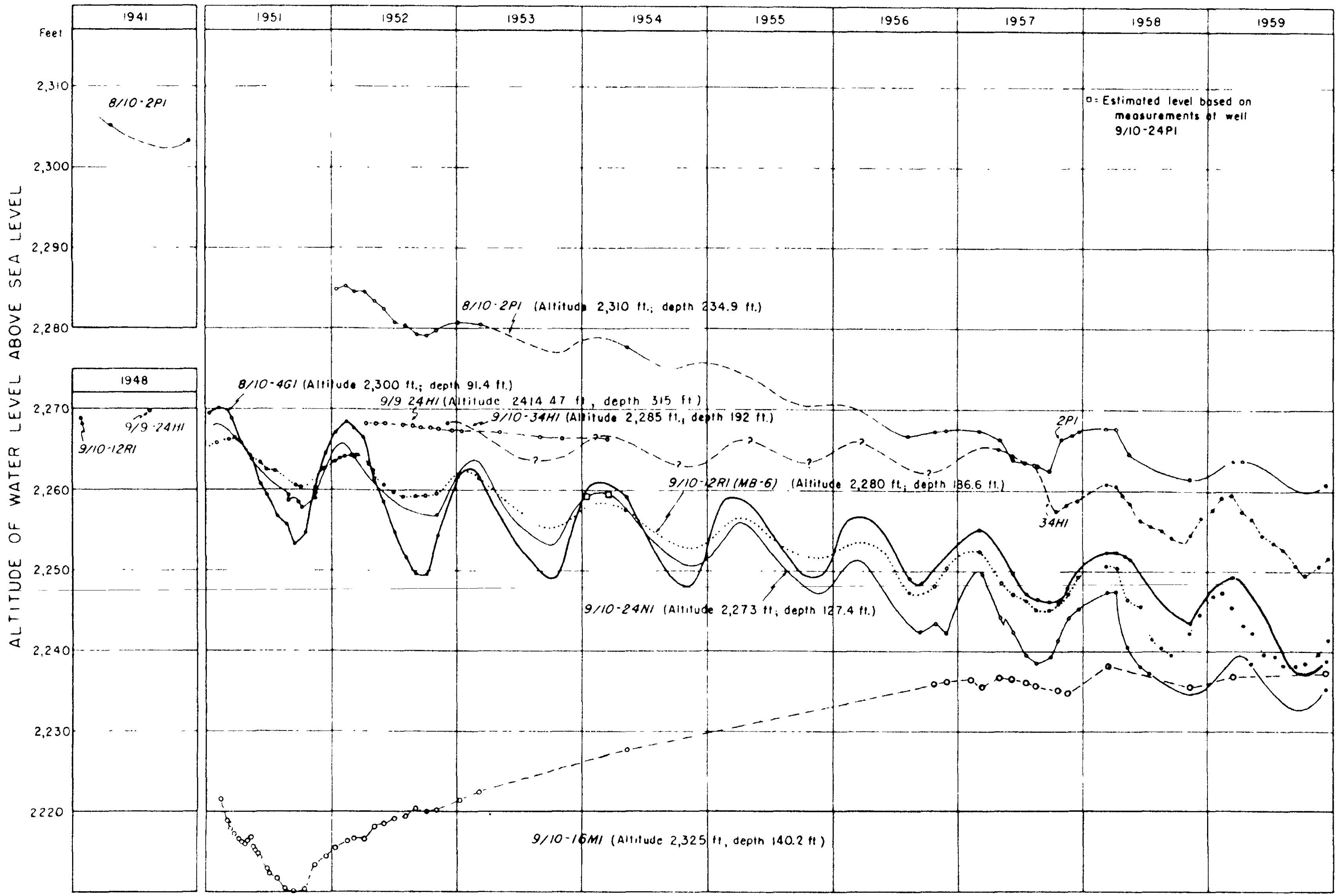



FIGURE 10. HYDROGRAPHS FOR SEVEN WELLS IN THE WEST ROGERS STORAGE UNIT

## Fluctuations in the Deep Water-Bearing Zone

The hydrographs of wells 7/10-5N3 and 8/10-19Q1 (figs. 7 and 8), 980 and 690 feet deep, respectively, which penetrate the deep water-bearing zone, show that the fluctuations of water levels closely parallel the fluctuations of water levels in intermediate-depth wells nearby that penetrate the principal water-bearing zone (figs. 7 and 8). Both deep and intermediate wells show an overall decline and the same type of seasonal fluctuation. The water-level altitude is higher in the deep water-bearing zone at well 8/10-19Q1 and, based on incomplete records, may be as much as 12 to 15 feet higher than the water level in the principal zone, as shown by the level in well 8/10-19N4. The amplitude of the seasonal fluctuations at deep well 7/10-5N3 are on the order of 60 to 80 feet, but for this well the spring water level is interpolated to be 5 to 10 feet lower than the level in intermediate-depth well 7/10-5M1. The disparity in head relationships between the principal and deep zones at these two sites probably is attributed to larger withdrawals in the deep zone in the vicinity of well 7/10-5N3 than at well 8/10-19Q1.

## Fluctuations in the Shallow Water-Bearing Zone

The fluctuations of water levels in wells that penetrate semi-perched water in the shallow water-bearing zone are plotted on figures 7 and 8 for comparison with the graphs for deeper wells. The hydrographs for wells 7/10-7B1 (fig. 7) and 8/10-9M1 (fig. 8), 81 and 28 feet deep, respectively, show an overall decline that lags behind the regional decline in the principal and deep zones. The water level in well 8/10-9M1 declined only about 18 feet from 1921 to 1946, when the well became dry, or an average of about 0.7 foot per year. The water level in well 7/10-7B1 declined about 40 feet from 1932 to 1948, when the well became dry, or an average of about 2.5 feet per year as compared to nearly 4 feet per year decline at nearby well 7/10-5M1, which penetrates the principal water-bearing zone. The water-level records for both wells show that seasonal fluctuations of large magnitude caused by pumping are not transmitted from either the principal or deep zones to the shallow zones.

It is concluded that the decline in the shallow zone is caused by slow downward leakage of ground water to the principal and deep water-bearing zones. The head differential between the shallow and deeper zones, which ranged from 5 to 40 feet--the shallow zone having the higher head--is the principal basis for this conclusion.

# NORTH MUROC BASIN

## Limits of the Basin

North Muroc basin extends north from Rogers Lake barrier about 6 to 7 miles to a discontinuous consolidated-rock boundary, and extends west about 12 miles from another discontinuous consolidated-rock boundary approximately along the San Bernardino County line to the Bissell Hills. This basin embraces about 80 square miles and contains alluvial deposits having a wide range in water-yielding character. The northern part of Edwards Air Force Base is within this basin, but the north part of the basin, largely north of U.S. Highway 466, is outside the Air Force Base boundary.

North Muroc basin is separated from Lancaster basin by Rogers Lake barrier, the top of which is believed to lie at shallow depth across Rogers Lake approximately as shown on figures 1, 2, and 3 and which is composed of granitic rocks. The presence of this barrier is inferred from both geologic and hydrologic evidence. The geologic evidence consists of (1) the presence of granitic rock in 10/9-20 and 10/9-21 at the surface of Rogers Lake, (2) the presence of bedrock at shallow depth as penetrated by wells in 9/9-6 (Dutcher, Bader, Hiltgen, and others, 1961, table 5), and (3) the presence of the large outcrop of bedrock east of the features described above and on the east side of Rogers Lake.

The hydrologic evidence which suggests the presence of a barrier at about the position shown consists of (1) the increased hydraulic gradient east of the approximate northeastern limit of confined ground water in Lancaster basin as shown on figures 3, 6, and 6A, and (2) the character of the water-level fluctuations in wells in North Muroc basin, which show practically no decline for the period of record and no seasonal effects due to pumping in Lancaster basin; in contrast, wells south of the barrier show marked seasonal fluctuations due to pumping and, even where little confinement exists as at well 9/9-24H1 (fig. 10), a noticeable overall decline in water level has been observed during the period of record. From the above evidence it is concluded that a broad, nearly completely buried bedrock ridge exists in the area shown on figures 3, 6, and 6A between Lancaster and North Muroc basins.

## Occurrence of Ground Water

The water body in North Muroc basin extends continuously from Lancaster basin on the southwest and from the surrounding highlands on the south and east to the Koehn Lake area on the northwest and is contained in the alluvial deposits which fill the structural depression north of Rogers Lake barrier. It is believed the water body is contained nearly everywhere in older alluvium. The bottom of the water body is considered to be at the base of the older alluvium where it overlies old fan deposits, granitic rocks, or virtually nonwater-bearing rocks of Tertiary age. The thickness of the water body varies with the depth to water below land surface and the depth below land surface of the older nonwater-bearing rocks. Adjacent to Rogers Lake barrier the granitic floor presumably is buried beneath only a few tens to a few hundred feet of playa deposits and older alluvium. In the central part of the basin little is known concerning the depth to bedrock, but based on logs from wells in sec. 36, T. 11 N., R. 9 W., the water body may extend only to about 250 to 500 feet below land surface. According to Gale (1946, p. 356-357), however, in the eastern part of the basin two wells in secs. 19 and 20, T. 11 N., R. 8 W., known as the "Bond" and "Kohler" wells (exact locations unknown), were reported to encounter basalt at 711 feet and 257 feet below land surface, respectively. Only a few wells in the basin are believed to have penetrated the full thickness of the water-bearing deposits.

The depth to water below land surface varies from place to place, but in general the greatest depths to water are along the southeast and east sides of the basin where water levels are about 140 to 175 feet below land surface. Beneath Rogers Lake, however, water levels are generally about 40 to 90 feet below land surface (fig. 3). Most of the wells available for water-level observation penetrate only 200 or 300 feet into the water body; a few penetrate the full saturated thickness. No differences in head with depth within the range of penetration were observed. There are no flowing wells in the basin and no indication that such wells were present in the area under native conditions.

Except for a relatively very thin water body which exists locally beneath the pediments and locally derived alluvial fans which surround the basin, no known minor water bodies exist in North Muroc basin. The minor water bodies beneath the pediments and fans presumably as supported by bedrock at shallow depth, are noticeably inferior in chemical quality to the water in the main body, and are locally recharged in the surrounding highlands. (See section on chemical quality of water.)

## Source and Movement of Ground Water

The principal source of ground water in North Muroc basin is the subsurface inflow from Lancaster basin across Rogers Lake barrier; minor amounts are supplied from the bordering hills and pediments. Movement is principally north from Rogers Lake barrier across the basin, and water discharges from the basin as underflow between Desert and Castle Buttes into the Koehn Lake area (figs. 3 and 6). The water-level contours for March 1952 (fig. 6) show the source and direction of ground-water movement. Section A-A' (fig. 3) shows a ground-water profile across North Muroc basin and shows that the gradient is steepest, about 10 feet per mile, across Rogers Lake barrier where bedrock is presumably at shallow depth. That ground water moves across North Muroc basin at a very slow rate is indicated by the very low gradient, which north of Rogers Lake barrier averages about 4 feet per mile. As shown on figures 3 and 6, the gradient in the Koehn Lake area north of Muroc basin is appreciably steeper, averaging about 12 to 15 feet per mile.

## Water-Level Fluctuations

Water-level records in wells in North Muroc basin are included in reports by Dutcher (1959) and Dutcher, Bader, Hiltgen, and others (1961); most have been made by the Geological Survey.

Figure 11 shows fluctuations of water levels in seven selected wells in North Muroc basin for the period January 1948 to November 1959. The locations of these wells are shown on figure 2.

Seasonal fluctuations of water levels in wells are minor because of the absence of pumping in the basin at that time. The hydrographs for the wells plotted on figure 11 indicate that little decline has occurred. The hydrographs for wells 11/8-32G1 and 11/9-17N1 show a gradual decline totaling about 2 feet during the period 1951-59.

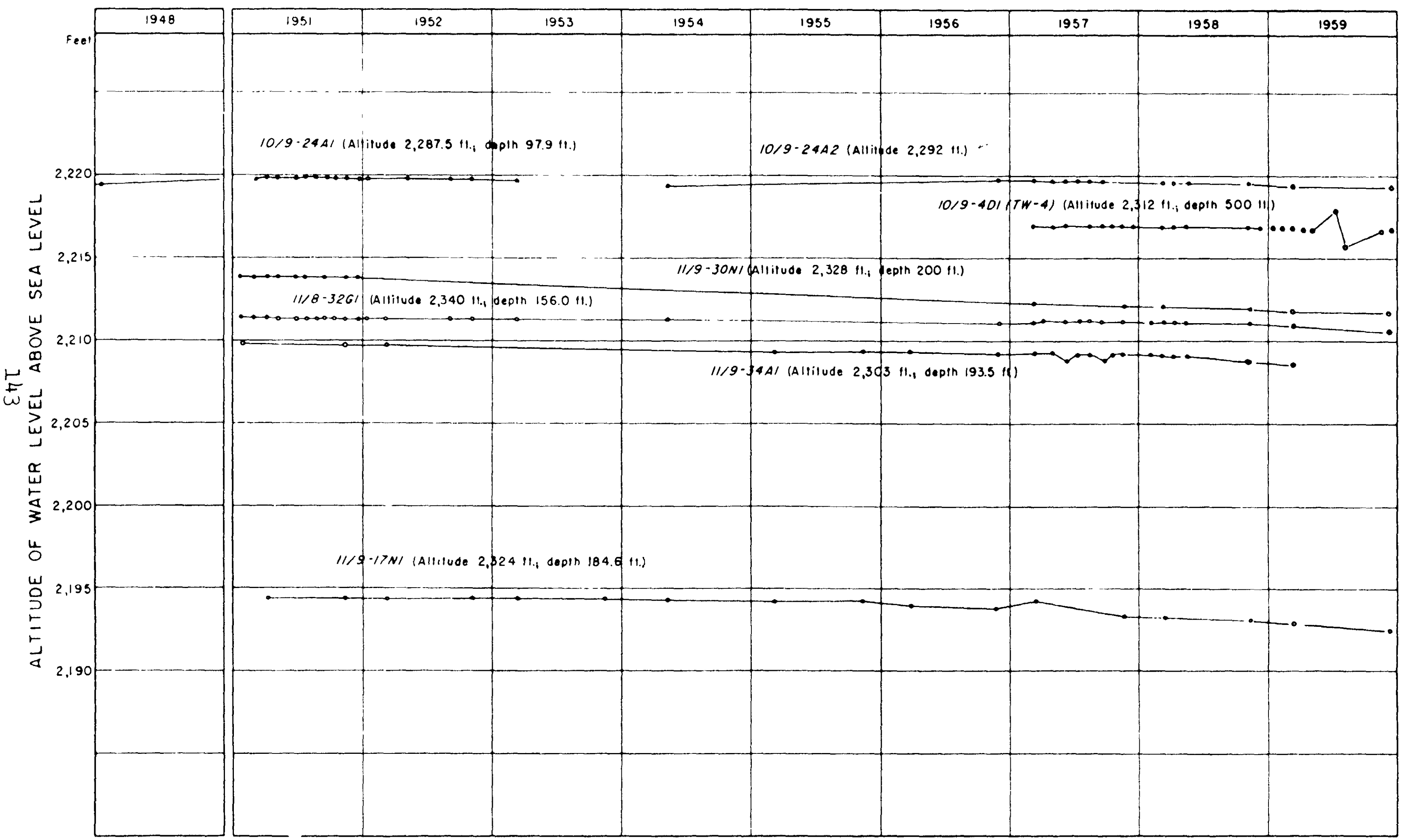



FIGURE 11. HYDROGRAPHS FOR SEVEN WELLS IN NORTH MUROC BASIN

# GLOSTER AREA

## Limits of the Area

The Gloster area extends eastward about 10 miles from a line arbitrarily established for convenience between Rs. 12 and 13 W. near the west side of Soledad Mountain to about Bissell; and northward from the Rosamond Hills about 3 miles to an arbitrary line, extending through the east-trending range of hills about 2½ miles north of Gloster, between Tps. 10 and 11 N. The valley floor as thus delimited embraces about 30 square miles (figs. 1 and 2). The Gloster area is bordered on the west by the Willow Springs area and on the north by the Chaffee area.

The Gloster area is divided into eastern and western parts by the Gloster fault (fig. 2), which strikes northwestward across the area and which is concealed beneath the younger alluvium. It is believed that the fault forms a barrier in the older alluvium and impedes the flow of water moving from west to east through the area. One shallow well, 10/12-14K1, depth 117.9 feet, had a water level of about 61 feet below land surface in May 1956, or about 20 feet below the water level in test well 10/12-23C1, depth 249 feet and about a mile southwest of well 14K1 (fig. 5). It is concluded, therefore, that the barrier effect of the Gloster fault causes a water-level displacement of about 20 feet between the east and west parts of the area.

## Occurrence of Ground Water

Except for the displacement across the Gloster fault, the water body of the Gloster area extends continuously from the basin boundary on the west and from the Rosamond Hills on the south to the Chaffee area on the north and is contained mainly in the older alluvium, which fills the shallow structural depression beneath the area. The bottom of the water body is considered to be at the base of the older alluvium where it overlies old fan deposits, granitic rocks, or the continental rocks of Tertiary age.

The thickness of the water body in the Gloster area, as in the other basins in the area, varies with the depth below land surface of nonwater-bearing rocks and the thickness of the unconsolidated alluvial deposits. In the area south and east of Soledad Mountain the bedrock surface is at shallow depth below land surface. In the northern part of the area little is known concerning the depth to bedrock. In general, the existing wells are less than 300 feet deep and penetrate only 100 to 200 feet into the water body. Near the margins of the basin the water body is believed to range in thickness from a featheredge to less than 100 feet, but generally in the central and northern parts of the basin the thickness is believed to range from about 140 to 240 feet. However, the possibility of local buried hills of consolidated rock concealed beneath the alluvium makes it impossible to estimate the thickness at any specific site.

The depth to water, in general, is greatest along the western margin of the basin where it ranges from about 200 to 250 feet below land surface. Along the northwestern margin of the Air Force Base boundary, however, the water levels in wells are about 35 to 50 feet below land surface (fig. 5). The water levels are shallowest just southwest (upgradient) from the Gloster fault where the depth to water at test well 10/12-23C1 was only about 32 feet in May 1956.

Except for the test wells drilled by the Air Force, the few wells available for observation penetrate only a few tens or hundreds of feet into the water body; none of the wells disclose determinable differences in head in the water in the full range of penetration, and water-table conditions are assumed to exist. A minor and relatively thin water body exists locally in the younger fan deposits along the north flank of the Rosamond Hills.

## Source and Movement of Ground Water

Ground water enters the Gloster area principally as subsurface flow in the alluvial deposits west of Soledad Mountain and from percolation from intermittent surface streams which rise in the Tehachapi Mountains and cross the area. These streams discharge to Rogers Lake after traversing the canyon east of Bissell (fig. 6). The water-level contours indicate that underflow enters the basin mainly between Soledad Mountain and the Rosamond Hills and to a lesser extent between Soledad Mountain and the small hill to the north. A minor amount of ground water enters the basin from the south from alluvial fans of the Rosamond Hills. The underflow moves eastward acorss the basin at a hydraulic gradient of about 20 to 25 feet per mile to the Gloster fault barrier; east of the barrier the movement is northward, and the gradient is only about 10 feet per mile to the north edge of the area.

The thin minor water body beneath the alluvial fans along the south margin of the area is presumably held up by bedrock and is noticeably inferior in chemical quality to the water in the main water body. (See section on chemical quality of water.) Presumably, it is derived locally from the Rosamond Hills and percolates basinward and becomes a part of the water body in the east part of the area (fig. 6).

Insofar as can be determined by shallow auger holes, no subsurface flow occurs from the Gloster area to Lancaster basin either through the thin alluvial deposits in the canyon east of Bissell or in the canyon leading southward toward Rosamond, south of Gloster. All natural ground-water discharge from the area enters the Chaffee area to the north as subsurface flow.

## Water-Level Fluctuations

The water levels have fluctuated only a few feet since 1917-19 when they were first measured by Thompson (1929, p. 326). Because there has been little change in water levels and because nearly all the wells are unused or used only for domestic or stock purposes, which require little water, nearly native ground-water conditions exist in the basin. There has been no long-term decline in water levels, as in Lancaster basin, and no seasonal fluctuations of water levels in wells due to pumping. The water levels indicate only minor seasonal fluctuations of 1 to 2 feet due largely to seasonal runoff from the Tehachapi Mountains.

## CHAFFEE AREA

### Limits of the Area

The Chaffee area extends eastward about 10 miles from an arbitrary west boundary along the north-south line between Rs. 21 and 13 W. to about the northern end of the Bissell Hills, nearly 10 miles east of Mojave; and extends northward from the edge of the Gloster area, the line between Tps. 10 and 11 N., to the northwest-trending Muroc fault barrier, about 7 miles northeast of Mojave (fig. 1). The valley floor as thus outlined covers nearly 75 square miles. The Chaffee area is not separated geologically or hydrologically from the Gloster area; they are connected through openings between small hills of consolidated rock.

### Occurrence of Ground Water

The ground-water body in the Chaffee area is contained mainly in the older alluvium that underlies the valley floor. The thickness of the water body varies with the depth to water and the depth below land surface to nonwater-bearing rocks. Little is known concerning the depth to bedrock in the Chaffee area, except in the east-central part. Wells described by Kunkel and Dutcher (1961, table 4) range in depth from 200 to 800 feet, but bedrock has not been reported in most privately owned wells drilled to date. However, in six test wells drilled during 1956 and 1957 for the Mojave Marine Corps Auxiliary Air Station in the eastern part of the area, the water body was found to range in thickness from about 200 to 600 feet. Well 11/12-26J2 (fig. 5) near the south margin of the area reportedly encountered granite at a depth of 361 feet.

The depth to water below land surface ranges from about 250 to 350 feet beneath the steeply sloping alluvial fans along the south flank of the Tehachapi Mountains to only about 32 feet at the Muroc fault barrier near the northeast corner of the Chaffee area. In the southern part of the area, farther from the mountains and downgradient from the steepest part of the alluvial fans, the depth to water decreases from about 170 feet on the west to about 70 feet on the east.

Water levels in the Koehn Lake area (fig. 6) northeast of the Muroc fault barrier range from about 570 feet below land surface on the northwest to about 300 feet below land surface on the southeast, or are 200 to 300 feet lower on the northeast side of the fault (fig. 5) than in the Chaffee area on the south side. Thus, the Muroc fault forms a barrier to the northeastward movement of ground water, and the displacement of water levels across the barrier is as much as 300 feet (figs. 5 and 6).

Most wells available for observation penetrate only a few feet to a few hundred feet into the ground-water body. The six test wells drilled for the U.S. Marine Corps during 1956 and 1957 in the north-central part of the area penetrate the full alluvial sequence. The wells are widely spaced and therefore do not enable water levels in deep wells to be compared to water levels in shallow wells. Under these conditions, possible differences in head between shallow and deep wells cannot be determined, but it is not believed that significant head differentials existed at the time the wells were drilled.

## Source and Movement of Ground Water

The water-level contours (fig. 6) and geologic data indicate that ground water is moving into the Chaffee area as underflow mainly from the Cache Creek and adjacent fans to the west and in lesser amounts from the Gloster area to the south. This indicates that the principal source of recharge is from streams flowing from the Tehachapi Mountains. Some recharge occurs infrequently when surface streams, principally Cache Creek, flow across the area to the Koehn Lake area. The movement of ground water in the Chaffee area is generally eastward and northeastward beneath a relatively large area toward the Muroc fault barrier. No quantitative data as to the amount of recharge to the Chaffee area are available, but based on the relatively large area of saturated older alluvium through which underflow occurs and the large specific capacities of some of the wells, which form a rough measure of transmissibility, the amount of recharge probably is larger than that to the Gloster area or to North Muroc basin.

In the vicinity of Mojave the eastward ground-water gradient, as indicated by the water-level contours (fig. 6), is about 40 feet per mile. Several miles east of the city, the gradient is to the northeast and flattens abruptly to about 2 feet per mile. All natural ground-water discharge from the Chaffee area is by subsurface flow across the Muroc fault to the Koehn Lake area. On the northeast side of the Muroc fault barrier, ground water moves generally northward under a gradient of about 20 feet per mile toward Koehn Lake in Fremont Valley (figs. 1 and 6).

## Water-Level Fluctuations

Except for a single set of measurements in 1917-19 reported by Thompson (1929, p. 327), all known measurements of water levels in wells in the Chaffee area and the Koehn Lake area are reported in tables in Dutcher (1959) and Kunkel and Dutcher. Except for measurements in 1929-30 by Williams (written communication), all measurements were made by the Geological Survey. There have been only minor changes in water levels during the period of record, as there are very few producing wells in the Chaffee area and all are used for domestic or stock-watering purposes only. Accordingly, in 1960, nearly native ground-water conditions existed in the area.

In the Chaffee area there have been no long-term changes of water levels in wells and no seasonal fluctuations of water levels in wells due to pumping; the water levels tabulated in table 5A (Kunkel and Dutcher, 1961) indicate that regional recoveries and declines of water levels in wells may take place, possibly owing to the cyclic nature of rainfall, runoff, and recharge. Data are not available to establish clearly the cause for the apparent slight rise of water levels in several wells in the Chaffee area between 1929-30 and 1951-54 (table 5A, Kunkel and Dutcher, 1961).

In The Koehn Lake area, several dozen large irrigation wells were drilled in conjunction with the agricultural development during the mid-1950's. The ground-water regimen of the area appears to be readjusting to changing conditions which occur during the initial development of every ground-water basin. In March 1954, water levels in wells in the area locally were as much as 8 to 14 feet below those of a comparable period in 1951 (Dutcher, 1959, table 3).

There are no indications in 1959 that ground-water withdrawals since about 1951 in the Koehn Lake area have affected water levels in the Chaffee area on the southwest side of the Muroc fault barrier. Moreover, considering the 200- to 300-foot displacement of water levels across the fault, pumpage in the Koehn Lake area is not expected to affect levels south of the barrier.

## CHEMICAL QUALITY OF WATER

In connection with the field canvass of wells and later as a part of a test-drilling program for the Air Force, the Geological Survey collected water samples for chemical analysis and assembled existing analyses for more than 240 wells to determine the quality of water in new areas considered for potential development by the Air Force and as an aid in determining source, movement, and general suitability of the ground water in areas already developed by Edwards Air Force Base. Of the more than 240 samples, 99 were analyzed for the principal anions and cations, and the remainder were analyzed only for chloride, hardness, and specific conductance. These data are tabulated in Dutcher (1959), Kunkel and Dutcher (1961), and Dutcher, Bader, Hiltgen, and others (1961). The Air Force supplied analyses of water from the Base wells, and others made available analyses of water from wells in the Gloster and Chaffee areas, and North Muroc basin. The dissolved solids (calculated from the determined constituents), chloride, and hardness, in parts per million for waters in Lancaster and North Muroc basins and the Gloster and Chaffee areas are shown beside the well symbol on figure 12.

To determine whether a water is of suitable quality for domestic and agricultural use a sample is usually analyzed for dissolved solids, the principal cations and anions, boron (B), nitrate ($NO_3$), fluoride (F), silica ($SiO_2$), and pH. If desired, the percent sodium (% Na), and the sodium-adsorption ratio (SAR) can be computed from the chemical analysis.

## REQUIREMENTS FOR DOMESTIC AND IRRIGATION USE

The Drinking Water Standards of the U.S. Public Health Service (1962) state that dissolved solids should not exceed 500 ppm (parts per million), but 1,000 ppm, which in many areas is indicated by a conductivity of less than 1,500 micromhos, is permissible. Magnesium (Mg) should not exceed 125 ppm; sulfate ($SO_4$), 250 ppm; chloride (Cl), 250 ppm; iron (Fe), 0.3 ppm; and manganese (Mn) 0.05 ppm. Fluoride (F) should not average more than 0.6 to 1.7 ppm depending on the air temperatures. Hardness, with respect to use of the water, has been classified by the Geological Survey (written communication, March 22, 1962) according to the following scale:

| Hardness as $CaCO_3$ (parts per million) | Class |
|---|---|
| 0-60 | Soft |
| 61-120 | Moderately hard |
| 121-180 | Hard |
| 181+ | Very hard |

Water having a hardness greater than about 200 ppm should be softened to be satisfactory for domestic use. In general, a good domestic water is a soft water, or a water relatively low in calcium and magnesium.

Depending on the air temperatures an average fluoride content of 0.6 to 1.7 ppm is the maximum permitted by the U.S. Public Health Service Standards, and quantities much in excess of that in the drinking water of children may cause mottling of the enamel of the teeth.

Nitrate ($NO_3$) in excess of about 45 ppm is believed to be responsible for the condition in infants known as methemoglobinemia or "blue babies."

Chloride in excess concentrations although not harmful may impart a salty taste to waters.

Boron presents no problem in the drinking water of the Edwards Air Force Base and vicinity because all known boron concentrations are less than a maximum value of 30 ppm, which according to Goudey (1936) is an acceptable limit for drinking water.

Except locally as discussed below, the ground-water quality in the area is within the quality limits outlined above and may be used for domestic purposes.

The standards for good irrigation water in some respects are considerably different from those for good domestic water. Water having a relatively high concentration of calcium, magnesium, iron, and fluoride that would be almost unusable for domestic purposes could be a good irrigation water, whereas a soft water suitable for domestic use, having a high sodium percentage and boron in excess of 3 or 4 ppm would be unsuitable for the irrigation of most plants.

The dissolved-solids content in water used for irrigation should be less than 1,400 ppm and preferably less than 1,000 ppm, which in general is indicated by an electrical conductivity of less than 1,500 to 2,000 micromhos at 25°C. The percent sodium usually should not be greater than 65, if the specific conductance exceeds about 750 micromhos; and should not be greater than about 50, if the specific conductance exceeds about 2,000. Also "good" irrigation water should not contain excessive amounts of chloride and not more than 1 ppm of boron. Boron in excess of 3 or 4 ppm is deleterious to most plants. Water in the area generally is within these limits, except locally as discussed below.

## GRAPHIC REPRESENTATION OF WATER ANALYSES

The chemical character of a ground water usually is determined by a consideration of two separate factors: (1) the concentration of dissolved solids and (2) the relative proportion of the various ions present in solution. Both these factors depend chiefly on the character of the deposits through which the water percolates, either in yielding to solution the more easily dissolved chemical constituents of the rocks, or in combination or replacement in exchange with those constituents already in solution. It is intended to show here the various chemical changes that occur, as water moves from basin to basin across the area, and to relate these changes to the geology and the hydrologic properties of the deposits.

Methods of describing the chemical character of water have become somewhat standarized and involve, in some cases, plotting the percentage of equivalents per million (epm), or reacting values, of individual constituents of specific analyses of water on rectilinear and trilinear graphs, as described by Piper (1944). The position of the plotted point on the field then symbolizes the general chemical character of the water as indicated by the relative proportions of the groups of anions and cations present in solution.

In this report, use has been made of the rectilinear graph, as described by Piper (1944), in which the cations, calcium and magnesium and sodium plus potassium, are plotted along one coordinate and the anions, bicarbonate (including carbonate), sulfate, and chloride, are plotted along the other. This permits a one-point plotting for each analysis and an immediate determination of the general character of the water by location of the point on the graph. A typical calculation, using an analysis of water from well 9/9-6A1, is demonstrated in table 6 and is plotted as point 11 on figure 13, diagram 1.

Table 6.--Calculation of percentage equivalents per million of a water analysis for well 9/9-6A1

| | Parts per million | x | Conversion factor[1] | = | Equivalents per million | Percentage equivalents per million[2] |
|---|---|---|---|---|---|---|
| $SiO_2$ | 25 | | - | | - | - |
| Fe | 0.02 | | - | | - | - |
| Ca | 30 | | 0.0499 | | 1.497 | 36.84 |
| Mg | 6.1 | | .0823 | | .502 | 12.36 |
| Na | 47 | | .0435 | | 2.044 | 50.31 |
| K | .8 | | .0256 | | .020 | .49 |
| Cations total | 109 | | | | 4.063 | 100.00 |
| $CO_3$ | 0 | | .0333 | | 0 | - |
| $HCO_3$ | 141 | | .0164 | | 2.312 | 56.18 |
| $SO_4$ | 63 | | .0208 | | 1.310 | 31.90 |
| Cl | 16 | | .0282 | | .451 | 10.97 |
| $NO_3$ | .8 | | .0161 | | .013 | .32 |
| B | .14 | | - | | (a) | - |
| F | .5 | | .0526 | | .026 | .63 |
| Anions total | 149 | | | | 4.112 | 100.00 |
| Sum[3] | 258 | | | | | |

1. The conversion factor is the reciprocal of the equivalent weight of the ion.

2. To compute percentage equivalents per million, divide the equivalents per million for each anion (or cation) by the sum of the anions (or cations), in equivalents per million.

3. In computing sum, only 49.2 percent of the value of $HCO_3$ (bicarbonate) is used, because the bicarbonate decomposes upon evaporation.

a. Practically non ionized; however, if present in large amounts as tetraborate, it is grouped with bicarbonate.

## QUALITY BY BASINS

The range in concentration and character of ground water in the Edwards Air Force Base area, as computed from analyses given in tables in Dutcher (1959), Kunkel and Dutcher (1961), and Dutcher, Bader, Hiltgen, and others (1961), are shown on figure 13. The most concentrated waters are from wells in North Muroc basin and locally around the margins of Lancaster basin and the Gloster area, and also from wells locally tapping the semiperched water body in the lowlands area of Lancaster basin. The occurrence of these waters of higher than average concentration of dissolved solids is related to causes discussed below.

### Lancaster Basin

The chemical quality of the ground water in the principal and deep water-bearing zones in Lancaster basin falls into two general types. Each type is related to a specific depth zone, and if the change that occurs as ground water percolates across the basin is considered, analyses might be used as an aid to estimate the depth from which the sample was pumped, if other data, such as depth of the well, interval perforated, and geologic unit penetrated, are not available. The water from the principal and deep zones generally contains less than the limits suggested by the U.S. Public Health Service for domestic purposes, and in general the quality of water is superior to that in North Muroc basin and the Chaffee and Gloster areas.

The water in the principal water-bearing zone (above the lacustrine deposits) is in general a calcium bicarbonate to soidum bicarbonate type.[1] Waters from wells penetrating the principal zone

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[1] In this report, terms describing the general chemical character of a water are after Piper, Garrett, and others (1953, p. 26, footnote) and are used in particular senses, as in the following examples: (1) "calcium bicarbonate" designates a water in which calcium amounts to 50 percent or more of the bases and bicarbonate to 50 percent or more of the acids, in chemical equivalents; (2) "sodium calcium bicarbonate" designates a water in which sodium and calcium are first and second, respectively, in order of abundance among the bases but neither amounts to 50 percent of all the bases; and (3) "sodium sulfate bicarbonate" designates a water in which sulfate and bicarbonate are first and second in order of abundance among the acids, as above.

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plot in the left-central or central part of the graph (fig. 13, diagram 1). The percent sodium ranges from about 30 to 60. A study of the distribution of the plotted points, however, shows that the water in the eastern part of the basin is considerably higher in the alkalies and strong acids than the waters in the central part of the basin (fig. 13, diagram 1), as is discussed in another section of this report.

The waters in the deep zone beneath the lacustrine deposits are in general of the sodium bicarbonate type, are very soft, and plot at the bottom of diagram 1. The percent sodium is about 90. The concentration of dissolved solids for the deep zone is about 220 ppm and for the principal zone ranges between about 220 and 360 ppm and averages about 250 ppm.

Outlined areas on figure 13, diagram 1, are labeled recharge area, deep zone, principal zone, and North Muroc basin. The relative positions of the principal and deep zones show pronounced differences in the calcium-sodium ratio. The increase in sodium in the deep zone probably is due to the base exchange of calcium for sodium ions. This phenomenon occurs when calcium ions, which are dissolved in the ground waters that recharge Lancaster basin, come in contact with sodium-rich materials in the aquifer, when some of the calcium ions are adsorbed by the clay particles dispersed in the materials of the water-bearing unit and an equal number of sodium ions are displaced into solution. This natural process, which results in softening of the water, would be expected to continue until all the potentially exchangeable sodium in the aquifer through which the water moves is exhausted.

In general, the water in the Air Force wells is superior in quality to that available from all other nearby ground-water sources. Periodic samples should be collected from the wells for chemical analysis, however, so that possible chemical changes due to the proximity of the sewage-effluent ponds or other causes can be detected.

## North Muroc Basin

In North Muroc basin the ground water in general is not a specific type; that is, no cation or anion greatly exceeds 50 percent of the total (fig. 13, diagram 1). The dissolved solids, as determined by analyses from 12 wells, range from 537 to 1,250 ppm and average about 800 ppm. If the water from wells tapping materials presumed to contain localized alkali deposits is excluded, the dissolved solids are about 600 to 700 ppm. Except for analyses for wells 11/9-22Q1, 31D1, 11/10-36H1, and 10/8-4A1 (fig. 13, diagram 3), which show an increase in magnesium (Mg), sulfate ($SO_4$), or chloride (Cl) that may be due to local conditions near the well, the waters in the area are similar. Locally, as in wells 10/9-7A1 and 7A2, the fluoride content is as high as 3 ppm, but varies slightly with each analysis of water from the same well. The water from test well 10/9-4D1, however, contains only 1.2 ppm of fluoride (table 7). Also, the water from that well is lower in dissolved solids, chloride, and sulfate than that tested from other wells in the basin. The water from this well compares favorably in quality with that from the Air Force supply wells in Lancaster basin (table 7) and Dutcher, Bader, Hiltgen, and others (1961, table 5).

Nitrate ($NO_3$) is present in water from wells in this area but generally in small quantities and nowhere was it found to exceed 27 ppm.

Locally, wells yield water containing more than 300 ppm of chloride (fig. 12). The occurrence of the high-chloride waters is discussed elsewhere in this report and, except around the margins of the basin (in the locally derived fan materials), the chloride generally is not in excess of 250 ppm and therefore the water is not salty to the taste. At test well 10/9-4D1 the chloride content, based on a single analysis, is only 24 ppm; the water at that well is of the sodium bicarbonate type and is excellent for domestic use.

## Gloster and Chaffee Areas

In the Gloster and Chaffee areas the ground water in general is of the sodium bicarbonate type, similar to that in the area of Lancaster basin (fig. 13, diagram 2). The dissolved solids, as shown by analyses from seven wells, range from 232 to 1,200 ppm, but in the central part of the Gloster area the dissolved solids average less than 300 ppm. Sodium-calcium sulfate-chloride waters from wells 10/11-18P1, 10/12-24N1, and 24P1 are not typical (fig. 13, diagram 3), as is discussed below.

The analyses for wells 10/12-24P1 and 11/13-24A1 show 56 and 52 ppm, respectively, of nitrate. Field examination of the physical conditions near those wells suggests that local contamination traceable to human activity may be the source of the nitrate.

The analysis of water from well 10/11-18P1 shows 5.1 ppm of fluoride. Based on the analyses for other wells in the area in which similar conditions exist, the high fluoride in the well probably is more closely related to the water in the locally derived fan deposits (fig. 13, diagram 3) than to the water in the central part of the area (fig. 13, diagram 2).

The waters in the southern part of the Chaffee area are slightly higher in sulfate and calcium than those in the Gloster area and are acceptable for human consumption. Analyses from three deep test wells drilled by the U.S. Marine Corps in the northeastern part of the Chaffee area indicate that the water is of the calcium sulfate type; the dissolved solids range from 640 to 825 ppm, the boron content is 1.0 ppm or less, and fluoride does not exceed 0.5 ppm. Analyses for three test wells drilled in the southeastern part of the area indicate that the water is of the calcium-sodium bicarbonate type, and the dissolved solids range from 265 to 310 ppm.

## CHANGES IN QUALITY WITH SUBSURFACE FLOW

Chemical changes in the ground water occur as the water percolates from areas of recharge to points of discharge within individual basins or as it passes from one basin 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 changes was made to attempt to determine basin boundaries and also as an aid in determining the original direction of ground-water flow in areas where large withdrawals have greatly changed or even reversed the original direction of movement.

An areal study of the water in the principal water-bearing zone in Lancaster basin generally shows a progressive chemical change in the water from southwest to northeast. The arrow shown on figure 13, diagram 1, indicates this change from the recharge area to the central and eastern parts of the basin, past the Air Force supply wells, and into North Muroc basin. The plotted analyses, as expected, conform with the previously presented hydrologic data which indicate that originally ground water percolated across Lancaster basin generally from southwest to northeast, and over Rogers Lake barrier to North Muroc basin.

The calcium bicarbonate water from wells 7/11-24Q1 and 7/12-2Q1 is similar to the water in the adjoining basins along the north edge of the San Gabriel Mountains. The calcium bicarbonate water in the southwest part of the area gradually changes across the area to sodium-calcium bicarbonate, and then to sodium bicarbonate water, which is typical in the eastern part of the basin. In the 15-mile reach between well 7/11-24Q1 and the Air Force supply wells in 9/10-24, the average chloride content increases only a few parts per million, but the 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 may be due to the solution of sodium and sulfate as the water passes through the generally sandy materials interbedded with the playa deposits which contain an excess of soluble sodium salts.

Farther north in the Lancaster basin, water samples were analyzed from wells 9/9-6A1, 6L1, and 6M1 (fig. 13, diagram 1). These waters also are of the sodium bicarbonate type, but the concentrations of sulfate and sodium are greater than in the southern part.

As the water percolates across Rogers Lake barrier to North Muroc basin (fig. 13, diagram 1) it changes in type from sodium bicarbonate to sodium bicarbonate-chloride, as indicated by analyses for wells in 9/10-6 and wells 10/9-7A1 and 7A2. This is in general a continuation of the trend already established as the water percolates across the area.

Available data indicate no appreciable changes in chemical quality of ground water moving across the Gloster and Chaffee areas, but more detailed data might reveal some changes. A slight indication of change is given by the analysis of water from well 10/13-24F1 (fig. 13, diagram 2, no. 3) which is of the sodium bicarbonate-sulfate type instead of the typical sodium bicarbonate type shown on figure 13, diagram 2, numbers 1, 2, and 4.

The analysis for well 32/37-24N2, northeast of the Muroc fault barrier in the Koehn Lake area, indicates a water of the sodium sulfate-chloride type.

## QUALITY OF WATER FROM LOCAL SOURCES OR IN THE FAN DEPOSITS

The analyses of water taken from several wells around the margins of Lancaster and North Muroc basins and the Gloster area and believed to penetrate fan deposits at depth, plot in the upper right part of the graph (fig. 13, diagram 3). For the most part these are waters in which no principal cation is dominant but in which sulfate and chloride together exceed the bicarbonate. The dissolved solids of these waters average about 970 ppm. These analyses are tabulated in tables in Dutcher (1959), Dutcher, Bader, Hiltgen, and others (1961), and Kunkel and Dutcher (1961), as are the partial analyses of water from several other wells believed to penetrate fan deposits.

There are not sufficient data, however, to prove that these waters are derived exclusively from the fan deposits. As shown on the water-level contour map (fig. 6), the wells from which this type water (fig. 13, diagram 3) is obtained are so situated that they might yield water recharged locally during periods of infrequent runoff from the nearby highland areas.

## QUALITY OF WATER IN THE SHALLOW WATER BODIES

Analyses of water from wells tapping the shallow water bodies are included in tables in Dutcher (1959), Dutcher, Bader, Hiltgen, and others (1961), and Kunkel and Dutcher (1961) and are shown graphically on figure 13, diagram 3. These data show that waters in the shallow water-bearing zones are mainly of the sodium bicarbonate or sodium bicarbonate-sulfate type and contain 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 is much higher in dissolved solids.

An examination of the analyses for shallow wells listed in tables in Dutcher (1959), Dutcher, Bader, Hiltgen, and others (1961), and Kunkel and Dutcher (1961) shows that the dissolved solids, hardness, and chloride sometimes vary greatly in successive samples collected from the same well. A change in chemical quality with pumping is demonstrated graphically on figure 13, diagram 3, points 4a and 4b, where analyses of two samples from well 9/9-2Q1 are plotted. These samples were collected after half an hour and 2 hours of pumping, respectively. The reasons for the change in quality as pumping progresses are somewhat obscure. In this area the inferior water that was produced initially by well 9/9-2Q1 probably originated in a semiperched water body which had a higher head than the water in the underlying deposits. During nonpumping periods, vertical circulation downward through the well casing from shallow perforations opposite a semiperched water body to deeper perforations opposite a deeper water body may occur. The water of poor quality that may enter the deeper zones in this manner must then be pumped out before water of a quality native to the deeper water at the well is pumped.

The quality of the water removed from a well after pumping begins apparently gradually improves because (1) as the water level in the shallow zone is drawn down, the shallow zone supplies a decreasing proportion of the total yield, and (2) the proportion of water pumped from the deep zone that originated in the shallow zone also decreases. Thus, the deeper water of the area supplies an increasing proportion of better quality water to the well as pumping progresses.

The result of mixing waters of different quality from shallow and deep water bodies is demonstrated by a comparison of the chemical analyses for waters from wells 9/10-16N1 (Dutcher, Bader, Hiltgen, and others, 1961, table 5) and 16P1. (See table 7.) The wells from which the water samples were collected penetrate the principal water body overlain by a "shallow" water body of higher head. At the time the first sample from well 9/10-16N1 was collected in 1952 the deep aquifers were heavily pumped for irrigation; the head differential between the principal and shallow water bodies was about 70 feet. The water from the principal water body was suitable for domestic use, having a chloride content of 119 ppm and dissolved-solids content of 697 ppm. Between April 1952, when the first sample was collected, and February 1956, when the well was test pumped and the second sample was collected, all pumping was stopped, and the movement of water toward the well in the principal water body was reduced. Thus, the water in the well tended to reflect, to a greater extent than during pumping, the inferior quality of water from the shallow water body. (See analyses from well 9/10-16C1, Dutcher, Bader, Hiltgen, and others, 1961, table 5.) During the period 1952-56, the head differential between the two water bodies decreased from about 70 feet to only about 20 feet, and the water quality in the deep aquifers at wells 9/10-16N1 and 16P1 deteriorated because of the constant addition of inferior-quality water from the shallow zone which may have had a chloride content as high as 1,810 ppm. (See well 9/10-16C1, Dutcher, Bader, Hiltgen, and others, 1961, table 7, analysis of May 1958.) At the time the second sample was collected the dissolved-solids content was 1,120 ppm and the chloride content was 231 ppm. The sulfate content increased from about 221 to 378 ppm during the same period. Based on a sample collected at deep well 9/10-16P1 on February 15, 1956, the dissolved-solids content was 1,320 ppm, the chloride was 235 ppm, and the sulfate was 488 ppm. Water pumped from wells 9/10-16N1 and 16P1 probably would improve gradually in chemical quality if the water were pumped until most of the blended water resulting from mixing of waters from the two zones was removed.

Table 7.--Chemical analyses of three well waters

Constituents: The sum of the determined constituents is the arithmetic total in parts per million of the concentrations of all constituents determined, except for bicarbonate which is divided by 2.03.

Analysis by: GS U.S. Geological Survey; CW Carl Wilson, Los Angeles, Calif.

Table 7.--Chemical analyses of three well waters--Continued

| | 9/10-16N1 | 9/10-16P1 | Test well 10/9-4D1 |
|---|---|---|---|
| Constituents in parts per million | | | |
| Silica ($SiO_2$) | 15 | 15 | --- |
| Iron (Fe) | 0.02 | 0.1 | --- |
| Calcium (Ca) | 178 | 205 | 4.3 |
| Magnesium (Mg) | 40 | 46 | 0.4 |
| Sodium (Na) | 135 | 178 | 119 |
| Potassium (K) | --- | --- | .6 |
| Bicarbonate ($HCO_3$) | 220 | 253 | 213 |
| Carbonate ($CO_3$) | 0 | 13 | 0 |
| Sulfate ($SO_4$) | 378 | 488 | a58 |
| Chloride (Cl) | 231 | 235 | 24 |
| Fluoride (F) | .5 | .7 | 1.2 |
| Nitrate ($NO_3$) | 3 | 3 | --- |
| Boron (B) | --- | --- | --- |
| Dissolved solids | 1,120 | 1,320 | a b 312 |
| Hardness as $CaCO_3$ | 609 | 698 | 12 |
| Percent sodium | 32 | 36 | 95 |
| Specific conductance (micromhos at 25°C) | --- | --- | 55 |
| pH | --- | --- | 7.5 |
| Temperature (°F) | --- | --- | 70 |
| Depth of well, feet | 396 | 532 | 500 |
| Date | 2-15-56 | 2-15-56 | 3-12-57 |
| Laboratory | CW | CW | GS |
| Laboratory number | --- | --- | 21603 |

a. Values calculated by the Ground Water Branch.
b. Calculated from determined constituents.

## STORED GROUND WATER AS THE PRINCIPAL SOURCE OF SUPPLY

Because of the large overdraft in Antelope Valley and because recharge to areas in Fremont Valley is small, the bulk of the ground water pumped by the Air Force and by other users in the area will be derived from ground water stored in the alluvial deposits. In other words, ground water will be "mined" in much the same way that any other mineral resource is mined. The agricultural economy will govern the depth to which the ground-water resource will be "mined" by the farmers. However, for the Air Force, the pumping costs are a minor part of the overall economy of the Base operation, and therefore, the depth to which the resource can ultimately be "mined" may be limited by the physical ability to withdraw sufficient water to meet the needs.

In this section of the report, estimates are made of the amount of ground water stored in the upper several hundred feet of the reservoir on Edwards Air Force Base and selected nearby areas. It was beyond the scope of this study to make similar estimates for all of Antelope and Fremont Valleys. The purpose of estimating the amount of stored water and the possible length of time the supply would last was to provide the Air Force with the knowledge needed to operate and to manage the water resource for the next several decades.

## GROUND-WATER STORAGE CAPACITY

Ground-water storage capacity may be defined as the reservoir space in a given volume of deposits; to be usable it must be physically possible and economically feasible to withdraw water from wells that penetrate the ground-water reservoir. In areas of large recharge, to be fully usable the reservoir space depleted by pumping must also be capable of being resaturated periodically by natural or induced recharge. In the Edwards Air Force Base area, and particularly in Lancaster basin, where the draft greatly exceeds the recharge, however, the principal concern is the total amount of ground water that can be removed from storage for use--there being insufficient natural recharge available to replenish the supply. Under 1959 conditions of development, little recharge reaches the northern part of Lancaster basin and very little recharge occurs in North Muroc basin. Accordingly, near Rogers Lake, where most of the supply wells for the Air Force Base are located and in North Muroc basin, which is an important source of reserve supply, the amount of usable ground water in storage within selected depth zones is critical with regard to the water supply of the Base.

Ground water in storage to a selected depth is estimated by multiplying the volume of the water-bearing material in an area by the specific yield[1] of the deposits. In general, the method used to estimate the ground water in storage in the Edwards Air Force Base area is nearly the same as that used in estimating the ground-water storage capacity of the Sacramento Valley, Calif., (Poland and others, 1951) and San Joaquin Valley, Calif., (Davis and others, 1959, p. 199).

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[1] Meinzer (1923, p. 28) defines specific yield as follows: "The specific yield of a rock or soil, with respect to water, is the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume. This ratio is stated as a percentage and may be expressed by the formula $Y = 100(\frac{y}{V})$, in which *Y* is the specific yield, and *y* is the volume of gravity ground water in the rock or soil, and *V* is the volume of the rock or soil."

## Storage Units

One of the principal purposes of this study was to investigate areas on and near Edwards Air Force Base where an adequate ground-water supply could be developed. Areas considered are Lancaster, Neenach, Buttes, Rock Creek, and North Muroc basins; Willow Springs, Gloster, Chaffee, and Koehn Lake areas; and Upper Mojave, Middle Mojave, and Harper Valleys (fig. 1A). Neenach, Buttes, and Rock Creek basins; Willow Springs and Koehn Lake areas; and Upper Mojave, Middle Mojave, and Harper Valleys not only are a considerable distance from the points of use on the Base but also support large-scale agricultural developments that are dependent on ground water. In addition, most of these areas already show evidence of being overdrawn. Therefore, they were not considered as potential sources of additional water supply. This left only Lancaster and North Muroc basins and Gloster and Chaffee areas.

Test drilling by the Air Force showed that adequate supply wells could not be obtained in the Gloster area but could be obtained in North Muroc basin. Test drilling by the U.S. Navy showed that adequate supply wells could be obtained in the north-central part of the Chaffee area. Lancaster basin, although greatly overdrawn, supplies water not only for Edwards Air Force Base use but also for a large agricultural development south of the Base boundary. Thus, three areas within 15 miles (airline) from the major points of use, which are near the former site of Muroc (fig. 12), offer possibilities of continued use and future development for Base supply. The supply from these areas is limited almost wholly to the ground water in storage, there being only minor replenishment from recharge.

On the basis of the above considerations, five areas, termed storage units, have been selected as follows: East Rogers, West Rogers, and Rosamond storage units in Lancaster basin, and North Muroc and Chaffee storage units (fig. 12). The East Rogers storage unit is in the northeastern part of Lancaster basin, east of Rogers Lake. This unit covers an area of nearly 19 square miles, or about 12,000 acres. There are supply wells having large yields near the north end of this storage unit.

The West Rogers storage unit, also in the eastern part of Lancaster basin, includes the southern part of Rogers Lake and a relatively large area to the southwest. This unit covers an area of about 40 square miles, or about 26,000 acres. The large-capacity supply wells of the Air Force Base and many former irrigation wells are in this unit. Pumping for irrigation south of the Base boundary also is drawing on the stored water in this unit.

The Rosamond storage unit is in the north-central part of Lancaster basin and includes most of Rosamond and Buckhorn Lakes and the area to the south. This unit covers an area of about 48 square miles, or about 31,000 acres. Several large-capacity wells in the southern part of the unit were formerly used for irrigation. Pumping for irrigation to the south is drawing on the stored water in the unit.

The North Muroc storage unit includes the northern part of Rogers Lake and a relatively large area to the north and east. It covers an area of nearly 40 square miles, or about 25,000 acres, of which about 17,000 acres is on the Base. Wells of moderate yield could be developed in the central part of this storage unit, principally in the area along the north edge of Rogers Lake east of wells 10/9-7A1 and 7A2. The relatively large area between this storage unit and the East Rogers and West Rogers storage units to the south has been omitted from consideration, because for the most part it overlies Rogers Lake barrier, and so far as is known the wells have relatively low yields. Nevertheless, any water present in it would drain into the adjacent storage units if water levels in those units were drawn down substantially.

Finally, the Chaffee storage unit is about 15 miles northwest of Muroc. The area has been tested by the U.S. Navy, and large-capacity wells were obtained in the north-central part of the storage unit. The storage unit covers about 30 square miles or about 19,000 acres.

Even though the West Rogers and Rosamond storage units are adjacent to an area of large agricultural development and even though the basin is overdrawn, considerable water is available in storage. Pumping in the central and northern parts of these storage units would be 3 miles or more from the area of heavy agricultural pumping and would be least affected by that pumping.

## Depth Zones

The depth zones selected in the five storage units extend from the ground-water surface in March 1952 (fig. 6) downward to a selected depth, which is based on the depth to water below land surface in the storage unit and the thickness of water-bearing materials. March 1952 has been used as a base for the storage computations, because it was a time of minimum pumping and a time when the most water-level data were available for determining the position of the ground-water surface in the area. In general, except in the Chaffee area, the thicknesses of the depth zones are in multiples of 100 feet of saturated deposits to a total depth of not more than about 300 feet below land surface.

In the East Rogers storage unit the depth to water in 1952 ranged from about 10 feet to 100 feet and averaged about 50 feet below land surface. Two 100-foot depth zones were selected, an upper zone averaging 50 to 150 feet below land surface and a lower zone averaging 150 to 250 feet below.

In the West Rogers storage unit the depth to water in 1952 ranged from about 5 feet to 60 feet and averaged about 25 feet below land surface. Two 100-foot depth zones were selected, an upper zone averaging 25 to 125 feet below land surface and a lower zone averaging 125 to 225 feet below. In the Rogers Lake portion of this unit, where the water level was 5 to 10 feet below the surface of the lake bed and where the clayey playa deposits are nearly 100 feet thick (fig. 3), the usable water in storage in the upper zone is relatively small (table 10).

In the Rosamond storage unit the depth to water in 1952 ranged from several feet above to 50 feet below land surface and averaged about 25 feet below. Two 100-foot depth zones were selected, an upper zone averaging 25 to 125 feet below land surface and a lower zone averaging 125 to 225 feet below. The playa and lacustrine deposits beneath Rosamond and Buckhorn Lakes are several hundred feet thick (fig. 4), and the usable water in storage in both depth zones beneath the lakes is relatively small (table 10).

In the North Muroc storage unit the depth to water in 1952 and also in 1959 ranged from about 60 to 125 feet and averaged nearly 100 feet below land surface. The depth to water in that part of the storage unit on the Base, south of Highway 466, averaged about 75 feet below the land surface. Two depth zones were selected: an upper zone 100 feet thick averaging about 100 to 200 feet below land surface and a lower zone 50 feet thick averaging 200 to 250 feet below. The lower zone is limited to a thickness of 50 feet because the poorly water-bearing older fan deposits are encountered at a depth of about 300 feet (fig. 3). For the area beneath Rogers Lake, the playa deposits are largely above the zone of saturation and do not reduce appreciably the amount of water available in storage.

In the Chaffee storage unit the depth to water in 1952 (and about the same in 1959) ranged from 50 to 400 feet and averaged about 350 feet below land surface. Owing to poorer well yields and relatively shallow bedrock in the marginal parts of the Chaffee storage unit, the thickness of the unit was decreased from 200 feet in the east part to 100 feet in the central part and to 50 feet in the marginal part (fig. 12). The three depth zones include: (1) An east part where the depth zone is 200 feet thick and ranged in average depth from about 250 to 450 feet below land surface, (2) a central part where the depth zone is 100 feet thick and ranged in average depth from about 250 to 350 feet below land surface, and (3) a marginal part where the depth zone is 50 feet thick and ranged in average depth from about 350 to 400 feet below land surface. The area of the east part is about 3,800 acres, the central part about 8,000 acres, and the marginal part about 7,200 acres.

## Specific-Yield Values

To estimate the quantity of ground water contained in storage in the deposits of the five storage units and available by lowering the water level in the several depth zones, the specific yield of the saturated deposits must be estimated.

The materials in the storage units penetrated by wells for which logs are available have been grouped into five general classes, which have relatively distinct hydrologic properties. Inherent in these properties is the specific yield. In the absence of field or laboratory tests it is necessary to assign a specific-yield value to each of the five classes. Because of the range in physical and hence hydrologic properties in each of the five general classes of materials, the specific-yield value assigned to each class is based on the results of several intensive field investigations in various parts of California. One of the most intensive of these was made by Eckis (1934) in the South Coastal basin (the Los Angeles area). Another intensive study was made in the Mokelumne area in the northern part of the San Joaquin Valley by Piper and others (1939). From these two sources and from less detailed investigations, specific-yield values have been selected which closely represent the types of materials comprising the younger and older alluvial deposits in the Edwards Air Force Base area logged by geologists of the Geological Survey and drillers as follows:

| Class | Material | Assigned specific yield (percent) |
| --- | --- | --- |
| Sand: | Sand, medium to coarse, clean | 30 |
| Gravel: | Fine, medium, and coarse gravel; sand and gravel; gravel and sand; fine, medium, or coarse sand and gravel; gravel and quicksand; gravel and rock; coarse gravel and rock; sand and boulders; and gravel and boulders | 25 |
| Sand and silt: | Dirty sand; hard sand; hard coarse sand; sand and clay; very coarse sand and some clay; sandy clay and streaks of coarse gravel and sand; sand and streaks of hard gravel; coarse, hard gravel and sand; coarse gravel and streaks of clay; gravel and some clay; and clayey sand | 15 |
| Cemented gravel: | Sandy clay and gravel; soft clay and gravel; coarse gravel and hard clay; coarse gravel and clay; small gravel and clay; gravel (fine, medium, or coarse) and clay; hard gravel; gravel, sand, and hard clay; sand, gravel and hard clay; coarse sand and clay; coarse sand, gravel, and clay; coarse sand and clay; cemented sand and clay; cemented sand and boulders; cemented sand and rock; sandy clay and gravel; sandy clay and boulders; cemented sand and gravel; cemented sand; rock and cemented sand; "rock sparr," rock, gravel, and clay; boulders; boulders and hard sand; bounders in cemented sand; boulders in sandy clay; hard sand and clay; | |

| Class | Material | Assigned specific yield (percent) |
| --- | --- | --- |
| Cemented gravel:--Continued | | |
| | hard fine sand, gravel and clay; hard sand and gravel; hard sand and clay; hard sand and rock; and clay and some fine sand---------------------------------------------- | 5 |
| Clay: | Clay, clay and decomposed granite, decomposed granite, and playa deposits---------------------------- | 3 |

The greatest potential errors in the calculation of ground water in storage are in the classification of drillers' terms and in the assignment of specific-yield values. The terms "clay and sand," "silty sand," and "sand and silt" cover about 45 percent of all the material logged. A small error in the specific-yield values assigned to these materials would have a large effect on the final calculations of ground water in storage. Based on a pumping test at wells in 11/9-36C in North Muroc basin, where materials dewatered during pumping were largely clay and sand, silty sand, "dirty" sand, and sand and silt, the coefficient of storage was 0.13--about equivalent to a specific yield of 13 percent. The weighted average specific yield for all the materials, as determined from well logs, which is affected strongly by the 45 percent of materials similar to those involved in the pumping test, is about 12 percent. Thus, for North Muroc basin the assigned values of specific yield shown above for the five groups of material probably are reasonably accurate.

In the West Rogers and Rosamond storage units the playa deposits occupy a relatively large part of the selected depth zones. The specific-yield value assigned to these deposits is 3 percent, rather than something less, because the deposits contain lenses of sand and silt which should yield some water by downward and lateral drainage to more permeable deposits tapped by wells. The clay also will yield a little water, increasing the total slightly.

## Estimated Ground Water in Storage

The estimated ground water in storage of the five storage units was computed as follows: (1) The areas of the storage units were measured; (2) for each storage unit the volume of deposits was determined by multiplying the area, in acres, by the selected thickness of each depth zone, in feet, to obtain a saturated volume, in acre-feet; (3) the logged materials in the wells were segregated into the five general types of material, as described, and the percentages of each type were multiplied by the assigned specific-yield values, then added to determine the weighted average specific yield of the depth zone. For broad expanses of the North Muroc storage unit for which no logs were available, the specific yield for the entire unit is based on the few logs in local areas; and (4) the estimated ground water in storage in 1952 in the five storage units was derived by multiplying the average specific yield of each by the total volume of the saturated deposits in each depth zone. Table 8 shows the estimated ground water in storage in 1952 in the five storage units.

Table 8.--Estimated ground water in storage in 1952 on and near Edwards Air Force Base

| Storage unit (fig. 12) | Average depth zone[1] (feet) | Thickness (feet) | Area (acres) | Volume of saturated deposits (acre-feet) | Estimated specific yield (percent) | Estimated ground water in storage, 1952[2]: Total (acre-feet) | Within Base (percent) | Within Base (acre-feet) |
|---|---|---|---|---|---|---|---|---|
| East Rogers | 50-150 | 100 | 12,000 | 1,200,000 | 12 | 140,000 | 100 | 140,000 |
| | 150-250 | 100 | 12,000 | 1,200,000 | 15 | 170,000 | 100 | 170,000 |
| Subtotal | 50-250 | 200 | 12,000 | 2,400,000 | -- | 310,000 | 100 | 310,000 |
| West Rogers | 25-125 | 100 | 26,000 | 2,600,000 | 5 | 130,000 | 100 | 130,000 |
| | 125-225 | 100 | 26,000 | 2,600,000 | 12 | 310,000 | 100 | 310,000 |
| Subtotal | 25-225 | 200 | 26,000 | 5,200,000 | -- | 440,000 | 100 | 440,000 |
| Rosamond | 25-125 | 100 | 31,000 | 3,100,000 | 3 | 90,000 | 100 | 90,000 |
| | 125-225 | 100 | 31,000 | 3,100,000 | 8 | 250,000 | 100 | 250,000 |
| Subtotal | 25-225 | 200 | 31,000 | 6,200,000 | -- | 340,000 | 100 | 340,000 |
| North Muroc | 100-200 | 100 | 25,000 | 2,500,000 | 12 | 300,000 | 70 | 200,000 |
| | 200-250 | 50 | 25,000 | 1,250,000 | 12 | 150,000 | 70 | 100,000 |
| Subtotal | 100-250 | 150 | 25,000 | 3,750,000 | -- | 450,000 | 70 | 300,000 |

Table 8.--Estimated ground water in storage in 1952 on and near Edwards Air Force Base--Continued

| Storage unit (fig. 12) | Average depth zone[1] (feet) | Thickness (feet) | Area (acres) | Volume of saturated deposits (acre-feet) | Estimated specific yield (percent) | Estimated ground water in storage, 1952[2] | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Total (acre-feet) | Within Base (percent) | Within Base (acre-feet) |
| Chaffee--East part | 250-450 | 200 | 3,800 | 760,000 | 10 | 80,000 | 0 | 0 |
| Central part | 250-350 | 100 | 8,000 | 790,000 | 10 | 80,000 | 0 | 0 |
| Marginal part | 350-400 | 50 | 7,200 | 360,000 | 10 | 40,000 | 0 | 0 |
| Subtotal | --- | --- | 19,000 | 1,900,000 | -- | 200,000 | 0 | 0 |
| Total | --- | --- | 113,000 | 19,450,000 | -- | 1,700,000 | 80 | 1,400,000 |

1. Average depth zone indicated is the uppermost part of the zone of saturation and extends downward from the approximate surface of the ground water in 1952 to the depth indicated.

2. All totals rounded to two significant figures.

Table 8 shows that the estimated total ground water in storage in the five storage units is on the order of 1,700,000 acre-feet. Of this total, about 1,400,000 acre-feet is within the limits of Edwards Air Force Base, and of this 1,400,000 acre-feet, about 440,000 acre-feet is in the West Rogers storage unit where the large supply wells are located. In East Rogers, West Rogers, and Rosamond storage units, all in Lancaster basin, the estimated stored water in the upper 100-foot depth zone is only 360,000 acre-feet, compared to 730,000 acre-feet in the lower 100-foot depth zone. This is due to the relatively low specific yield of the playa deposits in the upper zone.

## USABLE GROUND WATER IN STORAGE

Under conditions of proper well spacing and moderate rate of withdrawal, virtually all the estimated ground water in storage (table 8) should be available for use not only by the Air Force but also by others who withdraw water from the same ground-water basins. In this respect, the large-scale irrigation pumping in Lancaster basin has a pronounced effect on the supply available to the Air Force in the West Rogers and Rosamond storage units and a lesser effect on the supply in the East Rogers storage unit, which is remote from the area of pumping. On the other hand, in North Muroc basin, where little pumping has occurred, the supply now is available to the Air Force or to outside development by others.

## Lancaster Basin

Ground water in storage in the East Rogers, West Rogers, and Rosamond storage units is the sole source of supply available to the Air Force in Lancaster basin. Because of the large net draft for irrigation in the area south of the Air Force Base, estimated by Snyder (1955) to be 168,000 acre-feet (table 3) in 1951, the ground water in storage within the Base area has been and is undergoing moderately rapid depletion. This depletion would continue even if the pumping at the Air Force Base were discontinued; it would increase if the Base increased its pumping. Thus, the rate of depletion is a critical factor in estimating the length of time the supply will last.

For the 12-year period preceding 1952, the year for which the estimates of ground water in storage were made (table 8), the average annual rates of water-level decline were computed for the three storage units. These rates of decline have been converted to rates of storage depletion and are shown in table 9.

Table 9.--Average annual rate of water-level decline and estimated rate of storage depletion in East Rogers, West Rogers, and Rosamond storage units, 1940-52

| Storage unit | Estimated storage in 1952[1] (acre-feet) | Average annual rate of water-level decline, 1940-52 (feet per year) | Average annual rate of storage depletion, 1940-52 (acre-feet per year) |
|---|---|---|---|
| East Rogers | 310,000 | 1.2 | 1,700 |
| West Rogers | 440,000 | 2.2 | 2,900 |
| Rosamond | 340,000 | 2.5 | 2,200 |
| Total | 1,100,000 | 1.9 | 6,800 |

1. Data from table 8.

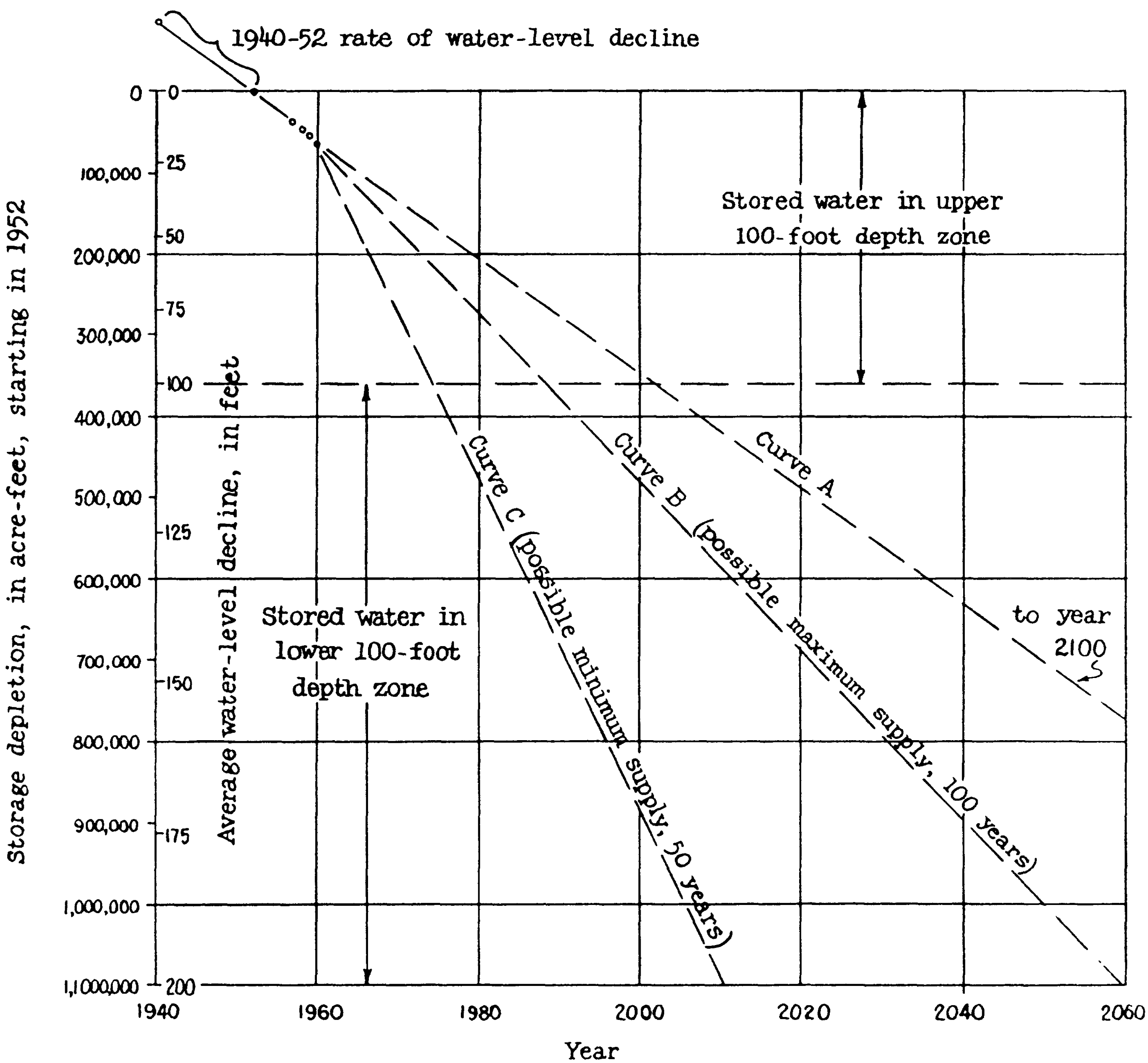
The table shows that for the period 1940-52 the average annual rate of storage depletion in the three storage units totaled nearly 7,000 acre-feet per year, which indicates that for the three units as a whole the ground-water outflow and pumpage exceeded ground-water inflow, plus any minor recharge, by this amount. If this rate of depletion were maintained beyond 1952 until the stored water in the upper 200 feet of saturated deposits (1,100,000 acre-feet) was exhausted, the supply would last roughly 150 years, or to the year 2100. This straight-line extrapolation is shown by curve A on figure 14. However, two principal variables are expected to cause an increase in the future rate of storage depletion shown in table 9 and curve A, as follows: Increases in pumping at the Air Force Base and in the net draft for irrigation outside the Base, which already have occurred since 1952. Pumpage from wells in the West Rogers and East Rogers units has increased from somewhat less than 1,000 acre-feet in 1952 to more than 2,000 acre-feet in 1956 (table 4). Similarly, net draft for irrigation increased from 79,000 acre-feet in 1942 to 168,000 acre-feet in 1951 (table 3), the last year for which data are available. Thus, the longevity of the long-term extrapolated supply beyond 1952, as shown by curve A (fig. 14), probably will be considerably less. This is already demonstrated by the point plots for storage depletion for the years 1957-60.

Several possible extrapolated rates of storage depletion in that part of Lancaster Basin within Edwards Air Force Base, Calif.

Curve A: Assumes rate of depletion prior to 1952 will continue.

Curve B: Assumes 1959 and 1960 rates of depletion, averaging about 10,000 acre-feet per year, will continue.

Curve C: Assumes rate of depletion after 1960 will average 15,000 to 20,000 acre-feet per year.



In connection with continued studies for the Air Force, annual estimates of storage depletion have been made since 1957. The status of storage each year is made at the time of highest water levels, which usually is in March or April, when the effects of pumping for agricultural use are least. The estimated depletion of ground water in storage since 1952 for the years 1957-60 is shown in table 10 and on figure 14.

The rate of depletion for the storage units in Lancaster basin for the 8-year period 1952-60 was more than 8,000 acre-feet a year, for the last 2 years of the period was about 10,000 acre-feet a year, and for the year ending in March 1960 was about 12,000 acre-feet. Thus, the depletion rate in 1959-60 was nearly double the average annual rate for the period 1940-52, which averaged nearly 7,000 acre-feet a year (table 9). Obviously, the increased rate of depletion in recent years indicates that the extrapolation of the years of supply remaining after 1952, as shown by curve A (fig. 14), is too great.

Table 10.--Estimated ground-water depletion, Edwards Air Force Base, 1952-60

(All values are in acre-feet and rounded to two significant figures)

| Basin and storage unit | Estimated ground water in storage in 1952[1] | Estimated ground-water depletion, in the year ending about March | | | | |
|---|---|---|---|---|---|---|
| | | 1952 to 1957 | 1957 to 1958 | 1958 to 1959 | 1959 to 1960 | Total 1952-60 |
| Lancaster basin | | | | | | |
| East Rogers | 310,000 | 11,000 | 2,600 | 2,200 | 4,300 | 20,000 |
| West Rogers | 440,000 | 17,000 | 2,400 | 4,100 | 3,600 | 27,000 |
| Rosamond | 340,000 | 11,000 | 1,900 | 1,900 | 4,000 | 19,000 |
| Subtotal | 1,100,000 | a39,000 | 6,900 | 8,200 | 12,000 | 66,000 |
| Accumulated subtotal[2] | -- | 39,000 | 46,000 | 54,000 | 66,000 | -- |
| North Muroc basin | | | | | | |
| North Muroc | b450,000 | c1,000 | 1,000 | 1,000 | 1,000 | 4,000 |
| Total | 1,500,000 | 40,000 | 7,900 | 9,200 | 13,000 | 70,000 |

1. Estimates from table 8.

2. Points plotted on figure 14.

a. Average rate of depletion for the 5-year period is 7,800 acre-feet per year.

b. About 300,000 acre-feet of this storage is within Base boundary.

c. Little pumpage from basin until 1956, when several large supply wells were drilled for public and industrial use north of U.S. Highway 466 on privately owned property.

Because of the variations in Base pumpage and rate of storage depletion, an equation can be utilized to extrapolate the years of supply remaining in storage at any particular time, as follows:

$$\text{Extrapolated years of supply} = \frac{(\text{Storage in 1952}) - (\text{Ground-water depletion since 1952})}{(\text{Estimated future annual rate of storage depletion})} \quad \text{----(1)}$$

Equation (1) can be used to extrapolate the years of supply in individual storage units or the average of the three units, as has been done in the following paragraphs, using several examples. In equation (1) the "ground-water depletion since 1952" is the total net depletion and can be estimated from the net change in water levels that has occurred since 1952; and the "estimated future annual rate of storage depletion" is the estimated annual storage depletion that would occur in the three storage units as a result of pumping by the Base and for irrigation in Antelope Valley south of the Base boundary.

Two examples are used to provide a reasonable range in the estimates of the years of supply remaining in storage beyond 1960. First, to estimate the maximum length of time the supply would last could be based on the assumption that the average rate of depletion for 1959 and 1960 (10,000 acre-feet per year, table 10) would continue until the supply in the upper 200 feet was exhausted. By substituting the values in equation (1) an extrapolation of the years of supply is obtained:

$$\text{Possible maximum years of supply after 1960} = \frac{1,100,000 - 66,000}{10,000}$$

$$= \text{about 100 years (curve B, fig. 14)}$$

The apparent fallacy in this estimate may be the same as that inherent in the criteria used to construct curve A; that is, to assume no increase in the rate of storage depletion.

The estimation of the minimum length of time the supply might last must be based on a reasonable maximum annual rate of storage depletion. Table 10 shows that the rate of depletion is increasing year by year. Moreover, the future planned Base pumpage is 8,000 acre-feet a year--an increase of about 3,500 acre-feet more than that pumped in 1959 (table 4). This increase alone would raise the estimated average annual rate of depletion of 10,000 acre-feet in 1959 and 1960 to roughly 14,000 acre-feet sometime in the future.

Still another variable is the future magnitude of the depletion of stored water that will result from the continued agricultural pumpage south and west of the Air Force Base. A comparison of the Base pumpage for the period 1952-59 (table 4) with the ground-water depletion (table 10) indicates that the increase in Base pumpage has accounted for about all the increase in the annual rate of depletion. In other words, the effect of agricultural pumpage has remained about constant and, although varying considerably from year to year, has accounted for roughly 6,000 acre-feet per year of the annual depletion, as is shown below. (Estimates are from tables 4 and 10.)

| Storage depletion (1) | | Base pumpage (2) | | Difference[2] |
|---|---|---|---|---|
| Year[1] | (acre-feet) | Year[1] | (acre-feet) | (1) - (2) |
| 1952-57 | a7,800 | 1952-56 | a1,900 | a5,900 |
| 1957-58 | 6,900 | 1957 | 2,800 | 4,100 |
| 1958-59 | 8,200 | 1958 | 4,100 | 4,100 |
| 1959-60 | 12,000 | 1959 | 4,500 | 7,500 |

1. Storage-depletion year extends from about April of 1 year to March of the next, and the pumpage year is a calendar year. Thus, when comparing the two, depletion for the year ending about March (e.g., 1960) and pumpage in the year ending December (e.g., 1959) are used.

2. That part of the annual storage depletion attributed principally to agricultural pumpage in Lancaster basin.

a. 5-year average.

However, the effects of the off-Base pumpage could increase in the future, as is suggested by the unusually large depletion attributed to this cause for the last year of record, about 7,500 acre-feet (above table). Accordingly, it seems reasonable to assume that the annual rate of depletion in the future caused by the agricultural pumpage might range from about 6,000 acre-feet, the average amount computed for the past 8 years, to as much as 10,000 acre-feet.

Thus, the future maximum rate of ground-water depletion in East Rogers, West Rogers, and Rosamond storage units can be estimated from the criteria presented in the foregoing paragraphs. It would be the sum of the future planned Base pumpage of 8,000 acre-feet per year and the probably depletion caused by agricultural pumpage of 6,000 to 10,000 acre-feet per year, or a total of roughly 15,000 to 20,000 acre-feet per year. By substituting the values in equation (1), an extrapolation of the years of supply is obtained:

$$\text{Possible minimum years of supply after 1960} = \frac{1,100,000 - 66,000}{15,000 \text{ to } 20,000}$$

$$= \text{at least 50 years (curve C, fig. 14)}$$

It is emphasized that the 50- and 100-year estimates of the supply remaining beyond 1960 are averages for the three storage units. It is not likely that the supply in all three would be exhausted to a depth of 200 feet at the same time, although with careful water management and placement of new wells, simultaneous depletion could be approached. The eastern part of the West Rogers storage unit is 5 miles or more from the area of pumping for irrigation, and the stored water would not be depleted as rapidly as that in the southwestern part of the storage unit, which is near the area of pumping. The East Rogers storage unit also is subject to depletion by pumping for irrigation, but because the unit is 10 miles or more from the area of pumping, the rate of depletion due to this cause will be considerably slower than that in the West Rogers and Rosamond storage units.

Table 9 shows that the average annual rate of water-level decline in the East Rogers storage unit was about half that for the other two units. If additional wells are drilled in the West Rogers storage unit to obtain the 8,000 acre-feet per year that is contemplated for the Air Force Base, proper spacing of the wells would intercept and salvage a part of the water being depleted by southeastward drainage from the East Rogers unit.

In the West Rogers storage unit the problem of proper well spacing is complicated by the position of Rogers Lake, which is used by the Air Force. Because pumping from wells in the agricultural area to the southwest is causing a substantial underflow out of the area, it appears probable that wells drilled at suitable intervals along the south and west sides of Rogers Lake would intercept a part of the underflow without causing an unduly large drawdown in the area of agricultural pumping, would be convenient to the principal points of use, and would be in a favorable position to utilize the storage.

At the present time (1959) there are no supply wells in the Rosamond storage unit. As shown by the water-level contours (fig. 6), ground water in this unit is moving toward the pumping depression south of the Air Force Base boundary. If the Air Force makes no attempt to develop ground water in this unit, the supply will continue to be depleted by pumping for irrigation south of the Base, and the estimated stored water of 340,000 acre-feet as of 1952 (tables 8 and 9) would not be available as a source of supply. Supply wells could be drilled near the south side of Buckhorn Lake on the east, south, and west sides of Rosamond Lake to supply water for any existing or planned installations.

## North Muroc Basin

In the North Muroc storage unit, where there is little pumping, the ground water in storage in 1960 was only slightly less than that in 1952 (table 10). The estimated 300,000 acre-feet of stored water within the Base boundary is available for development by the Air Force. However, some irrigation, domestic, and industrial development of ground water has occurred north of the military reservation, and if the use increases substantially, the supply would be subject to depletion in the same manner as that now occurring in the three storage units in Lancaster basin.

The estimated stored water on the Base as of 1960 would assure a draft of 8,000 acre-feet a year for roughly 35 years, if all of it could be captured for use on the Base.

## Gloster Area

With regard to the stored water in the Gloster area, where very little pumping has occurred, the test-drilling program showed that only small well yields, 20 to 50 gpm, with excessive drawdowns could be obtained--too small for consideration as a principal source of supply. The estimated ground water in storage in the upper 100 feet of saturated deposits is about 130,000 acre-feet. The yields of wells would be sufficient to supply water for many years to any facilities of small water demand that might be constructed in the Gloster area.

## Chaffee Area

The Chaffee storage unit, containing an estimated 200,000 acre-feet of stored water in 1952, offers the closest source of ground-water supply outside the Base boundary; it is outside of the drainage divide tributary to the Base. The estimated stored water in this area, as of 1960, would assure a draft of 8,000 acre-feet a year for about 25 years. However, in 1957 the town of Mojave started to develop a well field at the north edge of the storage unit and will obtain a substantial part of its supply from the ground water stored in this area.

## RELATION OF RECHARGE AND DISCHARGE TO STORAGE CHANGES

As discussed earlier, a very small amount of recharge occurs as seepage loss from the intermittent streams that rise in the hills surrounding the storage units and very minor amounts result from penetration of precipitation on the surface areas of the five storage units. Because the natural ground-water discharge from the storage units is almost wholly by subsurface flow, except for a very small amount of discharge by evaporation from bare soil areas and transpiration of plants near the southeast margin of Rogers Lake and the west side of Rosamond Lake, and because recharge is very small, for all practical purposes the annual change in ground water in storage is equal to the amount of discharge by pumping plus subsurface outflow minus the subsurface inflow to the storage units. Pumping for agriculture will continue to deplete the storage within the Base by subsurface outflow toward the areas of large-scale pumping so long as the draft is continued. Pumping from any new supply wells within the storage units outlined on figure 12 will not change materially the natural subsurface recharge or discharge for many years; nearly all water pumped and not later returned to ground water through deep percolation of irrigation water (mostly lawns) or sewage effluent, therefore, will be withdrawn from ground water in storage.

There is no water imported to any of the four storage units on the Air Force Base. In addition, probably very little water presently pumped from these storage units returns to ground water. Edwards Air Force Base maintains disposal ponds for evaporation of treated sewage effluent in 9/10-24 at the margin of Rogers Lake. It is probable that part of the sewage effluent percolates to ground water through the fine-grained, poorly permeable playa deposits. If shallow observation wells were drilled near the margins of the ponds, it probably would be possible to determine whether there is a significant return of sewage effluent to ground water. If the treated sewage effluent were to be pumped for irrigation of lawns, as planned, some deep percolation below the root zone would result, and that water would move toward the valley area and eventually recharge ground water in the West Rogers or North Muroc storage units. This would cause a small increase in the available supply, because the depletion of storage by pumping would be reduced by the amount of effluent returned to ground water. However, if large amounts of sewage effluent are returned to ground water, the quality of the supply pumped would deteriorate with time. This "recycling" of ground water would become critical in this area where there is little recharge to dilute the supply.

## THE TEST-WELL DRILLING PROGRAM

### PURPOSE AND SCOPE

The specific purposes of drilling test wells in the Gloster and Chaffee areas and the North Muroc basin were (1) to determine the potentialities of the several basins as sources of ground-water supply for the Air Force Base; (2) to ascertain the vertical and in part the horizontal extent of the water-yielding beds; (3) to determine the character and hydrologic properties of these deposits, both during drilling and afterwards by test pumping, so that estimates of productivity and ground water in storage could be derived or refined for various depth zones; (4) to obtain samples of ground water during drilling for chemical analysis to detect changes in character with depth and during test pumping to ascertain the composite character of the waters opposite the perforated intervals; and (5) where possible, to derive coefficients of storage and transmissibility by pumping tests for use in estimating the amount and movement of ground water in the basins.

Four test wells were completed--three in the Gloster area, wells 10/12-22J1, 10/12-23C1, and 10/12-13H1; and one in the North Muroc basin, well 10/9-4D1. The test drilling was started in the Gloster area in February 1956 and was completed in North Muroc basin in February 1957. The test wells were drilled to depths ranging from 185 to 500 feet, and the total footage drilled was 1,176 feet. The average rate of drilling was only about 5 feet per day.

The data obtained from the test-well drilling program and from tests on new privately owned wells indicate that North Muroc basin is a valuable potential source of water supply, but that the Gloster area is very inferior to other available sources of water. Test well 10/9-4D1 in North Muroc basin was fully developed by the driller and can be used as a well for Air Force Base supply. A pump capable of producing up to 400 gpm could be operated in the well with moderate drawdown.

## TEST-WELL DATA

Data obtained during the drilling and testing of the four test wells include (1) the logs of wells 10/12-22J1, 10/12-23C1, and 10/12-13H1, which were compiled from on-the-spot sampling by the Geological Survey, and the driller's log of well 10/9-4D1 in North Muroc basin; (2) a chemical analysis for 10/9-4D1 in North Muroc basin; (3) results of bail tests made during and after well construction, which show the yield and drawdown of selected water-bearing zones and of the completed well, respectively; and (4) the final results of test pumping well 10/9-4D1 in North Muroc basin, which was the only well having sufficient yield to warrant test pumping. The data are summarized in table 11.

Table 11.--Test-well logs

(Stratigraphic correlation by the authors. All depth measurements in feet below land-surface datum.)

Test well 10/12-22J1. In the Gloster area. Altitude about 2,530 ft. Casing diameter 12-inch; drilled February 27-March 26, 1956.

| Correlation (see table 1) | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| Qyal | Clay and sand; poorly sorted and mixed, sticky; light buff; granitic origin and grains are typically angular very coarse sand---------------------------------------- | 35 | 35 |
| Qoal | Clay and sand; hard, compact, sticky, mainly quartz, locally contains some chalky nodules in clay; light brown to buff------- | 33 | 68 |
| | Clay; slightly sandy, sticky and compact, medium to dark brown, contains numerous chunks or balls of very dark brown and light green clay--------------------------- | 9 | 77 |
| | Sand and clay; buff to brown, soft, granitic origin and has large proportion of quartz; silt and clay percentage increases with depth; may be very thin beds of silty sand and clay------------------------------------ | 75 | 152 |

Table 11.--Test-well logs--Continued

Test well 10/12-22J1.--Continued

| Correlation (See table 1) | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| | Sand, gravelly and silty and some intermixed clay; brown; gravel up to ½-inch but mainly coarse and very coarse sand of granitic origin---------------------------- | 3 | 155 |
| | Clay and sand; tough and compact, brown, some gravel up to 1-inch intermixed-------------- | 16 | 171 |
| | Clay, sand, gravel, sandy gravel, and clay and gravel; brown, in thin beds or stringers, soft to hard; open hole caved and heaved at 181 ft----------------------- | 12 | 183 |
| | Clay and sand; brown, sticky; sand is fine to very coarse, mainly quartz, silty, may be a few streaks of sandy clay, weathered and of granitic origin---------------------------- | 18 | 201 |
| | Sand and clay, silty; buff to light brown, weathered, hard; granitic origin, contains much weathered feldspar and biotite mica, some large mica books present------------- | 8 | 209 |
| | Clay and sand; reddish-brown, sticky; about half clay and silt and half poorly sorted angular sand------------------------------ | 13 | 222 |

Table 11.--Test-well logs--Continued

Test well 10/12-22J1.--Continued

| Correlation (See table 1) | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| | Gravel, sand, silt, and clay; brown, compact, very poorly sorted and mixed; gravel up to $\frac{1}{4}$-inch, granitic origin and contains large biotite mica books; soft from 232 to 234 ft | 12 | 234 |
| Tc or Qof | Boulders, gravel, and sand; cemented, very hard, angular blocks. This interval cored 5 times, 1 partial recovery | 8 | 242 |

Casing record: 0 to 242 ft, 12-inch, double 10-gage.

Perforations: 130 to 230 ft; 1/8-inch x $1\frac{1}{2}$-inch hydraulic (horizontal) louver, 6 cuts per round, 8 inches between rounds.

Water samples: Samples bailed during drilling and bail-testing contained much suspended clay which would not settle in sample container; an analysis was not made.

Water level: Before perforating, 36 ft.
After perforating, 36 ft.

Yield: Bail-tested on March 26, 1956, at a rate of about 60 gpm and water level declined from 36 ft to 220± ft after 25 minutes; after $1\frac{1}{2}$ hours second bail test was made at a rate of 20 gpm and water level declined to 220± after about 1,625 gallons was bailed.

Table 11.--Test-well logs--Continued

Test well 10/12-23C1. In the Gloster area. Altitude about 2,520 ft. Casing diameter 12-inch; drilled April 3-May 2, 1956.

| Correlation (See table 1) | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| Qyal | Silt, hard, yellow, sandy | 4 | 4 |
| | Silt, clay, and sand; gray, very sticky | 11 | 15 |
| | Sand, silt, and clay, and some fine gravel; gray, much white, carbonate | 6 | 21 |
| Qoal | Clay, silt, and sand; brownish-yellow, volcanic sand and fine gravel mixed with clay; sand mainly quartz | 27 | 48 |
| | Sand, poorly sorted, fine to very coarse and gravel up to $\frac{1}{4}$ inch; silty and clayey; brown; mainly of granitic origin but volcanic sand grains present; has very thin clay lenses | 20 | 68 |
| | Sand and very small gravel, silty and clayey; very hard, cemented, brown, entirely granitic origin | 24 | 92 |
| | Sand, silt, and clay, mostly clay and sand; hard, brown, percent silt and clay increases with depth; few chunks of very hard calcareous clay in bailer | 77 | 169 |
| | Clay, sand, and gravel; buff to brown; very hard; gravel pebbles are granitic and up to 1 inch; very hard drilling | 9 | 178 |

Test well 10/12-23C1.--Continued

| Correlation (See table 1) | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| Tc or Qof | Boulders, gravel, sand, and clay; cemented; very hard drilling; material quartz monzonite, granite, pegmatite, graphic granite cobbles; very muddy----- | 71 | 249 |

Casing record: 0 to 152 feet, 12-inch double 10-gage; open hole 152 to 249 ft.

Perforations: 45 to 90 ft; $\frac{1}{4}$-inch x $1\frac{1}{2}$-inch hydraulic Mills knife; 6 cuts per round, 12 inches between rounds.

Water samples: Samples collected but analysis not made because of much suspended clay in sample that would not settle.

Water level: Before perforating, 34 ft.
After perforating, 34 ft.

Yield: Bail-tested on May 2, 1956, at a rate of 20 gpm and the water level declined from 34 ft to 170 ft. At a rate of 13 gpm for 25-minute period, water level declined from 52 ft to 155 ft.

Table 11.--Test-well logs--Continued

Test well 10/12-13H1. In the Gloster area. Altitude about 2,505 ft. Casing diameter 12-inch; drilled May 7-June 7, 1956.

| Correlation (See table 1) | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| Qyal | Sand, silty; light buff to gray; very poorly sorted; some fine gravel--------- | 12 | 12 |
| Qoal | Clay and silt sandy, and a small amount of very fine gravel; brown and compact; entirely granitic origin; feldspar fairly fresh---------------------------- | 45 | 57 |
| | Gravel, sand, silt, and clay; brown, angular, granitic origin----------------- | 5 | 62 |
| | Clay and silt; same as 45-57 ft but clay comes out in chunks as very hard fractured pieces; some gravel to pea size--------- | 23 | 85 |
| | Sand and clay and some gravel; reddish-brown; loose but makes much mud; entirely granitic origin; very few pebbles up to ½ inch------------------------------------ | 39 | 124 |
| | Sand, silt, and clay; gray and micaceous, granitic, feldspar very rotten---------- | 5 | 129 |

Test well 10/12-13H1.--Continued

| Correlation (See table 1) | Material | Thickness (feet). | Depth (feet) |
|---|---|---|---|
| Qoal(?) | Sand, and silt, tight; poorly sorted, contains some gravel; brown; in very thin beds containing gray very fine silty sand and very rotten micaceous coarse sand lenses; this sequence might be lacustrine deposits | 30 | 159 |
| Tc or Qof | Granitic boulders, hard, fresh, and sand and clay | 16 | 175 |

Casing record: 0 to 153 ft, 12-inch double 10-gage; open hole 153 to 175 ft.

Perforations: 75 to 147 ft; $\frac{1}{4}$-inch x $1\frac{1}{2}$-inch hydraulic Mills knife; 6 cuts a round, 12 inches between rounds.

Water samples: Samples bailed during drilling and bail-testing were not suitable for analysis because of much suspended clay which would not settle to the bottom of the container after standing for a long period; an analysis was not made.

Water level: Before perforating, 52 ft.
After perforating, 52 ft.

Yield: Bail-tested on June 7, 1956, at a rate of 60 to 65 gpm, and well bailed dry at the end of 30 minutes; during second test, the well was bailed dry after 45 minutes at a rate of 30 gpm.

Table 11.--Test-well logs--Continued

Test well 10/9-4D1. In North Muroc basin. Altitude about 2,280 ft. Casing diameter 12-inch; drilled July 9, 1956-February 12, 1957.

Driller's log; correlations by U.S. Geological Survey

| Correlation (See table 1) | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| Qls | Quartz sand | 34 | 34 |
| Qp, Qyal, Qoal(?) | Clay, silty, and coarse sand | 108 | 142 |
| Qoal | Gravel and very fine sand, poorly sorted | 14 | 156 |
| | Clay, silt, and sand; with gravel, very hard; no water | 33 | 189 |
| | Gravel, sand, and silt, very dirty | 2 | 191 |
| | Clay, hard, sandy, light brown to red, very tight, forms balls; sand, fine to very coarse with intermixed fine gravel | 27 | 218 |
| | Sand and silt with some fine gravel, dirty | 10 | 228 |
| | Clay and sand, silty, some gravel to pebble size, clastics, very adhesive, forms compact balls | 87 | 315 |

Table 11.--Test-well logs--Continued

Test well 10/9-4D1.--Continued

| Correlation (See table 1) | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| Qof | Granite and quartz------------------------ | 87 | 402 |
| | Granite, decomposed----------------------- | 8 | 410 |
| | Gravel, fine------------------------------ | 8 | 418 |
| | Sand, cemented---------------------------- | 10 | 428 |
| | Silt, fine, tight------------------------- | 5 | 433 |
| | Sand, cemented---------------------------- | 4 | 437 |
| | Clay, hard, sandy, yellow----------------- | 27 | 464 |
| | Clay, hard, sandy------------------------- | 33 | 497 |
| | Clay, hard, blue-------------------------- | 5 | 502 |

Casing record: 0 to 500 ft; 12-inch double 10-gage.

Perforations: 144 to 195 ft and 200 to 433 ft; 3/16-inch x 2½-inch hydraulic Mills knife; 6 cuts a round, 1 round a foot.

Water sample: Sample collected during drilling (see table 9).

Water level: Before perforating, 95 ft.

After perforating, 95 ft.

Yield: Final test on February 6, 1957, pumped 440 gpm, drawdown was 20 ft; pumped 590 gpm, drawdown was 45 ft. Specific capacity thus was 13 and 22 gpm per foot of drawdown at the two rates.

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