UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GROUND-WATER RESOURCES OF THE HOLLOMAN AIR FORCE BASE WELL-FIELD AREA, 1967, NEW MEXICO

with a section on geophysical exploration

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GROUND-WATER RESOURCES OF THE HOLLOMAN AIR FORCE BASE WELL-FIELD AREA, 1967, NEW MEXICO

By W. C. Ballance

Abstract

Water consumption at Holloman Air Force Base (HAFB) reached an all time high in 1964 and 1965. Further increases in withdrawal without expansion of pumping facilities will hasten the chemical deterioration of the ground water pumped from the well fields.

Saline water in the well-field area is present both on the north and west sides of the potable-water area and in a thin shallow zone that overlies the potable-water sands in part of the potable-water area. The latter source is affecting quality of the water produced from most wells.

Geophysical exploration in 1965 indicates a greater saturated thickness of the aquifer than heretofore realized. The saturated thickness of material underlying the Boles well field ranges from about 3,500 feet in the western part of the field to about 1,200 feet in the eastern part of the field. Only about 300 feet of aquifer has been explored in this area. In the Douglass and San Andres well fields, the saturated thickness ranges from 3,500 feet to about 300 feet. Only about 300 feet of aquifer has been explored in the Douglass field. Two wells were drilled in 1965-66 to a depth of 2,000 feet in the San Andres well field. One well in the eastern part of the field was completed as a production well to a depth of 1,200 feet; the other well was completed as a production well to a depth of about 900 feet in the west side of the field. Water quality from these wells is comparable to water quality from the remainder of the San Andres well field and the Douglass well field.

Expansion of the boles and San Andres well fields to the east and southeast would move the center of pumping away from the highly saline water to the north and west. This would eliminate overpumping of the present wells that has resulted from the expanded facilities at Holloman Air Force Base.

Future construction of production wells should be such that the shallow zones of less desirable water would be excluded from the deeper more desirable water.

Introduction

Holloman Air Force Base (HAFB) is in the Tularosa Basin, in the northwest-central part of Otero County, New Mexico. Alamogordo is about 7 miles northeast and the HAFB well-field area is about 8 miles southeast of HAFB. Figure 1 shows HAFB and the well-field areas.

HAFB was first operational as a training base during World War II. Since then it has become a research and development center. Research activity has continued to increase and this has resulted in an increase in housing for Air Force personnel. The water requirement has grown with the increase in activity.

The source of HAFB water supply is partly from Bonito Reservoir on the eastern slope of the Sierra Blanca Mountains, a road distance of nearly 90 miles northeast of HAFB, partly from well fields of the City of Alamogordo, and from the well fields of HAFB. The Bonito Reservoir is small, and its yield is being taxed by other users. The City of Alamogordo is a growing city which at times requires all the water available from the Bonito Reservoir and from its own wells for its own use.

The Boles and San Andres well fields are owned and operated by the Air Force. The Boles well field contains 11 production wells. The capacity of these wells is small, ranging from 100 to 300 gpm (gallons per minute). In recent years several wells in the Boles well field have not been used because of their sand, low yield, poor quality water, or because of sand-pumping problems.

The San Andres well field is being developed. The first well was drilled in 1964 and the field now has four wells whose yields range from 500 to 1,000 gpm. It is adjacent to the Douglass well field and the water quality is about the same in both fields.

The Douglass well field is privately owned and water is purchased from the owner, Mrs. Douglass. The field, however, is maintained and operated by the Air Force. It consists of six production wells whose yields range from 300 to 700 gpm.

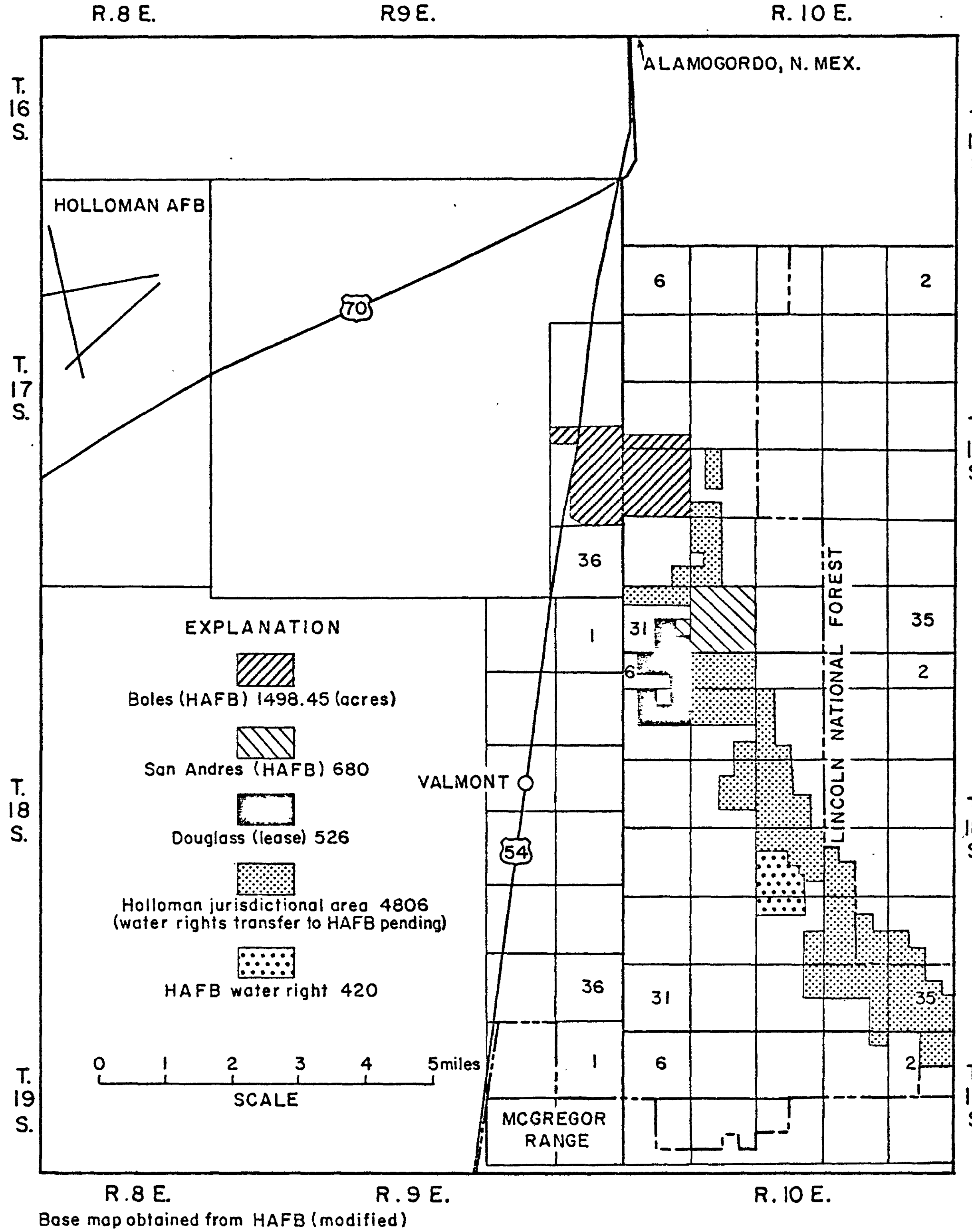

Figure 1.--Location and acreage of well fields and established and pending water-rights lands of Holloman Air Force Base, Otero County, New Mexico.

Favorable areas for exploration for ground-water supplies exist along the base of the western slopes of the Sacramento Mountains. Much of this area is in the public domain and is in the vicinity of the HAFB well fields. A request has been made by the Air Force to have the water rights to this land placed under their control. This property will be referred to in this report as HJA (Holloman Jurisdiction real-estate area).

Water rights to 420 acres south of the well-field areas are owned by HAFB. The water quality of a sample from a well in the vicinity of the water right indicates that the water is of satisfactory quality and that the area may be favorable for development of ground-water supplies.

Purpose and scope

In order to plan for a dependable supply of potable water for the future, it seems desirable first to appraise the ground-water supply in the well-field areas of HAFB.

The objectives of the investigation were to (1) assemble all quantitative and qualitative data on the well-field areas of HAFB; (2) analyze such data in order to determine the amount of potable water underlying the well-field areas, and other areas for which data are available, favorable locations and spacing of future wells, future effects of pumping on ground-water levels and saline-water encroachment, either vertically or horizontally, or both; (3) present obtainable facts and conclusions obtained from the assembled data with recommendations to aid in the formulation of plans for future exploration and development of the ground-water resources of the area.

Well-numbering system

The system of numbering wells used in this report is that used by the Geological Survey in New Mexico and is based on the common subdivisions in sectionized land. By means of it the well number, in addition to designating the well, locates its position to the nearest 10-acre tract in the land net. The number is divided by periods into four segments. The first segment denotes the township south of the New Mexico base line; the second denotes the range east of the New Mexico principal meridian; and the third denotes the section.

The fourth segment of the number, which consists of three digits, denotes the particular 10-acre tract in which the well is situated. For this purpose, the section is divided into four quarters, numbered 1, 2, 3, and 4, in the normal reading order, for the northwest, northeast, southwest, and southeast quarters, respectively. The first digit of the fourth segment gives the quarter section, which is a tract of 160 acres. Similarly, the quarter section is divided into four 40-acre tracts numbered in the same manner, and the second digit denotes the 40-acre tract. Finally, the 40-acre tract is divided into four 10-acre tracts, and the third digit denotes the 10-acre tract. Thus, well 17.9.24.342 at the Boles well field is in the NE¼SE¼SW¼ sec. 24, T.17 S., R.9 E., as shown in figure 2. If a well cannot be located accurately within a 10-acre tract, a zero is used as the third digit, and if it cannot be located accurately within a 40-acre tract, zeros are used for both the second and third digits. If the well cannot be located more closely than the section, the fourth segment of the well number is omitted. When it becomes possible to locate more accurately a well in whose number zeros have been used, the proper digit or digits are substituted for the zeros. Letters a,b,c,...are added to the last segment to designate the second, third, fourth, and succeeding wells in the same 10-acre tract.

Previous investigations

In 1954-55, ground-water resources in the vicinity of HAFB were studied by the U.S. Geological Survey (Hood, 1958). The report described the geology and ground-water resources of the area, with special emphasis on the area adjacent to and west of the Sacramento Mountains south of Alamogordo in the vicinity of the HAFB Boles well field.

A continuing observation of ground-water levels in a part of the Tularosa Basin by the Geological Survey in cooperation with the New Mexico State Engineer has been carried on for several years. These observations provided significant data on ground-water levels in the HAFB area.

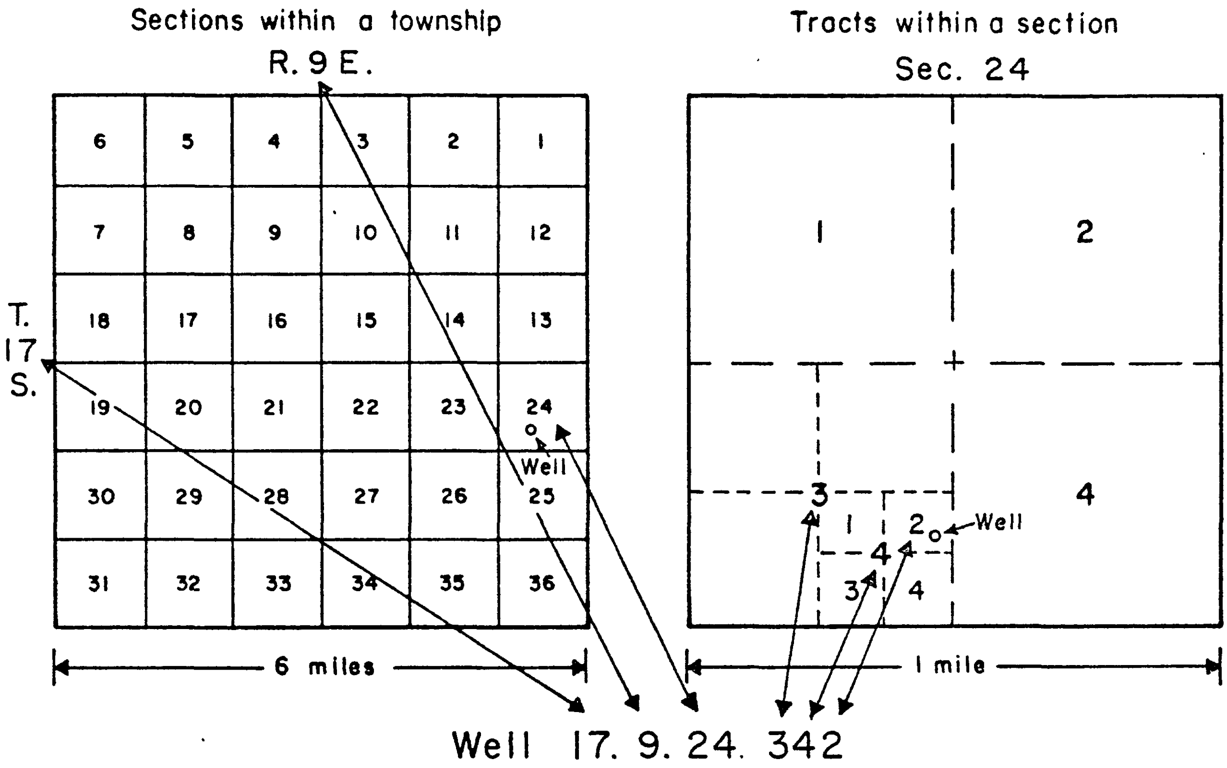

Figure 2.--System of numbering wells in New Mexico.

Methods of investigation

A program of periodic water-level measurements was begun in August 1965 to determine the seasonal fluctuation of the water table in the Boles, San Andres, and Douglass well fields. In January 1966, water levels were measured in the vicinity of the well fields to determine the long-term change in the water table. This information was used to construct a 10-year water-level change map, a water-table altitude map, and a depth-to-water map. Water samples were collected from wells outside the well-field area and analyzed. These chemical analyses along with the periodic anlayses of water in the well fields, sampled by HAFB personnel and analyzed by U.S. Geological Survey, were used to determine changes in water quality.

A geophysical survey was conducted in January and February 1966 to determine the configuration of the bedrock surface. This information was used to determine the saturated thickness of the bolson deposits.

Controlled pumping tests were conducted in the Boles, San Andres, and Douglass well fields to determine aquifer characteristics.

Two test wells were drilled to 2,000 feet each in the San Andres well field. One of these wells, San Andres 3, is located on the western side of the San Andres well field, north and east of the Douglass well field. The other well, San Andres 4, is located 0.75 mile east of San Andres 3 in the eastern part of the San Andres well field.

Samples of the bolson fill were obtained at intervals of 5 feet during the drilling of these wells. The samples were examined and described with regard to rock type, mineral content, physical characteristics and color. The test holes were electrically logged to obtain information on water quality, rock type penetrated, and permeability, and for correlation purposes with the descriptive log of samples.

Geology

The sedimentary rocks that comprise the bolson deposits of the areas discussed in this report are the most important rocks with regard to the occurrence of ground water. Hood (1958) discussed the geology of the area; the reader is referred to that report for details.

Hydrologic characteristics of the bolson fill

The principles governing the occurrence of ground water are discussed by Meinzer (1923 a, b); the reader is referred to that report for a detailed discussion of the subject.

The bolson deposits in the well-field area of HAFB consist of gravel, sand, silt, and clay. The proportions of each of these constituents to the whole vary considerably within short distances. Ground water in this varied mixture of sediments occupies the space between the particles. The percent, by volume, of the open space in a material is referred to as porosity. The porosity of the bolson deposits such as found in the Tularosa Basin, ranges from a few percent in poorly sorted material to 50 percent or more in beds of clay. The porosity of well sorted gravel rarely exceeds 30 percent. Although the openings will be filled with water within the zone of saturation, not all the water can be removed. A certain amount of water is retained by molecular attraction against the force of gravity as a thin film around each grain. In fine-grained material such as clay, nearly all the water may be retained when the material is subject to gravity drainage.

The specific yield of an aquifer is defined as the ratio of the volume of water that a saturated aquifer ultimately will yield by gravity to the volume of the aquifer. The specific yield can also be stated as the porosity less the specific retention, each expressed as a percentage. Specific retention of the material is the volume of water retained, expressed as a ratio or percentage of the total volume of the material. The specific yield plus the specific retention is equal to the porosity. Thus, for example (not necessarily in the Holloman area), if 1,000 cubic feet of saturated sediments will yield 100 cubic feet of water and retain 150 cubic feet, when drained by gravity, the specific yield is 10 percent, the specific retention is 15 percent, and the porosity is 25 percent.

The coefficient of storage of an aquifer is defined as the volume of water released from or taken into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface (Ferris and Knowles, 1955, p. 5), and it is an index of the amount of water available from storage in the aquifer.

When the upper surface of the zone of saturation is permeable rock or soil, the water is said to be under water-table conditions. Ground water in the well-field areas for the most part is under water-table conditions.

An estimate of the coefficient of storage of the aquifer underlying the Boles well-field area was calculated by Hood (1958, p. 72) to be about 8 percent.

The coefficient of storage of the aquifer underlying the Douglass and the western portion of the San Andres well field was computed by utilizing measurements of water level and the volume of water pumped. A water-level decline map was constructed using reported water-level measurements for 1953-55 and measured water levels for February 1966 (fig. 3). From this map the volume of aquifer drained as a result of the water-level decline was computed. The volume of water pumped from the area during this period is shown in table 1. The coefficient of storage is then calculated by dividing the volume of water pumped by the volume of aquifer drained. The coefficient of storage obtained by this method is 9 percent. This is not an absolute value, but an estimate used for computing the effects of future pumping in the well fields.

The coefficient of storage in the eastern part of the San Andres well field was estimated to be 12 percent. This estimate was based on comparison of drill samples from the aquifer underlying the area with samples of material from the Douglass well-field area. The aquifer underlying the eastern San Andres field contains very little clay and considerable well-sorted coarse sand and gravel. On the other hand, the aquifer underlying the Douglass and western part of the San Andres well fields contains predominately fine-grained material with considerable clay.

The capacity of a water-bearing material to transmit water under a head differential depends upon the thickness and permeability of the material. The permeability varies with the size, shape, and number of void spaces and their degree of interconnection. The coefficient of permeability used in this report is called the field coefficient of permeability and is defined as the number of gallons of water per day that percolates, under prevailing conditions, through each mile of water-bearing bed (measured at right angles to the direction of flow) for each foot of thickness of the bed for each foot per mile of hydraulic gradient (Wenzel, 1942, p. 7-11). The coefficient of transmissibility may be expressed as the number of gallons per day, under prevailing conditions, that is transmitted through each mile strip of the aquifer under a hydraulic gradient of 1 foot to the mile; hence, it is the average field coefficient of permeability, as defined above, multiplied by the saturated thickness of the aquifer in feet.

The apparent coefficient of transmissibility of the water-bearing materials in the bolson deposits was determined at seven wells in the Douglass and San Andres well fields by measuring the drawdown and recovery of water levels during and after pumping at measured rates and using the Theis recovery formula as described by Ferris and Knowles (1955, p. 31-32), and illustrated by Hood (1958, p. 62-69).

The highest transmissibility determined was about 150,000 gpd/ft (gallons per day per foot) in San Andres well 4 in the eastern part of the San Andres well field. This well is drilled in coarse fan deposits of boulders, gravel, and sand that extend outward from San Andres Canyon on the west slope of the Sacramento Mountains. Coefficients of between 9,000 and 28,000 gpd/ft were determined at wells in the Douglass and western part of the San Andres well fields and coefficients between 1,500 and 20,000 gpd/ft were determined in the Boles well field. The material penetrated by these wells was somewhat similar. Both areas are downslope from the fan deposits from the mountain and are underlain by considerable clay and silt. However, the aquifer penetrated by wells in the Douglass and western portion of the San Andres fields, averaged about 500 feet in thickness, and contained more and better sorted gravels and sands than the wells in the Boles well field which average about 250 feet in depth and penetrated mostly clay and silt and some sand and gravel.

Ground water moves in response to the force of gravity in the direction of least resistance. The quantity of water flowing through water-bearing materials is directly proportional to the permeability of the water-bearing materials (P), the slope of the water table (I), and the area of the cross section through which it flows (A). This quantity (Q) is expressed in accordance with Darcy's law: $Q = PIA$. The average velocity (V) of water moving through water-bearing materials is directly proportional to the slope of the water table and to the permeability of the materials, but it is inversely proportional to the porosity (p) of the material. It is expressed by the formula $V = \frac{PI}{p}$. The determination of actual rate of movement of ground water is of importance mostly in problems of contamination. Under natural conditions in the HAFB well-field areas, ground water moves through the bolson deposits at average rates of less than 1 foot per day, although the rate of movement may be greater or much less in particular zones within the aquifer when the permeability is high or exceptionally low. Near pumped wells the rate of movement toward the well is considerably increased.

Water consumption at Holloman Air Force Base

Table 1 lists the yearly water consumption at HAFB from 1943 through 1965. The contents of this table were supplied by Mr. Chris Gallegos, Civil Engineer, Holloman Air Force Base.

The total potable water supply for HAFB was supplied by the city of Alamogordo from 1943 through 1946. In 1947 a pipeline was constructed from the Boles well field and about one-third (20 million gallons) of the total water required for the year was supplied from this source. However, as the water requirement at HAFB increased, more wells were drilled in the Boles well field and a larger percent of the total water supply was obtained from the field.

Table 1.--Total yearly water consumption (in gallons) from 1943 through 1965 at Holloman Air Force Base, Otero County, New Mexico

Year	City of Alamogordo	Boles well field	San Andres well field	Douglass well field	Yearly total
1943	164,829,975	0	0	0	164,829,975
1944	168,257,316	0	0	0	168,257,316
1945	158,123,000	0	0	0	158,123,000
1946	41,474,942	0	0	0	41,474,942
1947	38,818,086	19,810,569	0	0	58,628,655
1948	4,855,742	88,669,481	0	0	93,525,223
1949	74,424,805	56,113,027	0	0	130,537,832
1950	142,355,410	26,520,000	0	0	168,875,410
1951	110,811,640	95,337,000	0	0	206,148,640
1952	100,901,473	135,859,891	0	0	236,761,364
1953	113,696,121	200,700,000	0	0	314,396,121
1954	172,223,662	139,989,000	0	0	312,212,662
1955	142,947,573	244,550,000	0	0	387,497,573
1956	62,996,862	319,375,000	0	0	382,341,862
1957	297,717,799*	132,732,000	0	0	412,450,000
1958	485,197,000*	8,781,000	0	0	493,978,000
1959	530,721,000*	755,000	0	0	531,476,000
1960	541,148,000*	68,386,000	0	0	609,534,000
1961	298,534,000*	361,114,000	0	31,244,000	690,892,000
1962	457,016,000*	198,765,000	0	36,620,000	692,401,000
1963	457,784,000*	205,948,000	45,562,000	73,665,000	782,959,000
1964	239,939,000*	265,446,000	122,769,000	351,374,391	979,528,391
1965	365,509,800*	117,739,000	122,323,000	300,303,700	905,875,500

*Includes water from Bonito Reservoir.

In 1957, a pipeline was completed from the Bonito Reservoir to Alamogordo and the Base. HAFB's share of the water from the reservoir is about 1.1 mgd (million gallons per day). However, the actual amount of water received from the reservoir by the Base and the other users is dependent on the amount of water available in the reservoir, which in turn is dependent upon the precipitation on the watershed. During years of below-normal precipitation, the amount of water available is not sufficient for all users. Thus, water from the Bonito Reservoir cannot be depended upon from year to year.

During the 10-year period, 1956-65 Alamogordo and the Bonito Reservoir supplied about 3,725 million gallons of water, or an average of 1,020,000 gpd (gallons per day) to HAFB. The well fields (Boles, San Andres, and Douglass) supplied a total of 2,763 million gallons or about 757,000 gpd for the same period. This amounts to a total average of 1,777,000 gpd used by the Base for the 10-year period.

The water requirement has increased from an average of 1,041,300 gpd in 1956 to 2,479,5200 gpd in 1965. This is shown on figure 4 which is a graph of the average daily water use by years at HAFB from 1956 to 1966 and predicted daily water consumption for both peacetime and emergency conditions through 1975. The graph also gives the population trend of the Base from 1953 to 1966 and the average daily per-capita use by years.

If these peacetime averages continue, the average daily water use in 1975 will be about 4 mgd or about 4,500 acre-feet per year, an increase of 1.5 mgd over the average daily water use for 1965. If a national emergency should occur, then the increase in demand for water would probably be on the order of 6.5 mgd, or possibly more.

In 1965 the City of Alamogordo and the Bonito Reservoir supplied an average of 1 mgd and the well fields of HAFB supplied 1.5 mgd.

The growth of HAFB will have a corresponding effect on the population of Alamogordo. The water requirements of Alamogordo may become so great that the limited potable-water supplies of the city may be insufficient to provide for even partial needs of HAFB, or few years of drought in the watershed of Bonito Reservoir could cause a serious water shortage for both Alamogordo and HAFB. If so, then the Base would be required to furnish its total supply of about 4,500 acre-feet annually, under normal-growth peacetime conditions, and about 7,300 acre-feet under emergency conditions, by 1975.

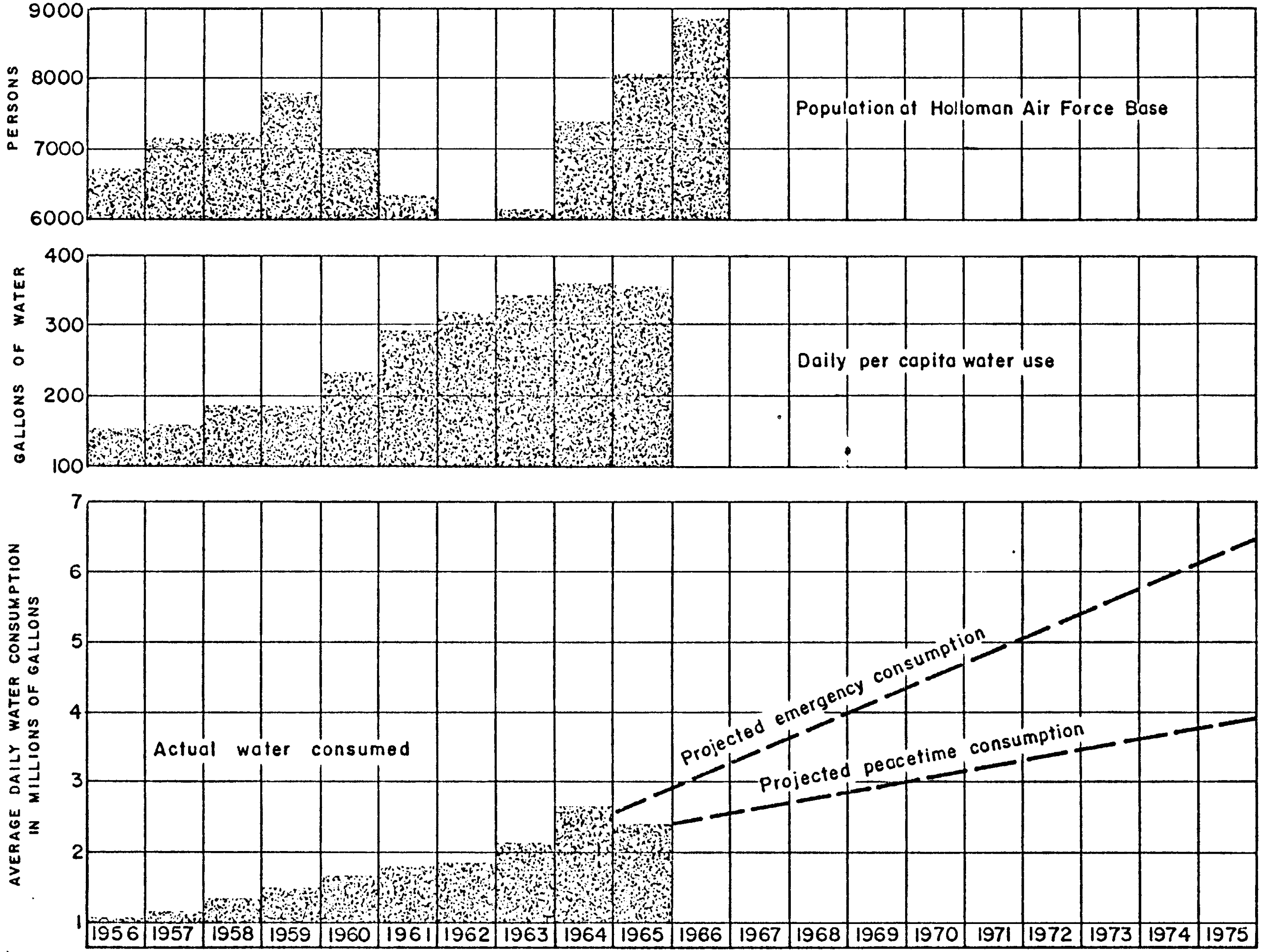

Figure 4.--Population, daily per-capita water use, and actual and projected water requirements at Holloman Air Force Base, Otero County, New Mexico.

Boles well field

The Boles well field, outlined in figure 1, comprises 1,498 acres. The first wells drilled in the area were privately owned and were for small scale domestic and irrigaiton uses. The Air Force became interested in the area and in 1947 drilled two production wells, installed a pipeline from the field to the base, and began to produce water for HAFB consumption. In 1965 there were 10 production wells in operation in the field. Table 2 shows the capacity and the depth of the wells in the Boles field and table 1 shows by years the water produced from the field, and from other sources.

Forty-four wells have been drilled in the Boles well-field area. Ten of these were test wells and 34 were production wells. All but 10 of the production wells have been abandoned for various reasons. Most of the wells were drilled to a depth of no more than 300 feet. Hood (1958) states that data from test wells drilled in the area in 1954 indicate that the water-bearing sands in most parts of the Boles area are divided vertically into at least two zones: a deep, thick zone containing water of good or fair quality; and a shallow, relatively thin zone containing water of fair to very poor quality. All production wells in the Boles well field produce from both zones, and the mixture of water from both zones is of acceptable quality. Although the zone of shallow mineralized water is of appreciable thickness, its effect upon the quality of water from wells in the area is significantly large only locally. For example, Boles well 10 is seldom used because of the high sulfate content of the water.

Potable water underlying the Boles well field

The saturated thickness of the proven potable water in the Boles well-field area is about 300 feet. The coefficient of storage of the saturated aquifer is about 8 percent. Therefore about 36,000 acre-feet (325,851 gallons per acre foot) of proven potable water underlie the 1,498 acres in the Boles well field. However, it should be realized that not all of this water can be removed and that the water under the field is in transit, moving southward through the field. This will be discussed more fully in a later section of the report.

Douglass and San Andres well fields

The Douglass and San Andres well fields are outlined in figure 1. The Douglass well field consists of 526 acres and is located in the southeastern part of sec. 31, T.17 S., R.10 E., the northeast and eastern parts of sec. 6 and the northeastern part of sec. 7, all in T.18 S., R.10 E.

Table 2.--Data on wells in the Boles well field, Holloman Air Force Base, Otero County, New Mexico

Boles well field

Well no.	Date drilled	Depth (feet)	Casing diameter (inches)	Yield in 1966 (gpm)
2	1947	215	10	280
5	1948	205	10	170
10	1948	261	10	150
15	1950	372	10	200
16	1952	217	10	100
17	1952	202	12, 10	270
26	1963	510	12	300
32	1953	205	10	120
33	1951	180	8	245
35	1955	200	10	260

The San Andres well field consists of 680 acres. Forty acres are located in the NE¼SE¼ of sec. 31 and the bulk in sec. 32, all in T.17 N., R.10 E.

The San Andres and Douglass well fields are discussed as one area because of the proximity of the two and the similarity of aquifer characteristics.

Ground water was first obtained from the privately-owned Douglass field by the Air Force in 1961 when about 95 acre-feet of water was pumped. The number of wells were increased from one in 1961 to six in 1965 when about 920 acre-feet were pumped for use at HAFB.

The San Andres well field is owned by the Air Force and was first used in 1963. About 140 acre-feet of water was pumped in 1963, and about 375 acre-feet in 1965.

The total amount of water pumped from the Douglass and San Andres well fields from 1961 through 1965 was about 3,230 acre-feet; about 2,750 acre-feet of this was pumped in the period 1964 to 1965. Thus an average amount of about 1.2 million gallons of water was pumped daily from the San Andres and Douglass well fields during the latter two-year period.

Table 3 gives the yield and other data for the wells in the Douglass and San Andres fields.

Potable water underlying the Douglass and San Andres well fields

The Douglass (526 acres) and the western part of the San Andres (200 acres) well fields are underlain by a known saturated thickness of potable water of about 700 feet, as shown by tests made in San Andres well 3 that was completed in February 1966. This represents about 500,000 acre-feet of saturated sediment, which, with an estimated coefficient of storage of about 9 percent, contains about 45,000 acre-feet of potable water.

In July 1966, San Andres well 4 was completed in the eastern part of the San Andres well field in the approximate center of the eastern half of sec. 32, T.17 S., R.10 E. Chemical analysis of drill-stem water samples collected during the construction of this well indicates that potable water extends to a depth of 1,245 feet at this location. This is a saturated thickness of about 800 feet. More highly mineralized water was found in the interval 1,624 to 1,842 feet.

Table 3.--Data on wells in the Douglass and San Andres well fields, Holloman Air Force Base, Otero County, New Mexico

Well no.	Date drilled	Depth (feet)	Casing diameter (inches)	Yield in 1966 (gpm)
		Douglass well field		
1	1961	300	12	200
2	1962	315	12	500
4	1962	295	12	350
5	1963	306	12	250
6	1963	305	12	350
7	1964	495	10, 12	700
		San Andres well field		
1	1963	370	12	500
2	1964	510	12	500
3	1966	980	16	1,000
4	1966	1,200	14, 12, 6	1/

1/ Well is presently used as an observation well. However, a pumping test revealed that the yield of the well is in excess of 1,000 gpm.

Samples of drill cuttings from the well and an aquifer test indicate that the aquifer is more permeable and has greater porosity than does the aquifer in the western part of the San Andres field and in the Douglass field. Before a definite figure on storage can be obtained, more exploration is necessary in this locality; however, in comparison with the estimated figure of 9 percent calculated for the western portion of the field, a coefficient of storage of about 12 to 15 percent would seem to be reasonable. If the estimated value of 12 percent for storage is used, then about 46,000 acre-feet of potable water underlies the eastern three quarters of section 32.

Ground-water levels

The flow of ground water under natural conditions is in a state of approximate equilibrium. Over a long period of time the average recharge is equal to the average discharge of the body of ground water, and the water table generally remains in a near-static condition. If recharge exceeds discharge, the water table rises; if discharge exceeds recharge, the water table declines. The pumping of wells causes discharge to exceed recharge at least for a period of time, with consequent lowering of water levels and a reduction in the amount of water stored in the aquifer. Continued records of water-level fluctuations in wells indicate whether the water table is declining and whether ground-water supplies in the area are being reduced, and if so, at what rate.

In February 1966, water levels were measured in the Boles and Douglass well fields, and vicinity, in the same wells that were measured in 1953, 1954, and 1955. In addition, water levels were measured in most of the wells drilled in the area since 1955. These data were used to construct a water-level change map (fig. 3) from 1953-55 to 1966. This map indicates the area where ground water was taken from storage.

The measurements of the ground-water levels made in February 1966 were converted to ground-water level altitudes by subtracting the depth of water for each well from the altitude of the land surface at the well. The altitude of the water surface was then plotted at the respective well locations and a water-level contour map (fig. 3) was constructed.

Accurate records of water levels in the well-field areas are few for the period 1955 to 1965. However, four wells in the Boles well field were measured seasonally by the U.S. Geological Survey (fig. 5). These measurements show considerable fluctuation of the water level from 1954 to January 1966. From 1958-1960, pumpage from the field was reduced considerably and water levels rose higher in all wells for which water levels are shown. However, starting in 1960 the pumping rate was greatly increased in the Boles field and between 1960 and 1966 the greatest decline of record occurred. Table 4 is a record of water levels in other observation wells in the vicinity of Holloman Air Force Base. The decline in water levels for the period of record ranges from 3 to 8 feet. Prior to 1954, water levels were reported to be much higher.

After 1960, a trend of water-level declines is indicated (fig. 5). The water-level decline was about the same in the 4 wells measured, as shown below:

Well no.	Date	Water level (feet below land surface)	Date	Water Level (feet below land surface)	Decline 1960-66 (feet)
17. 9.24.343	Apr. 1960	61.42	Feb. 1966	68.50	7.08
17.10.18.432	Jan. 1960	101.67	Feb. 1966	108.59	6.92
17.10.19.321a	Jan. 1960	77.05	Feb. 1966	82.99	5.94
17.10.19.323	Jan. 1960	75.71	Feb. 1966	81.39	5.68

The decline in water levels reflects the withdrawal of water from storage between 1960 and 1966 in the Boles well field; pumpage for this period was 1,217 million gallons.

These declines do not represent the maximum declines in the well field as the observation wells are on the fringe of the well field. The maximum declines are at the center of pumping in the field.

Accurate water-level records have not been maintained in the San Andres and Douglass well fields. However, the water levels for most of the wells in these areas were noted when the wells were drilled. These data indicate that water-level declines since 1961 range from 23 feet near the center of the area to 15 feet at a distance of about one and a quarter miles.

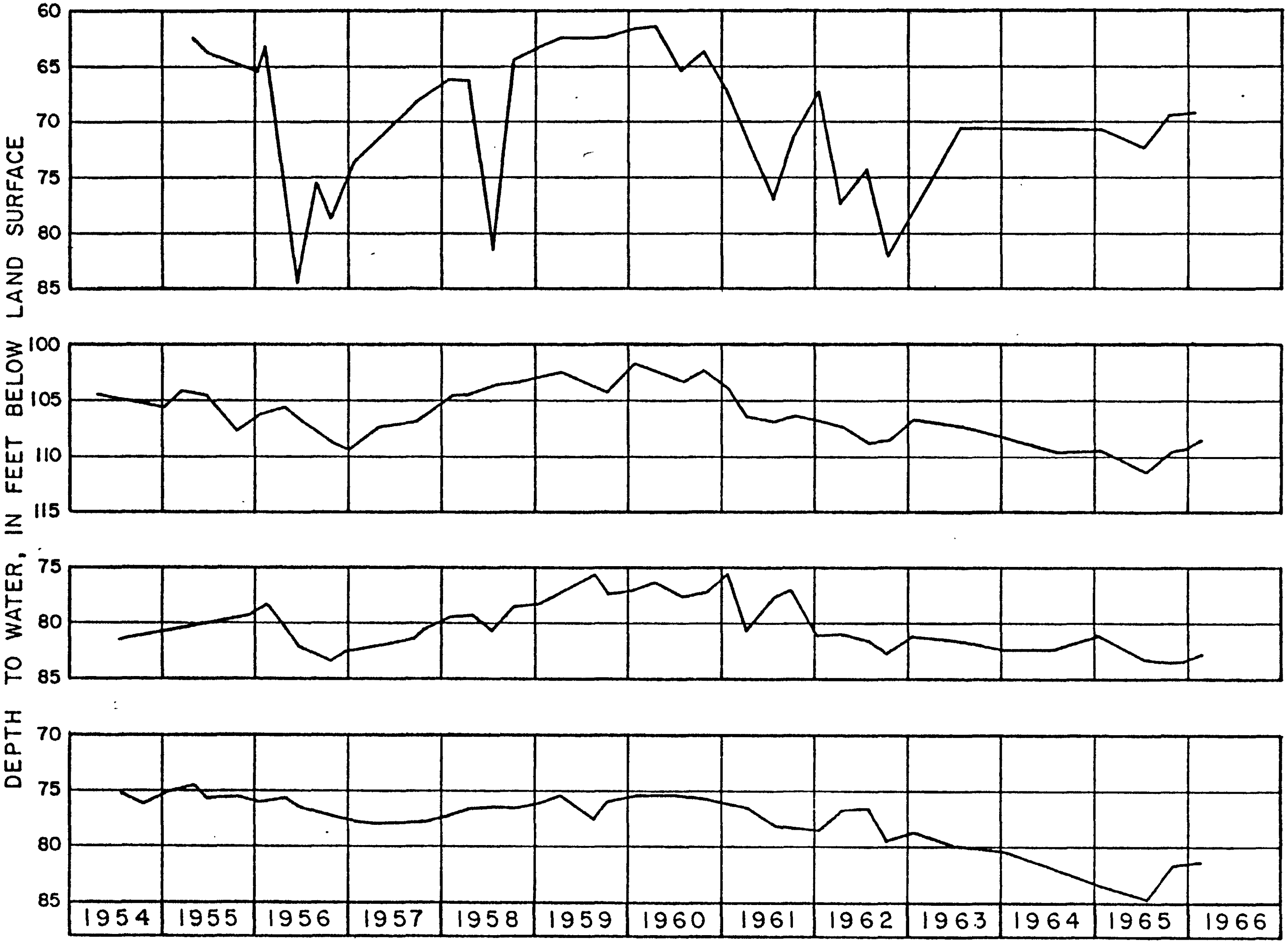

Figure 5.--Change in ground-water levels in four wells in the Boles well-field area, 1954-January 1966, Holloman Air Force Base, Otero County, New Mexico.

Recharge

The principal source of recharge to the aquifer is precipitation in the adjacent Sacramento Mountains and consequent floodflows from the mountain canyons. According to the U.S. Weather Bureau records, Alamogordo received an average of 10.09 inches of precipitation annually during the 12-year period 1954-65. Mountain Park, about 9 miles northeast of Alamogordo, during the same period received an average of 18.64 inches annually; and Cloudcroft, about 15 miles northeast of Alamogordo received an average of 26.06 inches of precipitation annually.

The water table in the vicinity of the well-field areas slopes away from the mountains, indicating some recharge to the bolson fill at the base of the mountains. The material at the entrance to the canyons is more coarse grained than the material found downslope where the land surface is comparatively flat. The streams issuing from the canyons are intermittent; however, at times they transport large amounts of water which result from the infrequent thunderstorms in the area. It is doubtful if a high percent of the water flowing over the more permeable areas near the mountain front reaches the water table; more likely most of the fast-moving water flows out into the basin and is lost to evaporation and transpiration.

The surface of the bolson fill in the vicinity of the Boles well field consists of an adobe-like clay. The land surface farther south in the vicinity of the San Andres and Douglass well fields consists of sand and gravel in a matrix of dense clay. Water falling on these areas probably would not penetrate to the water table but would dissipate by evaporation and transpiration from vegetation.

During the spring and summer of 1966 several pumping tests were conducted in the San Andres well field. The rate of pumping ranged from 750 to 1,200 gpm and the duration of the pumping was from 24 to 32 hours. After the tests were concluded the pumped water remained in small ponds for as long as 24 hours or more and in some places for several days until it evaporated.

The amount of recharge in an area may be estimated by computing the amount of water flowing through a cross section of the area. In the vicinity of the Boles well-field area the average transmissibility of the aquifer has been estimated from pumping tests to be about 8,000 gpd/ft. The slope of the water table is about 40 feet per mile. The width of the well field parallel to the water-table contours is about 2 miles. Thus, the quantity of water flowing through a cross section of this part of the Boles well field is approximately 8,000 x 40 x 2 = 640,000 gpd or about 700 acre-feet per year.

The slope of the water table in the San Andres and Douglass well fields is about 25 feet per mile. The average transmissibility of the aquifer is estimated to be about 10,000 gpd/ft. The width of the area is about 2 miles. The quantity of water flowing through a cross section of the San Andres and Douglass well fields is approximately 10,000 x 25 x 2 = 500,000 gpd or about 600 acre-feet per year.

Artificial recharge, using floodwater from the canyons of the Sacramento Mountains, may be feasible. The watershed of Mule Canyon and of those canyons south to, and including San Andres Canyon, contain more than 15 square miles. The altitude of the watershed ranges from about 4,500 feet at the base of the Sacramento Mountains to about 9,000 feet along its eastern side. The average annual precipitation ranges from more than 10 inches at the lower altitude to more than 20 inches at the upper altitude. An average of 15 inches over the entire area probably would be a conservative estimate of the average annual precipitation. If it is assumed that 50 percent is lost directly to evaporation, transpiration, and percolation, then 50 percent is runoff, nearly all of which in turn is lost to the atmosphere. Fifty percent of 15 inches of precipitation on 15 square miles is about 5,000 acre-feet of water.

The well fields are adjacent to their recharge areas, at the base of the mountains. Any additional recharge would cause a rise in the ground-water surface. This rise in the ground-water surface would reduce the pumping lift in the well fields, and would create a buffer zone between the well fields and the less desirable water to the west by increasing the slope of the ground-water surface from the well fields westward.

Dams could be constructed at the mounth of the canyons east of the well fields. By thus restricting the floodwaters to the more permeable area adjacent to the exit of the canyons, a greater proportion of the floodwater would reach the ground-water body. Additional recharge wells supplied by water from the reservoirs might be constructed near well fields to recharge selected areas more effectively.

Chemical quality of ground water in the well-field areas

Table 5 lists the chemical analyses of ground water from the well-field areas from 1961 through 1966. Chemical analyses of ground water in the area prior to 1961 can be found in the report by Hood (1958).

The potability of ground water in the well-field areas generally can be identified by the sulfate and the dissolved-solids content. Constituents such as chloride and other elements commonly are not in sufficient concentration to be of concern. The U.S. Department of Health, Education, and Welfare (1962) recommends that sulfate, and dissolved solids should not be present in a water supply in excess of 250 and 500 ppm (parts per million), respectively, providing that in the judgment of the reporting agency and the certifying authority, other more suitable supplies are or can be made available.

The sulfate content of water produced from the Boles well field is generally below the maximum recommended limit and the dissolved-solids content is generally slightly higher than the maximum recommended limit.

Figure 6 indicates the sulfate content of ground water in the well-field area. This map for the most part is based on information obtained by Hood (1958) but changes have been made in lines showing equal sulfate concentration in some areas where Hood had little or no data. In parts of the area where data were available, recent information on the quality of water indicate little change.

Boles well field

The water quality in most wells in the Boles well field is of better quality than water in the San Andres or Douglass well fields.

Hood (1958), in his study of the Boles well-field area, found two zones of water, each of different quality, one shallow zone of highly mineralized water and a deeper zone of water of better quality. Hood explains that the source of the shallow minerzlized water is local recharge from runoff not absorbed at the edge of the mountains. This recharge percolates downward through soluble playa deposits, dissolving and carrying to the water table a large amount of mineral matter. Farther downward movement of this water is halted by deeper stratas of silt and clay. However, the silt and clay are not perfect aquicludes, and when the hydrostatic pressure beneath them declines, the shallow mineralized water eventually drains downward into the underlying sands.

Most wells in the Boles well field produce water with a sulfate content of less than 300 ppm. The quality of water in these wells has not deteriorated appreciably during the 6-year period for which chemical analysis are tabulated. However, the sulfate content of water from Boles wells 5 and 10 is considerably higher. These were mentioned by Hood as wells which produce more highly mineralized water than do wells in the remainder of the field. The sulfate content in wells 5 and 10 increased from 359 ppm and 346 ppm, respectively, in 1961 to 482 ppm and 407 ppm, respectively, in 1966. These two wells, together, yield approximately 322 gpm.

San Andres and Douglass well fields

San Andres well 2 in the San Andres well field was drilled in 1964 to a depth of 510 feet and was the second of two wells drilled in the field up until that time. The sulfate content of water from the well when drilled was 342 ppm. In March and September of 1966 samples from San Andres well 2 indicated a sulfate content of 514 and 453 ppm, respectively.

The two wells in the San Andres field are pumped at approximately 500 gpm each, and in 1965 yielded an average of 334,000 gpd, more than all the wells in the Boles well field combined. Probably San Andres well 2 pumped more water than San Andres well 1. These wells are about 1,000 feet apart and their radius of influence in regard to water-level decline overlap.

The information on quality of water in the vicinity of San Andres well 2 indicates that the increased mineralization of the water in the well is caused by the downward draining of poor-quality water from an overlying shallow zone. It is doubtful that this contamination is caused by horizontal movement of the known saline water from the west of the field. Probably a shallow zone of poor-quality water underlies the San Andres and Douglass fields with hydrologic conditions similar to those in the Boles well field.

Chemical analyses of water collected during drill-stem tests made in San Andres well 4 during the test-drilling period indicated the water between the interval 660-715 feet had a sulfate content of 493 ppm. A water sample from the interval 1,160-1,245 feet had a sulfate content of 240 ppm. The well was completed at a depth of about 1,200 feet. A sample of water collected from the well after pumping at the rate of 750 gpm for 24 hours had a sulfate content of 370 ppm. By averaging the sulfate content from the two drill-stem tests, 493 and 240 ppm, the result is 366 ppm, about the same as the composite sample after the 24-hour pumping test.

With the exception of San Andres well 2 discussed above, the wells in the San Andres and Douglass fields produce water with a sulfate content ranging from 276 ppm in Douglass well 4 to 370 ppm in San Andres well 4.

Effects of pumping on water levels

The effects of pumping on water levels can be estimated in an area if the quantity of water removed from storage and the hydrologic characteristics of the aquifer are known.

Theis (1935 pp. 519) developed a nonequilibrium formula by which the drawdown of water level at any time and any place can be computed. The formula is based on the following assumptions: (1) The water-bearing formation is homogeneous and isotropic, (2) the formation is of infinite areal extent, (3) the discharge well penetrates the entire thickness of the formation, (4) the coefficient of transmissibility is constant at all places and at all times, (5) the discharge well has an infinitesimal diameter, and (6) water taken from storage is discharged instantaneously with the decline in head.

Theis' formula is:

$$s = \frac{114.6\ Q}{T} \int_{\frac{1.87\ r^2\ S}{Tt}}^{\infty} \frac{e^{-u}}{u}\, du$$

in which: s = drawdown, in feet, at any point in the vicinity of a discharging well

Q = the rate of discharge of the well, in gallons per minute

T = coefficient of transmissibility, in gallons per day per foot

S = the storage coefficient

r = the distance from the discharging well, in feet

t = the time since pumping began, in days

e = the natural-logarithm base (2.71828)

$u = \frac{1.87\ r^2\ S}{Tt}$

It should be noted that T appears on both sides of the integral sign and, hence, a direct solution of the equation is not possible. However, the term under the integral sign is commonly represented by an abbreviation, "W(u)", so that:

$$s = \frac{114.6\ Q}{T} W(u) \qquad \text{or}$$

$$T = \frac{114.6\ Q}{s} W(u)$$

For every given numerical value of u there is a corresponding value for W(u). A table of values for the two variables has been published by Wenzel (1942, p. 88a).

Boles well field

Hood (1955, p. 74) predicted future water-level declines in the Boles well field and vicinity based on 1955 pumpage and predicted future pumpage. His predictions may have become a reality if pumpage continued as it appeared it would at that time. However, in 1957, the pipeline from Bonito Reservoir was completed and total withdrawal of ground water from the Boles well field decreased to less than 1 million gallons for the 3-year period, 1958-60. During this time water levels rose as much as 18 feet in the well field and as much as 7.5 feet outside the well field.

Pumpage from the Boles well field in 1961 rose to 361 million gallons and has fluctuated between about 120 and 265 million gallons per year through 1965. This pumpage has resulted in water-level declines, and declines will continue as pumping of such magnitude continues. Comparison data recorded in 1954 and 1966 indicate a water-level decline of about 10 feet over the entire field with the exception of well 34 on the western border of the field. The maximum decline recorded is about 18 feet in Boles well 28 which is used as an observation well. Larger declines may have occurred in the field during this period; however, records are nonexistent except for the four wells which were measured by the U.S. Geological Survey.

Table 6 is the computed ground-water-level decline in the Boles well-field area when pumping is at a continuous, constant rate. These estimates are theoretical and are based on certain necessary assumptions. In addition to the basic assumptions regarding the aquifer that are essential to the computations, a continuous pumping rate as given in table 6 has been used. The average yearly pumping rate in the Boles field from 1961-65 was about 224 million gallons, or about 610,000 gallons daily--a continuous pumping rate of about 425 gpm. Pumping rates of 600 and 1,000 gpm were also used in order to give the magnitude of ground-water-level decline should the pumping rate increase. Actually, the wells are pumped intermittently at a greater rate. However, continuous pumping at the lower rates would have about the same long-term effect as intermittent pumping at higher rates insofar as water-level trends are concerned.

The coefficient of transmissibility used for the Boles well-field area was an estimate of the transmissibility of the entire area and was based on the aquifer test conducted by Hood (1958, p. 60) and observations in the area in 1965. The average transmissibility for the area was estimated to be about 8,000 gpd/foot. A coefficient of storage of 0.085 was used in the computations.

The computed declines are based on assumptions that are not satisfied in full and they should not be considered exact values but within a factor of 0.5 of expected declines.

Table 6.--Estimated ground-water-level declines in the Boles well-field area when pumping at a constant rate, Holloman Air Force Base, Otero County, New Mexico

Distance from field center (miles)	Average rate of well-field pumping (gpm)	Estimated decline in feet		
		5 years	10 years	20 years
0.2	425	23.9	28.2	-
.2	600	33.8	39.9	-
.2	1,000	56.3	66.6	-
1.0	425	5.5	8.9	-
1.0	600	7.7	12.5	-
1.0	1,000	12.9	20.9	-
5.0	435	2.0	4.2	7.6
5.0	600	2.8	6.0	10.8
5.0	1,000	4.7	10.0	18.0

Douglass and San Andres well fields

Pumping of large quantities of ground water from the Douglass-San Andres well-field area began in 1961. Pumpgage increased from about 31 million gallons in 1961 to 474 million gallons in 1964 and 423 millions gallons in 1965.

Water-level declines resulting from this ground-water withdrawal are based on reported water-level measurements in the area when pumping began in the various wells. The greatest decline is 34 feet in Douglass well 1. A decline of at least 15 feet covers the entire area and extends out beyond the Taylor well which is about 1 1/4 miles NE of the center of the field. The water level in Mr. Taylor's well has declined 17.4 feet since 1955.

The average yearly pumping rate for the Douglass-San Andres well field for 1964 and 1965 was about 428 million gallons or about 1.17 million gallons daily. This amounts to a continuous pumping of about 800 gpm.

Table 7 is the computed ground-water-level decline in the Douglass-San Andres well-field area using various constant pumping rates.

A coefficient of transmissibility of 10,000 gpd/foot was used for computing the water-level declines. This was an estimate of the transmissibility of the entire area and was based on an aquifer test conducted in the well field in 1965 and 1966. The coefficient of storage used was 9 percent.

Encroachment of saline water

Two sources exist from which saline water can migrate to the production wells of HAFB as a result of pumping water from storage in the well-field areas. The largest source of saline water and the one which presents the greatest ultimate threat of contamination to the well fields (fig. 6) is to the north and west of the Boles well field and southwest of the San Andres and Douglass well fields. A secondary source is the shallow saline ground water in the well fields.

The shallow saline water is the most immediate problem. Adulteration from that source is evident in wells 5 and 10 in the Boles well field and in wells 2 and 4 in the San Andres well field. The change in quality of the water in the Boles well field is probably the result of downward migration of the shallow ground water through beds of slightly permeable silt and clay. If such is the case, little can be done to remedy the condition other than to stop pumping the wells.

Table 7.--Estimated ground-water-level declines in the Douglass-San Andres well-field areas when pumping at a constant rate, Holloman Air Force Base, Otero County, New Mexico

Distance from field center (miles)	Average rate of well-field pumping (gpm)	Estimated decline in feet		
		5 years	10 years	20 years
0.2	800	37.7	44.0	50.4
.2	1,000	47.2	55.1	63.0
1.0	800	10.2	15.9	23.1
1.0	1,000	12.7	19.9	29.0
5.0	800	-	1.2	7.9
5.0	1,000	-	1.5	9.9

Saline waters from the north and west may eventually move into the Boles well field. The time required for such encroachment of saline water will depend on the rapidity of the removal of ground water from storage in the well field. Measures which will retard the movement of saline water toward the well field are: reduction in pumpage in secs. 24 and 25, T.17 S., R.9 E.; locating new wells to the east and south; rotation of pumping among the wells so as to reduce large water-level declines; and artifically recharging the aquifer in the western part of the well field.

In January 1966 no evidence of saline-water encroachment into the Boles well field from the north or west was apparent; however, ground water containing 500 ppm or more of sulfate is present about half a mile west-northwest of Boles well 33 (fig. 6). Hood (1958, pl. 1) shows the shape of the water table in the well-field areas in January 1955. Figure 3 shows the shape of the water table in February 1966. A comparison of the two maps indicates that in 1966 the slope of the water table is southward, whereas in 1955 the slope of the water table was southwestward. Water-level decline in the well field has caused the water-table contour lines to shift northward in the vicinity of the Boles field, whereas the contour lines to the west and northwest have remained relatively static. The movement of the contour lines northward indicates a steepened water-table slope north of the field with a flattened slope to the south of the field. This steepened slope causes the movement of water in the aquifer to increase. Therefore the saline water north of the field is moving at a greater velocity toward the well field in 1966 than it was in 1955.

Saline water may eventually move into the Douglass and San Andres well fields. Water-level declines in the area has caused the 4,025 feet water-table contour line to shift about one mile to the north-east since 1955. The slope of the water table has not increased north of the field because of the flattening effect on the water table caused by pumping in the Boles well field.

In 1966 no evidence of saline-water encroachment into the Douglass or San Andres well field from the southwest was apparent. However, the slope of the water table to the southwest is extremely flat and continued decline of water levels in the Douglass and San Andres well fields will eventually reverse the slope of the water table. As pumping continues the slope of the water table will gradually curve southward and will then be from the southwest and south with the Douglass well field the focal point. Then the hydraulic gradient of the water table will cause saline water to move toward the well field from the southwest.

It would be desirable to know the location of the leading edge of this body of highly mineralized water prior to its movement into the well fields. Hood (1958, p. 77) suggested at least three quality-of-water observation wells at locations between the saline-water body and the well field with a schedule of semiannual water sampling established to monitor the quality of water in the wells. A program of accurate water-level measurements in the well-field area should also be maintained, on at least an annual basis, in order to have a continuing record of the direction and slope of the water table.

Exploration, location, and spacing of future wells

The location of real estate and water rights owned by HAFB, real estate pending transfer of ownership to HAFB, and real estate leased for water production is shown on figure 1. Figure 15 shows the depth to bedrock (approximate thickness of unconsolidated material) in these areas. Figure 7 shows the saturated thickness of materials underlying the area and figure 6 shows the approximate depth to water in the area. The information obtained thus far indicates that large quantitites of potable water may underlie the area adjacent to the Sacramento Mountains. Most of this area is unexplored with respect to the quality and quantity of water available; thus, test wells should be drilled prior to any planning for production wells and pipelines. The various areas that have a potential for water-supply development will be discussed separately in order of their importance for present and future exploration and development.

Boles well field

The Boles well field, which consists of 1,498 acres, is owned by HAFB. Exploration and development of ground-water supplies in this area began in 1947 and continued sporadically till June 1963 with the completion of production well 26a.

The average depth of the production wells now in operation in the field is about 255 feet. The deepest well is 510 feet and is located near the northeast corner of the field. The eastern part of the well field in sec. 19, T.17 S., R.10 E., has not been explored; however, figure 15 indicates that the thickness of unconsolidated material in this area ranges from about 2,500 feet near the center to about 1,500 feet at the eastern side. The saturated thickness of materials underlying this part of the well field averages more than 1,500 feet (fig. 7). The sulfate content of water (fig. 6) on the eastern side of the field is less than the sulfate content of the water farther west in the field. Exploration and development of the eastern side of the field to a minimum depth of 1,000 feet should take priority over the exploration and development of other areas because of the greater probability of potable water, HAFB ownership, and proximity of existing pipelines. Test wells to determine the quality of water and amount of water available should be drilled prior to the planning of production wells in this area. If the results of the test wells are favorable, then four large-diameter high-capacity production wells could be planned for and constructed along the eastern border of section 19, with a quarter of a mile spacing between wells. Suggested locations and spacings of these wells are shown on figure 15 (numbers 1, 2, 3, and 4). If successful wells are drilled in this area then the less-desirable wells of low capacity and those which yield poor-quality water in the Boles field could be abandoned.

San Andres well field

The San Andres well field, which consists of 680 acres, is owned by HAFB. The field consists of four production wells; however, only two are presently being used. Three of the wells are located on the western border of the field.

San Andres well 4 was drilled to about 2,000 feet in the eastern side of the San Andres well field. Figure 15 indicates that the thickness of unconsolidated material overlying the bedrock surface at this site is about 700 feet. San Andres well 4 is located at the mouth of San Andres Canyon and the greater thickness of unconsolidated material may be due to a buried channel beneath this location. The eastern side of the San Andres well field is underlain by saturated deposits having a thickness in excess of 1,000 feet (fig. 7).

The map showing the sulfate content of the ground water (fig. 6) indicates that water of better quality is present along the eastern side of the area. Water with a sulfate content of 240 ppm was found at a depth of about 1,150 feet in San Andres well 4. Additional exploration with test wells is desirable in the eastern 1/2 of sec. 32, T.17 S., R.10 E. Favorable results from these tests wells might lead to planning and construction of more production wells in this section. The spacing of wells should not be less than a quarter of a mile (see suggested locations 5 and 6 on fig. 15), due to interference between wells and to the proximity of the Sacramento Mountains. These mountains form an impermeable barrier to the flow of ground water, and the withdrawal of large quantitites of ground water in the vicinity of the barrier may result in large declines in water levels.

HJA (Holloman jurisdictional real-estate area)

The HJA (Holloman jurisdictional real-estate area) indicated on figure 1 consists of 4,806 acres. A request by HAFB for the water rights to this property is pending.

This property, a narrow intermittent strip of land, borders the western slope of the Sacramento Mountains and extends from just north of the Boles well field to 6 miles south of the San Andres well field, a total of 9 miles. Its location with respect to known source areas of good-quality ground water makes it a promising prospect for future development of ground-water supplies.

The map showing the approximate sulfate content of water (fig. 6) and the saturated thickness map (fig. 7) indicates that large quantities of potable water may be stored in the area.

The deepest well in the vicinity of the HJA prior to the drilling of production wells San Andres 3 and San Andres 4 (both drilled to about 2,000 feet) was about 500 feet due to the questionable potability of ground water at greater depths. The success of the two deeper production wells leads to the assumption that potable water may underlie the HJA along the Sacramento Mountain front; however, this is an unexplored area. The quality and quantity of water in this area can be proven only by exploring with test wells.

That part of the HJA adjacent to existing well-field areas where transmission lines and storage facilities are presently available is probably of more immediate concern to HAFB than the more distant part of the area.

If recommendations for exploration and development of wells in the Boles and San Andres well fields are accomplished, an approximation of the water quality in the adjacent HJA then can be made. However, in the center of each area in the HJA considered for production wells, a test well should be drilled to a minimum depth of 1,000 feet, or to the bedrock surface if it is shallower than 1,000 feet. Water samples to determine the water quality should be collected, and electric logs to indicate the more permeable zones should be made in the test wells. The test wells should be cased with a minimum 8-inch diameter casing so that pumping tests can be conducted in order to determine the aquifer characteristics. Following these tests an approximation of the ground-water reserves in these areas can be made. The casing installed in these wells could be retrieved; however, it is advisable to leave the casing in place in some wells so that water-level changes in the area, resulting from pumping in the nearby well fields, might be observed.

The HJA land in sec. 5 and the north half of sec. 8, T.18 S., R.10 E., is located south of the San Andres well field and east of the Douglass well field. The quality of water in this area should be about the same as that in the San Andres well field, and more desirable than that in the Douglass well field. This area of about 640 acres probably is underlain by an average thickness of more than 1,000 feet of saturated natural material (fig. 7). A suggested location for a test well in this area (number 10) is shown on figure 15.

The HJA land in secs. 9 and 16, T.18 S., R.10 E., and south to sec. 2, T.19 S., R.10 E., probably is underlain by water of a more desirable quality (fig. 6) than that found in the Douglass or San Andres well fields and may be underlain by very important reserves (fig. 7) of ground water. However, along the eastern border of the HJA land the underlying bolson-fill sediments probably are saturated. The suggested locations (numbers 11, 12, 13, and 14) of these wells in this portion of the HJA land are indicated on figure 15.

HAFB water right

(White Sands National Monument)

This area, which consists of 420 acres, is located in the southwest part of sec. 21 and the northwest part of sec. 28, T.18 S., R.10 E. The water right to this land was obtained by HAFB from the National Park Service, which held title to this water right for the White Sands National Monument.

It is desirable to test drill this property to determine the quality and quantity of water available as a future reserve supply. An approximate location for a test well (number 15) is shown on figure 15.

The location of this property is promising, insofar as water quality is concerned. A sample from a well on the south-central border of the property had a sulfate content of 253 ppm. The saturated thickness of the aquifer underlying the property is in excess of 1,000 feet (fig. 7).

Douglass well field

The Douglass well field, which consists of 526 acres, is leased by HAFB. The ground water produced from this field, like that from the western part of the San Andres field, contains sulfate in amounts which exceed the recommended limits set by the U.S. Department of Health, Education, and Welfare. Figure 6 shows that the more desirable ground water is in the eastern part of the Douglass field where six production wells are now located. Any exploration to the west of the present production wells in the field would be in an area of less desirable water. Further exploration and development of the Douglass field is not warranted unless an insufficient supply of water of better quality is not found in other areas that are suggested for exploration.

Pumping schedule in the well fields

The amount of water that can be pumped from the well fields depends upon the distribution pattern of pumping in the fields. In order to minimize possible movement, either vertically or horizontally, of undesirable water into the area of the production wells, it is necessary to keep the water-level decline to a minimum over the entire field. Pumping only a few wells for long periods results in the creation of large, deep cones of depression of the water table and thick sections of dewatered aquifer. In addition the reduction of hydraulic head increases the possibility of encroachment of less-desirable water into the area.

Measurement procedures presently used in the well fields obtain data that could be used advantageously in scheduling the production of water from the fields so as to keep the water-level decline to a minimum.

The following is the procedure presently used at the time of starting and stopping a pump on a well. Prior to starting the motor on a pump in a production well:

a. The cumulative meter on each production well is read to the nearest 100 gallons and noted.

b. The depth to water in each production well is measured with an air-line gage or electric tape and noted.

c. The motor is turned on and the time is noted.

Prior to stopping the motor on a pump in a production well:

a. The depth to water is measured and noted while the pump is discharging.

b. The pump is stopped and the time is noted.

c. The cumulative meter is read and noted.

This day-to-day accumulation of data can be used effectively to start a pumping program that will cause the water levels over the well field to decline at a nearly even rate. The day-to-day decline or rise in the water level, and pumpage, can be plotted for each well. Each week or so, the pumping schedule can be shifted so that wells with large water-level declines can be rested, and those with small water-level declines can be pumped.

Conclusions

1. Production of ground water from the HAFB well-field areas reached an all-time high in 1964 and 1965. Water consumption by HAFB (fig. 4) under normal peacetime conditions is expected to amount to about 4 mgd by 1975, an increase of about 1.5 mgd between 1965 and 1975. Under emergency conditions the anticipated pumpage will amount to approximately 6.5 mgd by 1975, an increase of about 4 mgd between 1965 and 1975. The well fields of HAFB reached their maximum potential production in 1964-65. Additional increases in pumpage without expansion of pumping facilities to the east and southeast of the present wells will hasten the chemical deterioration of the ground water pumped from the fields.

2. The well-field areas are underlain by a shallow zone of poor-quality water and a deeper zone of more desirable water. Probably the ground water pumped from all wells in the well fields is contaminated to some extent by water from the shallow zone. Excessive contamination of wells 5 and 10 in the Boles well field was known as early as 1955. Increased contamination of water noted in 1966, from San Andres well 2 in the San Andres well field has resulted in a reduction in the use of the well. Probably a large percent of this poor-quality water is entering the well through the more permeable layers of the shallow zone with a lesser amount moving vertically downward through the semi-confining beds of clay. A change in well construction so as to exclude this poor-quality water from the well may reduce the amount of contamination from the shallow zone in wells drilled in the future.

3. The effects of pumping water from the bolson-fill aquifer cannot increase the rate of recharge. A very long pumping period will be required to reduce the natural discharge because the discharge area is far from the well field; therefore, all the pumped water comes from storage. The removal of water from storage causes declines of water level in the pumped areas that will continue as long as pumping continues. The declines extend or will extend into areas of saline water because the saline and potable ground waters are stored in the same aquifer.

4. The coefficient of storage of the aquifer in the vicinity of the Boles well field is about 8 percent; in the Douglass field and western part of the San Andres well field about 9 percent; and the eastern part of the San Andres well field about 12 percent. Calculations based on these data show that the amount of known potable water that underlies the Boles well field, Douglass and western portion of San Andres well fields, and the eastern part of the San Andres well field is about 36,600, 45,000, and 46,000 acre-feet respectively.

5. It is desirable that future wells be located east and southeast of the well fields; location of new wells in that direction will lessen the encroachment of saline water.

6. Well spacing of a quarter of a mile or more is desirable in the area east and southeast of the present well fields.

7. The saturated-thickness map (fig. 7) of the well-field areas indicates that more water is available than heretofore realized. The saturated thickness of material underlying the Boles well-field range from about 3,500 feet in the western part of the field to about 1,200 feet in the eastern part of the field. Only about 300 feet of aquifer has been explored in this area. In the Douglass and San Andres well field, the saturated thickness ranges from about 3,500 feet to about 300 feet. Only about 300 feet of aquifer has been explored in the Douglass field. One well in the western part of the San Andres field was completed to a depth of about 960 feet. About 700 feet, or one third of the aquifer, is penetrated in this well. A well in the eastern half of the San Andres field was drilled to a depth of 2,000 feet and was completed at a depth of about 1,200 feet. Transfer of water rights to about 4,800 acres of land to HAFB is pending. The saturated thickness of material underlying this area varies; however, it ranges from about 3,500 feet in sec. 31, T.17 S., R.10 E., to less than 100 feet in some areas. The area parallels and is adjacent to the Sacramento Mountains and is identified in this report as HJA land.

8. During the period 1953-55 to February 1966, water levels have declined (fig. 3) about 10 feet in the Boles well field and more than 15 feet in the Douglass and San Andres well fields. The decline of water levels in the Boles well field has increased in the water-table gradient to the north (fig. 3) and the saline water (fig. 6) north of the field is now moving toward the field at an increased rate. The decline in water levels in the Douglass-San Andres well fields has decreased the gradient of the water table to the southwest. Additional water-level declines in this area will reverse the gradient of the water table, and the saline water to the southwest will begin to move toward the Douglass and San Andres well fields.

9. Except for contamination by poor-quality water from the shallow zone, the quality of water in the well-field areas has not changed perceptibly. No indication has been found that the saline water near the well fields has moved horizontally into the well-field areas.

10. The principal source of recharge to the aquifer in the area of the well fields is precipitation in the adjacent Sacramento Mountains. A very small percent of the total runoff water from the canyons reaches the aquifer underlying the area. Most of the fast-moving water from the canyons moves across the more permeable recharge area adjacent to the mountain onto the relatively flat impermeable area of the well field and is evaporated or taken up by the desert plants and transpired into the atmosphere.

11. At the 1964-65 rate of pumping from the existing production wells the water level in the center of the fields will decline over a 2,000-foot radius about 24 feet in 5 years in the Boles well field and about 38 feet in the Douglass-San Andres well fields, in 10 years about 28 and 44 feet, and in 20 years about 33 and 50 feet, respectively. An increase in pumping will result in an increase in water-level decline.

Suggestions

1. Immediate expansion of the Boles and San Andres well fields to the east is desirable. This will move the center of pumping away from the highly saline water to the north and west. Additional production wells in section 32 of the San Andres well field and section 19 of the Boles well field should be planned. These wells should initially be test holes to obtain as much information as possible on ground-water conditions at the sites. By use of such data, more efficient construction and development of wells can be accomplished.

2. The present wells in the San Andres and Douglass well fields should not exceed an average daily pumpage of 1.2 million gallons a day in order to minimize water-level decline and reduce possible encroachment of undesirable water.

3. The maximum average daily pumpage from the Boles well field should not be greater than 700,000 gpd in order to reduce the possibility of the encroachment of less-desirable water.

4. Future spacing of wells in the eastern part of the San Andres and Boles well fields should be a minimum of a quarter of a mile in order to minimize water-level declines.

5. Test wells should be drilled in the HJA and Holloman's water-right area. Proven ground-water supplies in these areas would be most helpful in planning the future storage capacity and pipeline design in the area.

6. Water samples from production wells should continue to be collected and analyzed to determine any change in water quality.

7. Bonito Reservoir should not be relied upon as a dependable source of potable water. Sufficient wells should be drilled to supply the increasing water demand at HAFB, independent of the Bonito supply. The water supplies from the Bonito reservoir could then be used to relieve the demand on the well fields. Reliance on the Bonito supply causes overpumping in the well fields during those years when precipitation is below normal and the reservoir contains a below-normal supply of water.

8. A large part of the surface flow from Arrow, Lead, and San Andres Canyons is lost to evaporation and transpiration. The possible use of this water for recharge in the well fields should be considered. Stream-gaging stations should be installed in order that an accumulation of surface-flow records will be available should a feasibility study be made on recharge to the aquifer by using floodflow from the Sacramento Mountains.

9. During the construction of future production wells a better quality water may be obtained by cementing off the shallow zones of less desirable water.

10. Wells 5 and 10 in the Boles well field and well 2 in the San Andres well field should be used on standby basis only.

11. The "sled track" just north of the Base and the golf course which is in the Base area require large quantities of water. This is a serious drain on the supply of good-quality water piped in from the well fields about 8 miles southeast of the Base. The water for use on the golf course and sled track probably could be of a poorer quality than that necessary for domestic use at the Base. Deep test exploration is needed in the vicinity of the Base area to determine if a supply of water is available for use on the golf course and sled track.

12. Successful high-capacity gravel-walled wells can be developed in the well fields if sufficient care is exercised in choosing the screen and gravel sizes.

13. Before drilling a production well at any location, a test hole should be drilled first and an electric log of the strata obtained. Data from the test hole will indicate whether a production well will be successful and will form the basis for choosing the amount of screen to be used, the size of the screen opening, and the size of gravel, if any, to be used.

14. The development of future production wells should be thorough. The wells should be (a) surged with close-fitting surge block and bailed to remove the sand washed into the well be surging, (b) treated after surging, with mud-cutting chemicals, and (c) surged and overpumped with the test pump. Development should be continued until the amount of sand obtained from the well diminishes measurably.

15. The well should be test pumped after development both to determine the hydrologic characteristics of the aquifer around the well and to provide a basis for specifying the size of the production pump.

16. No production well should be pumped at its maximum capacity. Generally the production pump should be capable of pumping not more than three fourths of the maximum yield of the well.

17. In order to provide a basis for continuing re-evaluation of the status of ground-water supplies in the well-field areas, it is suggested that complete records of all phases of well-field operation be collected and filed together in an accessible place.

18. In order to facilitate the orderly keeping of records it is desirable to continue the practice of numbering wells and test holes consecutively, in the order of drilling, throughout the life of the well fields.

19. The area of ground-water studies should be broadened. This report is confined primarily to the immediate vicinity of the well fields. In view of the limitations of the well-field areas and the anticipated growth of the Base and Alamogordo, all possible sources of potable water within a reasonable distance from the airbase should be investigated.

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Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico

EXPLANATION:

Number: See explanation in text.
Name: Name of owner or designation of well at time of visit.
Depth to water: Measurements made with steel tape unless otherwise noted.
Remarks: b/ - pumped recently; e/ - estimated from USGS topographic map; r/ - repeated measurement; t/ - electric tape measurement.

17.9.2.331. L. H. Dyvad
Elevation of land surface 4,139e/

Date	Depth to water
February 9, 1966	44.34

17.9.14.422. City of Alamogordo
Elevation of land surface 4,035e/

Date	Depth to water
February 9, 1966	65.88

17.9.24.324.
Elevation of land surface 4,145e/

Date	Depth to water
February 10, 1966	64.24

17.9.24.342a. (Well No. 33, Boles well field)
Elevation of land surface 4,144.30

Date	Depth to water
1952	
April 14	56.2
1955	
February 15	59.7
1965	
November 17	67.64
1966	
February 14	67.20

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.9.24.343. (Well No. 34, Boles well field)
Elevation of land surface 4,136e/

Date	Depth to water
1955	
April 29	62.46
June 15	63.63
1956	
January 6	65.58
February 9	63.42
June 22	84.75 b/
August 23	75.88
October 23	78.72
1957	
January 16	73.91
September 24	68.37
1958	
January 28	66.06
April 2	66.32
July 24	81.55 b/
October 9	64.25
1959	
January 7	63.20

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.9.24.343. - Continued

Date	Depth to water
1959 - Continued	
April 7	62.55
August 12	62.58
October 7	62.45
1960	
January 11	61.92
April 7	61.42
July 28	65.66
October 12	63.95
1961	
January 24	67.35
July 28	77.20
October 10	71.36
1962	
January 8	67.33
April 10	77.15
July 20	74.27
October 3	82.28 b/
1963	
July 29	70.63 b/

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.9.24.343. - Concluded

Date	Depth to water
1965	
January 12	70.94
July 13	72.28
October 21	69.65
October 29	69.49
November 8	69.34
November 17	69.39
December 2	69.54
December 9	69.14
1966	
January 12	69.02
February 14	68.50

17.9.25.111.
Elevation of land surface 4,120e/

1966	
February 10	59.95

17.9.25.143. (Well No. 37, Boles well field)
Elevation of land surface 4,120e/

1965	
November 10	69.45
December 9	69.15
1966	
February 14	68.03

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.9.25.212. (Well No. 35, Boles well field)
Elevation of land surface 4,136.59

Date	Depth to water
1955	
May 23	70.6
1956	
January	73.3
1965	
September 8	76.72
October 6	75.78
October 21	75.44
November 5	75.00
December 9	75.74
1966	
February 14	75.69

17.9.25.213. (Well No. 17, Boles well field)
Elevation of land surface 4,129.3

Date	Depth to water
1954	
February	62.9
May	72.5
1955	
January	65.2
1956	
January	72.0

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.9.25.213. - Concluded

Date	Depth to water
1965	
September 8	77.14
September 24	75.36
October 6	74.86
October 15	74.64
October 21	74.54
October 29	74.29
December 2	76.27
1966	
February	73.25

17.9.25.222. (Well No. 16, Boles well field)
Elevation of land surface 4,145.02

Date	Depth to water
1952	
May 1	62R/
1955	
January	67.09
1960	
January	70.50
1965	
October 21	73.13
November 8	71.83
December 2	72.01
December 9	71.81
1966	
February 14	70.73

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.9.25.343. (Well No. 33, Boles well field)
Elevation of land surface 4,105e/

Date	Depth to water
1965	
September 24	68.6T/
October 6	68.10
October 15	67.96
October 21	67.53
October 29	67.23
November 4	67.04
November 10	66.79
November 17	66.78
December 2	66.49
December 9	66.75
1966	
February 14	65.32

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.9.26.242. (L. C. Boles)
Elevation of land surface 4,110e/

Date	Depth to water
1966	
February 10	58.88

17.9.35.242. (City of Alamogordo)
Elevation of land surface 4,110e/

Date	Depth to water
1954	
April 1	42.97
1966	
February 15	51.35

17.9.35.331 (Dora Longwill)
Elevation of land surface 4,061e/

Date	Depth to water
1966	
February 9	42.72

17.10.6.122. (Golf Course)
Elevation of land surface 4,350e/

Date	Depth to water
1966	
February 10	181.78

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.18.432. (Well No. 24, Boles well field)
Elevation of land surface 4,187.26

Date	Depth to water
1953	
August 26	90R/
1954	
February 8	105.9
1955	
January 2	106.66
March 7	105.31
June 15	105.59
October 14	107.81
1956	
January 6	106.21
April 20	105.67
June 22	106.70
October 23	108.80
December 20	109.05
1957	
April 15	107.49
September 24	106.84
1958	
January 29	104.53
April 2	104.33
July 24	103.55
October 9	103.39

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.18.432. - Continued

Date	Depth to water
1959	
January 7	102.85
April 7	102.17
October 7	104.25
1960	
January 11	101.67
April 7	102.35
July 28	103.14
October 12	102.17
1961	
January 24	103.85
April 5	106.35
July 28	106.80
October 11	106.15
1962	
January 8	106.87
April 10	107.15
July 20	108.78
October 3	108.52
1963	
January 9	106.75
July 29	107.07

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.18.432. - Concluded

Date	Depth to water
1964	
January 13	108.17
July 26	109.71
1965	
January 12	109.42
July 13	111.27
October 22	109.74
December 2	109.28
1966	
February 15	108.59

17.10.18.442a. (Observation Well No. 26, Boles well field)
Elevation of land surface 4,206.68

Date	Depth to water
1955	
January 1	107.8
1966	
February 15	117.74
April 1	117.44

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico

17.10.18.442b. (Well No. 26a, Boles well field)
Elevation of land surface 4,207e/

Date	Depth to water
1965	
September 9	122.44
November 4	120.49
December 2	121.09
1966	
February 14	117.77
April 1	117.73

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.19.113. (Well No. 32, Boles well field)
Elevation of land surface 4,148.67

Date	Depth to water
1954	
July	70.2
1955	
February	66.4
1956	
January	68.7
1965	
September 24	72.52
October 6	72.29
October 29	71.95
1966	
February 14	69.45

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.19.123 (Well No. 2, Boles well field)
Elevation of land surface 4,160.77

Date	Depth to water
1955	
January	83.5
1956	
January	84.1
1965	
September 9	88.20
October 6	86.54
November 23	85.40
1966	
February 14	84.03

17.10.19.132. (Well No. 7, Boles well field)
Elevation of land surface 4,147.0

Date	Depth to water
1965	
September 8	78.91
November 4	78.40
December 2	78.26

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.19.141. (Well No. 15, Boles well field)
Elevation of land surface 4,152.46

Date	Depth to water
1950	
August	74R/
1965	
October 21	83.56
November 8	83.10
December 2	82.64
1966	
February 14	81.75

17.10.19.144. (Well No. 5, Boles well field)
Elevation of land surface 4,150.10

Date	Depth to water
1955	
January	80.6
1956	
January	81.1
1965	
October 15	85.39
November 8	85.05
December 9	84.59
1966	
February 14	83.89

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.19.214. (Well No. 4, Boles well field)
Elevation of land surface 3,175.88

Date	Depth to water
1948	
March	85R/
1954	
August 25	98.27
1965	
September 9	103.98
November 4	103.55
December 2	103.28
1966	
February 15	102.53

17.10.19.321a. (Well No. 30, Boles well field)
Elevation of land surface 4,140.7

Date	Depth to water
1953	
September 13	55R/
1954	
July 20	81.52
1955	
December 12	79.38
1956	
February	78.75
April 20	80.38
June 22	82.14
October 23	83.43
December 20	82.88

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.19.321a. - Continued

Date	Depth to water
1957	
September 24	81.29
October 29	80.82
1958	
January 29	79.76
April 2	79.74
July 24	80.95
October 9	78.79
1959	
January 7	78.17
April 7	77.53
August 12	75.82
October 7	77.58
1960	
January 11	77.05
April 7	76.53
July 28	77.78
October 12	77.58
1961	
January 24	75.80
April 5	80.99
July 28	77.95
October 11	77.00

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.19.321a. - Concluded

Date	Depth to water
1962	
January 8	81.14
April 10	81.04
July 20	81.83
October 2	82.72
1963	
January 9	81.17
July 29	81.68
1964	
January 13	82.37
July 26	82.38
1965	
January 12	81.04
July 13	83.40
October 22	83.64
November 4	83.56
December 2	83.45
1966	
February 14	82.99

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.19.323. (Well No. 29, Boles well field)
Elevation of land surface 4,135.2

Date	Depth to water
1954	
July 20	75.30
October 8	76.18
1955	
January 4	75.42
April 28	74.83
June 15	75.75
October 14	76.56
1956	
January 6	76.02
April 20	75.88
June 22	76.64
October 23	77.48
1957	
January 16	77.89
April 15	78.01
October 29	77.88

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New México - Continued

17.10.19.323 - Continued

Date	Depth to water
1958	
January 29	77.25
April 2	76.74
July 24	76.62
October 9	76.73
1959	
January 7	76.23
April 7	75.69
August 12	77.45
October 7	76.05
1960	
January 11	75.71
April 7	75.22
July 28	75.52
October 12	75.90
1961	
January 24	76.25
April 5	76.67
July 28	78.07
October 11	78.38

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.19.323. - Concluded

Date	Depth to water
1962	
January 8	78.55
April 10	76.78
July 20	76.73
October 3	79.34
1963	
January 9	78.88
July 29	79.83
1964	
January 13	80.36
July 26	81.79
1965	
January 12	83.30
July 13	84.67
October 22	81.60
December 9	81.63
1966	
February 14	81.39

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.29.314. (Don Taylor)
Elevation of land surface 4,219e/

Date	Depth to water
1954	
April 27	174.52
1966	
February 15	191.95

17.10.31.411. (Well No. 4, Douglass well field)
Elevation of land surface 4,142.2

1962	108R/
1966	
February 15	121.06

17.10.31.412. (Well No. 5, Douglass well field)
Elevation of land surface 4,157.2

1963	112R/
1966	
February 15	135.52

17.10.31.424. (Well No. 3, San Andres well field)
Elevation of land surface 4,238.5

1966	
February 15	170.24
February 23	170.43

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

17.10.31.432. (Well No. 6, Douglass well field)
Elevation of land surface 4,153.16

Date	Depth to water
1966	
February 15	133.33

17.10.31.442. (Well No. 7, Douglass well field)
Elevation of land surface 4,193.67

Date	Depth to water
1966	
February 17	172.64

17.10.31.444. (Well No. 2, Douglass well field)
Elevation of land surface 4,191.00

Date	Depth to water
1966	
February 15	170.5T/

17.10.32.111. (Well No. 2, San Andres well field)
Elevation of land surface 4,207.19

17.10.32.113. (Well No. 1, San Andres well field)
Elevation of land surface 4,207.78

Date	Depth to water
1963	170R/
1965	
November 17	185.65
1966	
February 15	181.78

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Continued

18.9.11.412. (Mrs. Jack Prather)
Elevation of land surface 4,045e/

Date	Depth to water
1966	
February 9	43.60

18.9.11.432. (Mrs. R. C. Stinnet)
Elevation of land surface 4,040e/

1966	
February 9	41.25

18.9.11.444. (Mrs. R. C. Stinnet)
Elevation of land surface 4,045e/

February 9	41.85

18.9.14.432
Elevation of land surface 4,040e/

February 9	36.82

18.9.26.311. (Mrs. Jack Prather)
Elevation of land surface 4,013e/

February 9	29.52

18.10.6.322. (Well No. 3, Douglass well field)
Elevation of land surface 4,122.40

February 15	115.70

Table 4.--Depth to water, in feet below land surface, in observation wells in the vicinity of Holloman Air Force Base, Otero County, New Mexico - Concluded

18.10.6.430. (Douglass well field)
Elevation of land surface 4,125e/

Date	Depth to water
1954	99.75
February 15	114.97

18.10.6.441. (Well No. 1, Douglass well field)
Elevation of land surface 4,170.00

Date	Depth to water
1961	115R/
1966	
February 15	149.10

18.10.18.224. (Mr. Moya)
Elevation of land surface 4,095e/

Date	Depth to water
1954	
April 8	74.15
1966	
February 15	81.08

18.10.30.242. Owner unknown
Elevation of land surface 4,055e/

Date	Depth to water
1966	
February 9	61.69

Seismic-refraction and gravity measurements in the vicinity of HAFB well-field area, Otero County, New Mexico

By Robert Mattick

Introduction

Continuous seismic-refraction measurements were made along two lines of profile which extend westward from the Sacramento Mountains. One profile (about 3 miles in length) extends across Boles well field (fig. 8); the other (about 4 miles in length) is located near Dog Canyon (fig. 9). The primary objective of the seismic-refraction survey was to delineate depths to bedrock. One recording unit which recorded the output of 12 vertical seismometers on photographic paper was used. The 12 seismometers were evenly spaced along a cable at intervals of 650 feet.

The scheme for shooting a profile was as follows: the cable was laid at one end of the profile and the output from a dynamite charge exploded at each end of the profile was recorded. The cable was then moved forward about 7,000 feet and the previous shot points at each end of the profile were reshot. This procedure of reshooting at the same shot points and moving the cable was continued until the entire distance along the profile was covered. In addition, intermediate shots at about 7,000-foot intervals were used to record velocity changes occurring in the near-surface sediments. The dynamite charges, which varied from 20 to 600 lbs., were loaded in dug holes (backhoe used for digging) at depths of 7 to 10 feet. Shot breaks were not recorded on the records, but short spreads were shot at shot points to determine near-surface velocities.

The resulting seismograms were of good quality with the first arrivals easily identifiable on most of the records. In most cases the energy from first arrivals was too strong to distinguish later arrivals. Only one of the records showed distinguishable second arrivals.

ALAMOGORDO QUADRANGLE
NEW MEXICO - OTERO CO.
15 MINUTE SERIES (TOPOGRAPHIC)

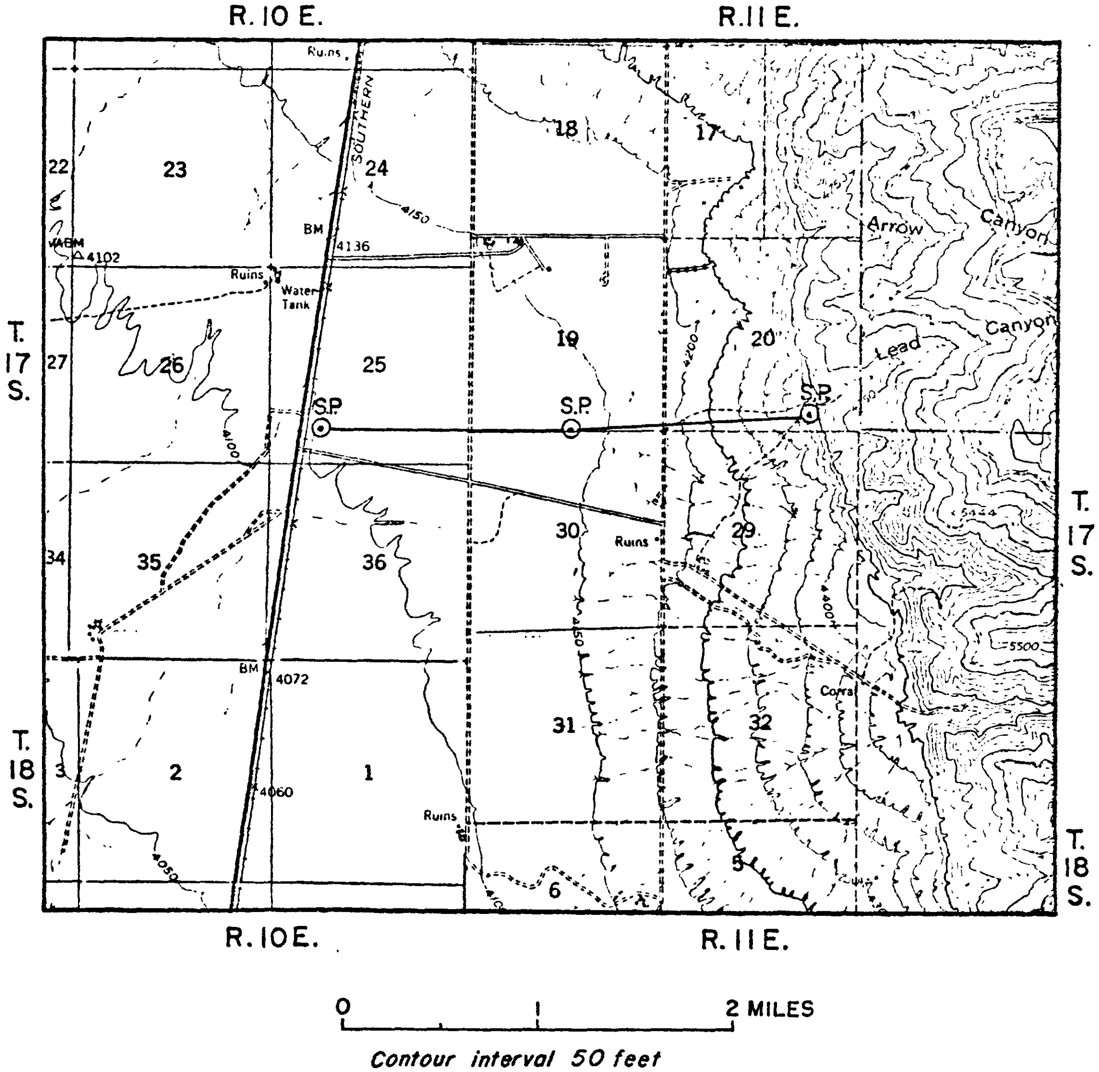

Figure 8.--Location of seismic-refraction profile across Boles well field, New Mexico.

ESCONDIDO CANYON QUADRANGLE
NEW MEXICO - OTERO CO.
15 MINUTE SERIES (TOPOGRAPHIC)

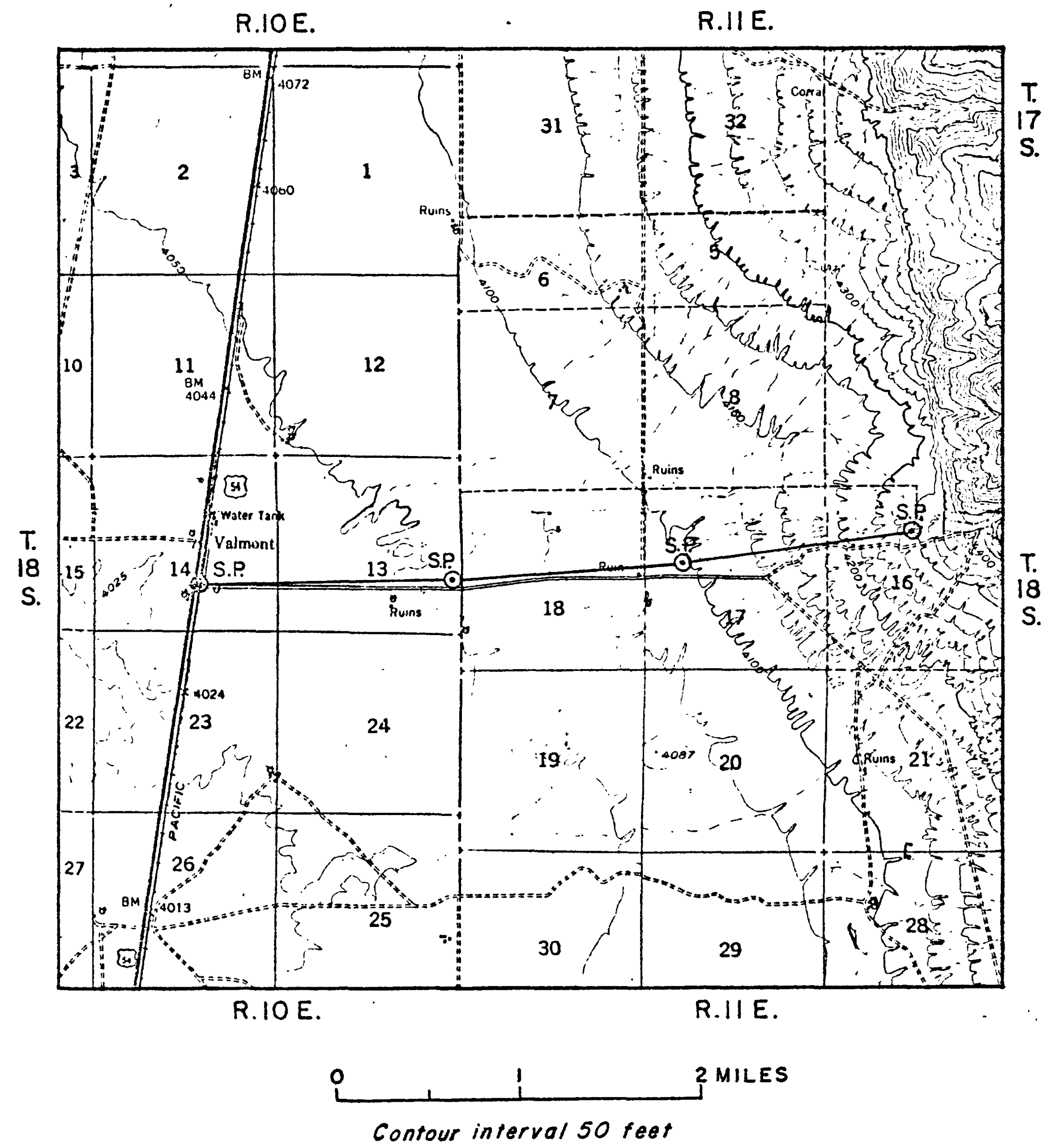

Figure 9.-- Location of seismic-refraction profile near Dog Canyon, New Mexico.

Travel-time curves were constructed for each of the profiles and velocities were determined by visual fitting of straight-line segments to the travel-time data. Along both profiles the ground elevation was relatively constant or sloped at a constant angle and no elevation corrections were necessary.

Conventional seismic interpretation methods were used in calculating depths to basement. In all cases the final interpretation was checked by fitting theoretical wave paths to the computed model.

Seismic-refraction profile across Boles well field

This profile extends from the mouth of Lead Canyon westward to a point about 500 feet east of Highway 54 (fig. 8). The total length of this profile is approximately 13,650 feet with 21 geophones spaced at intervals of 650 feet. Shot points were located at the eastern and western ends of the profile with an additional shot point near the center. The center shot point was used to gain additional information as to the velocity characteristics of the sediments overlying the limestone basement. The easternmost shot point is located about 200 feet west of an extensive limestone outcrop at the base of the Sacramento Mountains. This shot hole was dug to a depth of about 7 feet. Large boulders, 3 to 4 feet in diameter, were encountered near the surface and the difficulty of digging forced a halt at a depth of 7 feet. The remaining two shot points were dug to a depth of 10 feet in unconsolidated sand.

The resulting travel-time curve is shown in figure 10. The first-arrival times at the west and center shot points show an intercept on the time axis of about 0.10 seconds. This intercept time can be explained by the presence of a thin layer of low-velocity weathered material (weathering layer) at the surface; this layer, about 150 feet thick, could also represent the low-velocity material above the water table.

The remainder of the travel-time curve is relatively straightforward, and can be interpreted as a simple "two-layer case." The travel-time curve shows that the velocity of the "overburden material" at the west and center shot points varies from 6,400 feet/second to 6,600 feet/second and a good average velocity is about 6,500 feet/second. The P wave velocity for waves along the basement surface is calculated to be about 15,700 feet/second. This basement velocity is computed from apparent downdip and updip velocities, recorded near the east shot point, of 12,200 and 21,700 feet/second respectively. The velocities of 6,500 and 15,700 feet/second were used in the final depth computations and assumed to remain constant along the entire profile.

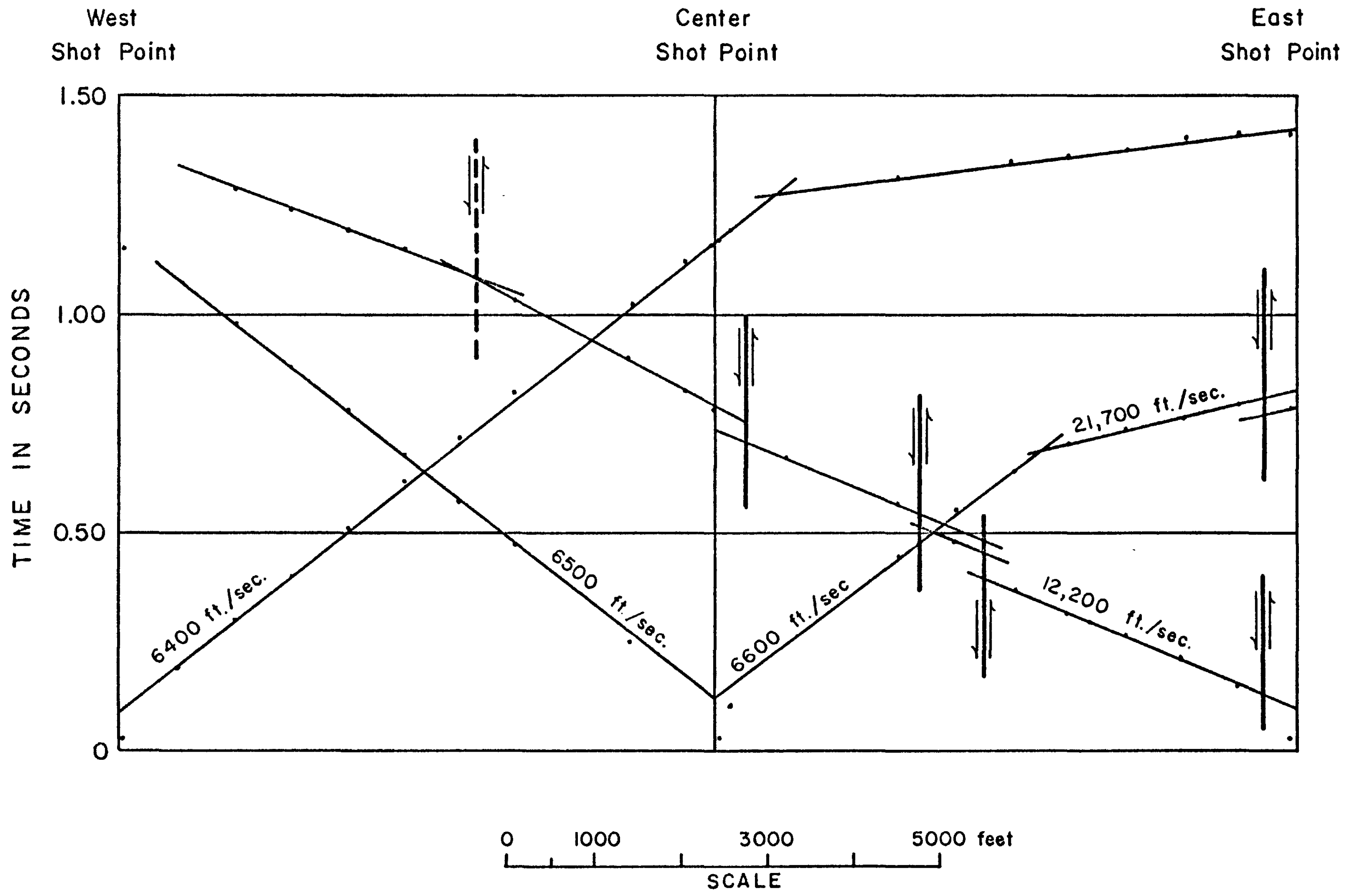

Figure 10.--Time-distance plot for seismic-refraction profile across Boles well field, New Mexico.

In shooting from the east shot point, the travel-time curve shows four distinct offsets (shown by heavy vertical lines). These offsets are interpreted as basement faults. On the computed cross section (fig. 11), the faults are seen to be shifted eastward in relation to their location as shown on the travel-time curve. This is due to the fact that waves arriving at surface geophones do not travel vertically upward from the basement, but are refracted at an angle determined by the dip and velocity of the basement surface. An additional fault, shown by a heavy dashed vertical line on the travel-time curve, is questionable. Rather than a fault, this break in the velocity segment could represent only a change in dip of the basement surface. Either interpretation would not significantly change the computed depth to basement.

It should be noted that in shooting from the west shot point, the segment of the travel-time curve representing basement arrivals does not show the significant offsets which appear on the reversed segment of the profile; instead, the arrival times show more of a scattering about the average velocity line. This can be explained by the fact that the frequency of the former arrivals is about one-half the frequency of the latter arrivals. This difference in frequency is probably due to attenuation of the higher frequency waves along the longer travel path in shooting from the west shot point. In this case, due to the "lesser" resolving power of low frequency waves, the average velocity line for basement arrivals from the west shotpoint would be indicative of an average dip along the step-faulted basement surface.

Figure 11 is a computed model which fits all the observed travel-time data.

Seismic-refraction profile near Dog Canyon

This profile extends from near the mouth of Dog Canyon westward a distance of about 20,900 feet to a point about 150 feet east of Highway 54 (fig. 9). Four shot points were located at about 7,000 foot intervals among the profile. The easternmost shot point is located about 0.3 mile west of the limestone outcrops exposed at the base of the Sacramento Mountains.

The resulting travel-time curve is shown in figure 12. As in the previous profile, the intercept of the first-arrival times on the time axis indicates a thin weathering layer about 80 to 100 feet thick. The first-arrival times along the western two-thirds of the profile indicates that the recorded overburden velocity varies from 6,400 to 6,500 feet/second. An average velocity of 6,500 feet/second was used in the final depth computations along this portion of the profile.

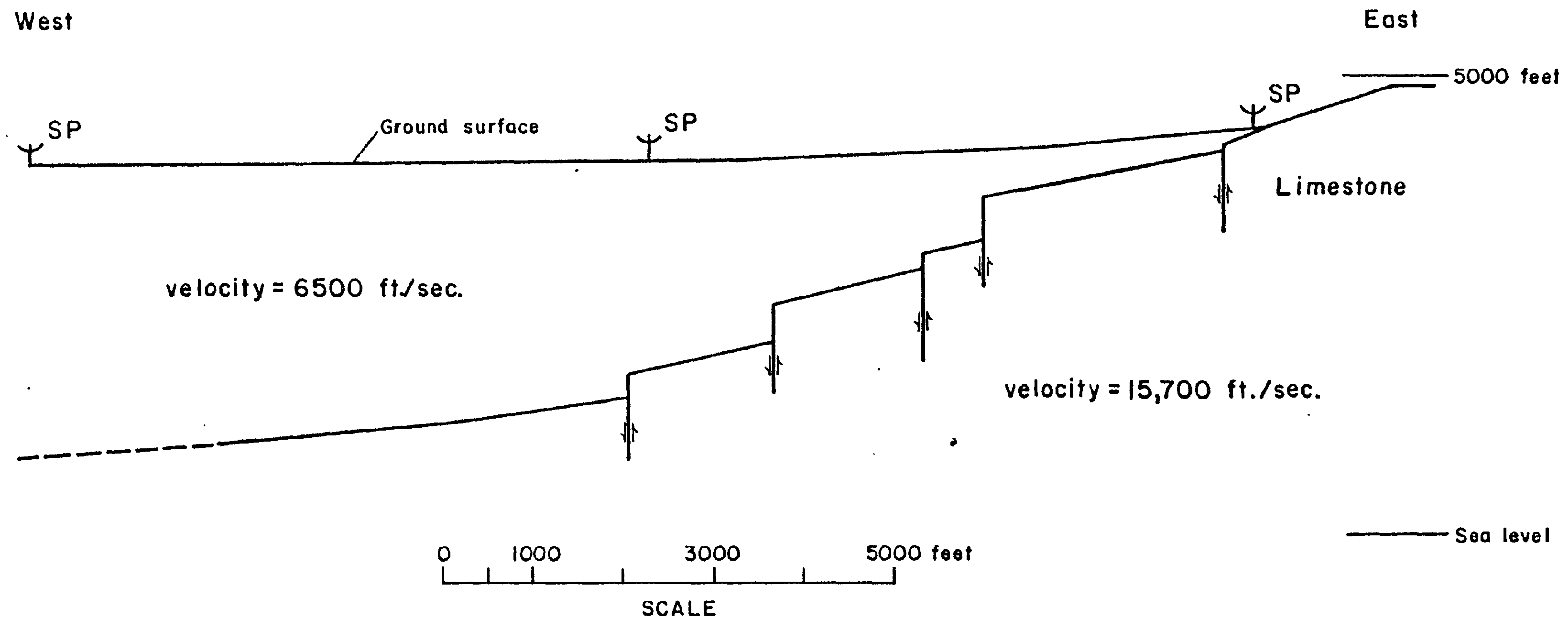

Figure 11.--Seismic-refraction profile across Boles well field, New Mexico.

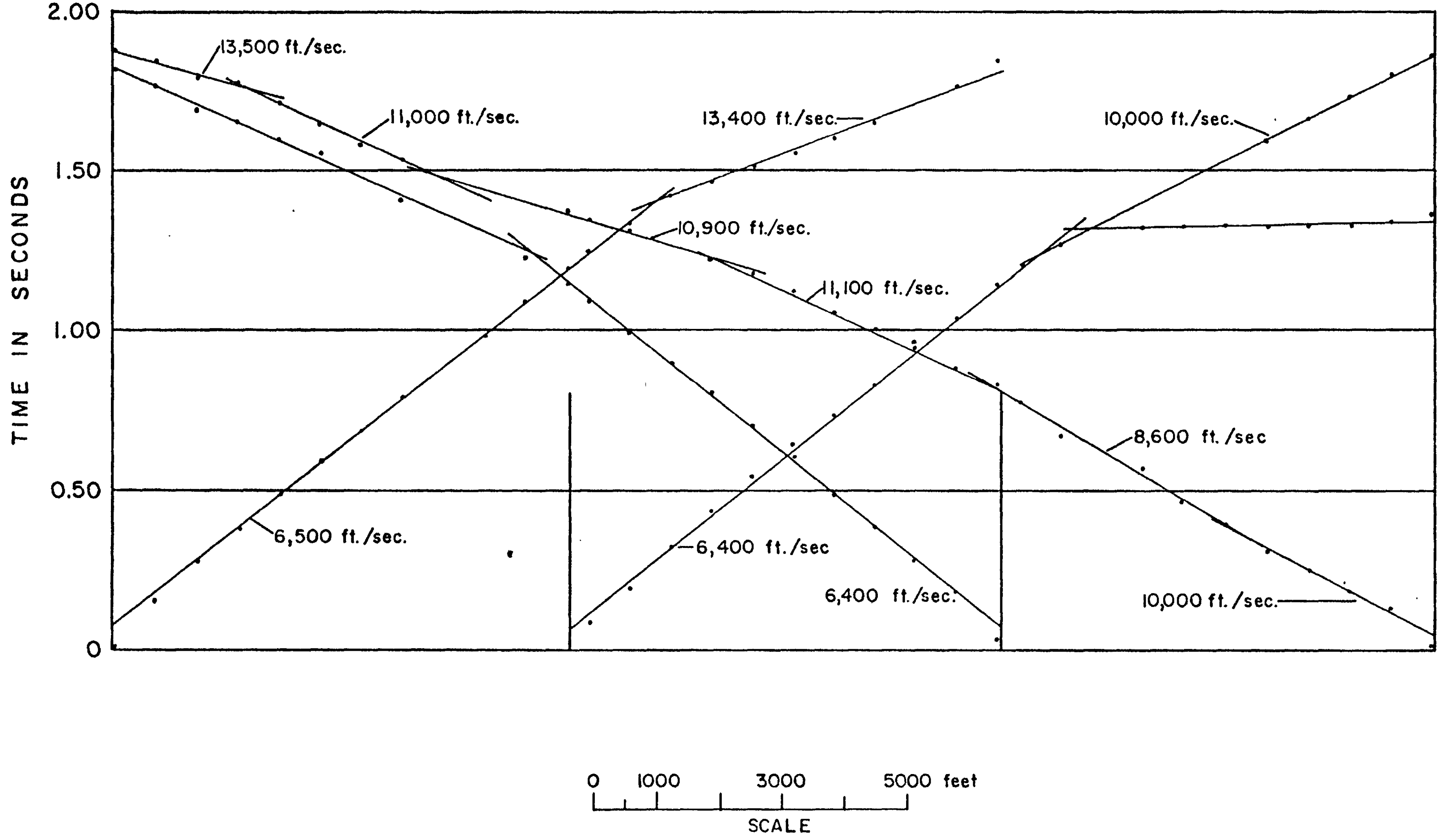

Figure 12.--Time-distance plot for seismic-refraction profile near Dog Canyon, New Mexico.

At the easternmost shot point the first-arrival times show an apparent velocity of about 10,000 feet/second. In this case there are two possibilities of interpretation. First, it is possible that the apparent velocity of 10,000 feet/second represents a downdip refraction along a steeply dipping basement surface. Secondly, it is possible that the velocity of the "overburden material" at the east shot point is about 10,000 feet/second. Additional evidence substantiates this latter hypothesis. In shooting from the west-center shot point, second arrivals recorded on 5 geophones located near the east shot point indicate an apparent velocity of about 10,000 feet/second (fig. 12). A steeply dipping basement surface overlain by overburden material of velocity 6,500 feet/second would not produce these second arrivals. Also, if it is assumed that the first arrivals with an apparent velocity of 10,000 feet/second were refractions from the basement surface, the calculated depth to basement at the east shot point would be about 50 feet. Additional gravity data contradicts such a shallow depth computation. In a like manner the segment of the velocity curve showing an apparent velocity of 8,600 feet/second is interpreted to represent a change in velocity occurring in the overburden material. The remainder of the velocity curve originating at the east shot point is interpreted as originating from waves refracted along the basement surface.

Higher apparent velocities of 13,400 feet/second and 11,000 feet/second are seen to have been recorded when shooting eastward from the west shot point and westward from the east-center shot point. These arrivals suggest the possibility of a nearly flat-lying layer with a velocity of about 12,000 feet/second immediately below the 6,500 foot/second horizon and overlying a higher velocity basement surface. Several theoretical models were computed with such an intermediate horizon. In this case the depth to the intermediate horizon was computed from the travel-time curves originating at the west and east-center shot points and the depth to the basement surface was computed from arrival times originating at the east shot point. Using this computed model and calculating theoretical travel paths for basement refractions originating at the west and east-center shot points, the resulting travel-time curve should show evidence of basement arrivals at about 1.6 or 1.7 seconds. Since no evidence for such arrivals are substantiated by the field records, it was concluded that the 11,900 and 13,400 feet/second arrivals represent velocities recorded on downdip segments of a higher velocity basement surface. Hence, the resulting computed cross section (fig. 13) shows a small basement high near the west-center shot point.

Figure 13 is a computed model which fits all the observed travel-time data.

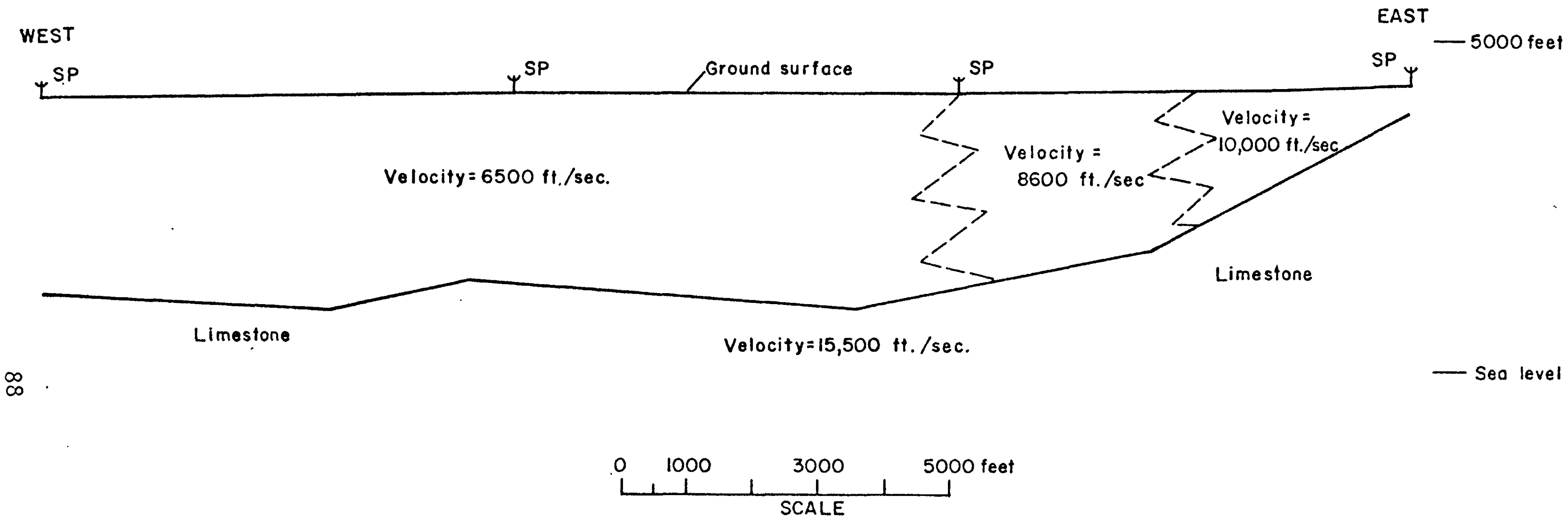

Figure 13.--Seismic-refraction profile near Dog Canyon, New Mexico.

Gravity measurements

Gravity measurements were made at approximately 90 stations located between longitude 105°50' and 106°10' and between latitude 32°35' and 33°00 in the vicinity of Alamogordo, N. Mex. These measurements were made with a Worden gravity meter with a sensitivity of about 0.5 mgal per dial division. The stations were located mainly along roads and to the gravity base station at the El Paso airport. A density of 2.67 gm/cm^3 was used in computing the Bouguer anomaly and the values were corrected to a sea level datum. Terrain corrections were applied to those stations located near the base of the Sacramento Mountains. The largest terrain correction was about 8 milligals. Horizontal control was obtained from U.S. Geological Survey maps at a scale of 1:62,500. In some areas station locations were determined by odometer measurements. Vertical control was obtained from bench marks, spot elevations, and by altimetery. Theoretical gravity was computed from the international formula. Don Peterson and Don Mabey of the U.S. Geological Survey did the fieldwork and compiled the final gravity map.

The complete Bouguer anomaly map is shown in figure 14. The map shows the station locations and values and is contoured at an interval of 2 milligals. The prominent feature of the gravity map is the north-south trending low of about 20 milligals which parallels the Sacramento Mountains near the center of the map. A discussion of relationship of the gravity to the computed thickness of unconsolidated sediments follows.

Bedrock map

Figure 15 is a contour map showing the approximate depth to bedrock (thickness of unconsolidated valley-fill material) as computed from the gravity and seismic data in the vicinity of Holloman Air Force Base well-field area. Interpretation was based primarily on gravity data since seismic-refraction measurements were limited to two profiles near the center of the prominent gravity low. Local changes in the Bouguer anomaly reflect changes in density of the rock in an area surrounding and below the gravity meter, hence, reasonable depth determinations hinge on three primary assumptions: (1) the main source of the gravity anomaly arises from a density contrast between the unconsolidated valley-fill material and the underlying rock, (2) an accurate estimate of this density contrast can be established, and (3) the regional gradient, i.e. that part of the gravity anomaly which has its source in or below the rocks underlying the unconsolidated valley-fill material, can be reasonably estimated and removed.

Local geology and well data suggest that the primary source of the gravity anomaly is due to a density contrast between unconsolidated valley-fill material and the underlying rock. The valley-fill material consists mainly of unconsolidated clays, sands, gravels, and boulders at least 2,000 feet thick in places as indicated by well data. In contrast, the underlying rock and outcrops at the base of the Sacramento Mountains consist primarily of a thick section of limestone. A reasonable density contrast in this case is about 0.5 gm/cm^3. There is no reason to believe that any substantial change occurs in the underlying limestone in the area of the survey.

One of the primary sources of error in computing thicknesses of the unconsolidated valley-fill material probably arises from the difficulty of determining a precise regional gradient. If it is assumed that the regional gradient can be represented as a planar surface then the component of the gradient must be estimated in two directions. No north-south component of the gradient was removed; although the gravity values for stations located on limestone outcrops at the base of the Sacramento Mountains do suggest a small north-south component (possibly 0.2 milligals per mile). A larger east-west component of the regional gradient was estimated to be about 1 milligal per mile and was removed prior to final computations. This value is based on a measured thickness of the unconsolidated sediments in a well located at the White Sands National Monument Headquarters which penetrated limestone at a depth of 820 feet. A more precise determination of the apparently large east-west gradient would require gravity measurements on limestone outcrops (which are limited) along the western edge of the gravity map or else a number of known depths to limestone in the same area.

Cross sections were computed along two east-west lines corresponding in location to the seismic profiles and a density of 0.5 gm/cm^3 was used to compute the thickness of unconsolidated sediments. The depths as computed from the gravity data were in overall agreement with depths computed along the seismic profile, hence, it is reasonable to assume that the density contrast of 0.5 gm/cm^3 is a valid estimate. The contour map showing thickness of unconsolidated valley-fill material (fig. 15) was constructed by using the two computed gravity cross sections as a basis for interpolation over the entire map area.

Due to the wide spacing of gravity stations which requires interpolation between gravity measurements and the few wells drilled to limestone, the accuracy of depth determination on this type of map is difficult to determine. If the map is used to determine overall volume of unconsolidated sediments, the map will give a good average estimation; but it would be unrealistic to use the map to pinpoint depths. This especially applies to the area along the eastern edge of the map where the gravity shows a steep gradient.