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Ground-water resources of the headquarters (cantonment) area, White Sands Proving Ground, Dona Ana County, New Mexico, by E. H. Herrick

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GROUND-WATER RESOURCES OF THE HEADQUARTERS (CANTONMENT) AREA, WHITE SANDS PROVING GROUND, DONA ANA COUNTY, NEW MEXICO

By

E. H. Herrick

OPEN-FILE REPORT

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GROUND-WATER RESOURCES OF THE HEADQUARTERS (CANTONMENT) AREA WHITE SANDS PROVING GROUND, DONA ANA COUNTY, NEW MEXICO

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ABSTRACT

This report describes the geology and ground-water resources in an area of about 200 square miles in the vicinity of the military headquarters[1]

[1] "Headquarters" as used in this report is to be interpreted to mean "cantonment."

at White Sands Proving Ground in east-central Dona Ana County, New Mexico. A detailed study was made of the occurrence of ground water in the bolson deposits, the principal aquifer in the area.

The headquarters is within a reentrant in the mountains bordering Tularosa Basin on the west. The reentrant is bounded on the south and southwest by the Organ Mountains, on the northwest by the San Augustin Mountains, and on the north by the San Andres Mountains. The total relief of the area is nearly 5,000 feet. Several small springs occur in the mountains, but there are no perennial streams. Playas in the basin east of the headquarters occasionally contain water after heavy showers. The average annual precipitation in the area is estimated to be about 13 inches, and the average annual temperature at the headquarters is about 65°F.

The Organ and San Augustin Mountains are composed principally of Tertiary intrusive and extrusive rocks. In the northern part of the San Augustin Mountains and in the San Andres Mountains, Paleozoic sedimentary rocks overlie Precambrian granite. The north half of the reentrant is a pediment surface developed on a Precambrian basement complex. Several prominent hills of Precambrian rock rise above the pediment surface. The south half of the reentrant is underlain by unconsolidated bolson deposits, which resistivity measurements indicate to be more than 1,500 feet thick in places. On the geologic map accompanying this report the Precambrian granite and metamorphic rocks, the Paleozoic sedimentary rocks, the Tertiary extrusive and intrusive rocks, and the Tertiary(?)-Quaternary bolson deposits are delineated.

Electrical-resistivity measurements were made at 57 sites, principally in the south half of the reentrant. Maps of the area showing the thickness of the bolson deposits and the altitude of the bedrock are based upon the resistivity measurements and the formation logs of 5 test holes and 3 wells drilled during the course of this study.

The source of the ground water in the bolson deposits in the headquarters area is precipitation within the reentrant and the nearby mountains, an area of approximately 40 square miles. The average annual recharge to the area is estimated to be approximately 6,000 acre-feet. Water-table contours indicate that the ground water moves eastward out of the reentrant to the lower part of the basin east of the headquarters area, whence it moves southeast toward the Hueco bolson in Texas. Chemical analyses of 44 samples of water from wells and test holes indicate that the ground water within the reentrant, at least to a depth of 1,000 feet, contains very little mineral matter, but that even the shallow ground water in the basin only a few miles east of the headquarters is highly mineralized. At the present (1960) rate of withdrawal, there appears to be little danger of contamination of the ground water tapped by wells; however, as the conditions are not known exactly, samples of water from the eastern-most wells probably should be analyzed at least every 6 months.

Approximately 1,000,000 acre-feet of water is stored in the bolson deposits underlying the reentrant west of the access highway to the Proving Ground headquarters. Much of this stored water is not available to wells. Water levels in some of the pumped wells have declined more than 10 feet in the 4 years since the wells were completed. As recharge to the ground-water body of the bolson deposits in the reentrant cannot be increased appreciably nor the natural discharge reduced appreciably within the foreseeable future, pumping in the headquarters area must continue to remove ground water from storage. Therefore, water levels will continue to decline. The declines over a period of 30 years are estimated to range from 16 feet at well 10 to 70 feet at well 11.

The available data indicate that the most promising locations for wells are in sec. 12 and the eastern parts of secs. 11 and 13, T. 22 S., R. 4 E.

INTRODUCTION

Purpose and Scope of the Investigation

Until 1947, White Sands Proving Ground was able to supply its requirements for water from several wells having small yields in the SE$\frac{1}{4}$ sec. 31 and the SW$\frac{1}{4}$ sec. 32, T. 22 S., R. 5 E. In 1948 a well was drilled in the NE$\frac{1}{4}$ sec. 24, T. 22 S., R. 4 E., and by 1952 three additional wells in the SW$\frac{1}{4}$ sec. 13, and the NE$\frac{1}{4}$ sec. 23, T. 22 S., R. 4 E., had been completed and added to the water-supply system. Until 1952, these last 4 wells and 2 wells in the old well field supplied sufficient water for the Proving Ground.

Continued expansion at the Proving Ground led to an increase in water consumption. The yields of some wells apparently were declining, and it was evident that the wells in use in 1952 would be inadequate for future water requirements. The reasons for the low yields of some of the wells were not known. Furthermore, the amount of ground water in storage and available to wells and the effects of heavy pumping in the area were not known.

In June 1952, in compliance with a request from the Albuquerque District, U.S. Army, Corps of Engineers, the Ground Water Branch of the U.S. Geological Survey prepared a plan for study of the ground-water resources in the headquarters area at White Sands Proving Ground. Some of the major objectives of the study were to determine:

(1) The general geology of the area and particularly the extent, thickness, and nature of the bolson deposits in the vicinity of the housing and cantonment areas of the Proving Ground.

(2) The hydrologic characteristics of the bolson deposits.

(3) The performance and characteristics of wells and the possibility of increasing the yields of wells.

(4) The amount of potable ground water available to wells in the area.

(5) The probable effects of pumping on ground-water levels and the chemical quality of the water.

(6) The most favorable locations for wells and the optimum spacing of wells.

Previous Investigations

The only previous investigation of ground water in the area was a reconnaissance by Murray (1947), made at the request of the U.S. Army to suggest a new area for water wells, as wells at that time were inadequate. Murray suggested that wells be drilled in the reentrant, the area of the present well field.

The geology and water resources of the Tularosa Basin were the subject of a comprehensive report by Meinzer and Hare (1915). Their study was confined principally to the northern and eastern parts of the basin and did not describe the cantonment area in any detail. Ground water in the southwestern part of the Tularosa Basin and in the Hueco bolson, south of White Sands Proving Ground, was discussed in detail by Sayre and Livingston (1945), and a study of the Hueco bolson by the Ground Water Branch of the U.S. Geological Survey was in progress in 1954.

Lindgren, Graton, and Gordon (1910) discussed the geology of the Organ Mountains in their description of the ore deposits of New Mexico. Darton (1922, 1928a) described the general geology of the area, and Dunham (1935) described in detail the geology of the Organ Mountains. Many shorter papers discuss briefly the geology and hydrology of small areas in and near the Tularosa Basin.

Methods of Investigation

A working agreement between the Corps of Engineers and the Geological Survey was completed in October 1952, and fieldwork in the area outlined in figure 1 was begun in February 1953.

Figure 1.--South-central New Mexico with area described in this report enclosed by hachures.

Topographic maps of the area compiled by the Army Map Service and aerial photographs taken by the Soil Conservation Service of the U.S. Department of Agriculture provided basic control data. Most of the geology was taken directly from the map prepared by Dunham (1935), although some changes, particularly in the positions of the contact between the bolson deposits and the igneous rocks, were made on the basis of reconnaissance mapping during this investigation.

All known wells were inventoried, and, wherever possible, water levels were measured with a steel tape from a fixed measuring point. Considerable difficulty was encountered in obtaining water-level measurements in the wells at the Proving Ground that were equipped with turbine pumps. In none of those six wells was it possible to measure the water level with a steel tape; it was necessary to depend upon air-line gages. No accurate records of water levels prior to February 1953 are available, but since that time water levels in several wells have been measured periodically in order to determine the nature of the fluctuations. In the spring of 1953, recording gages were installed on two unused wells in the area, and almost continuous records of water-level fluctuations in those wells have been obtained. A third recording gage was installed for short periods on various other unused wells and test holes.

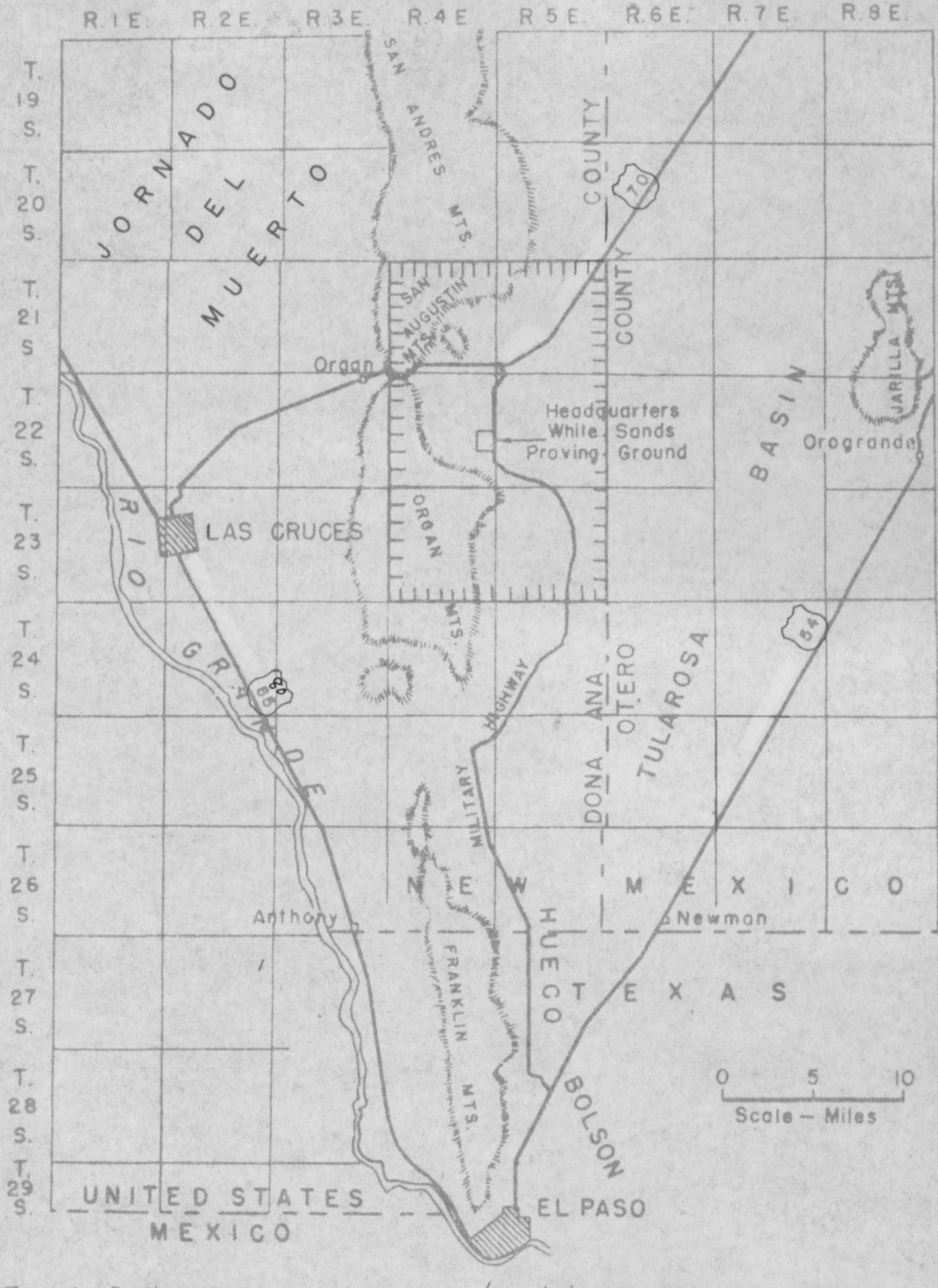


Figure 1.--South-central New Mexico with area described in this report enclosed by hachures

Samples of water from most of the wells in the area were analyzed chemically by the Geological Survey in Albuquerque.

In February, March, and April 1953, an electrical-resistivity survey was made in an area of about 34 square miles by C. B. Yost, Jr., and A. E. Robinson of the Arizona District of the Ground Water Branch, to aid in determining the nature and thickness of the bolson deposits in the reentrant. Interpretations of the resistivity survey were made by Yost, and these appear in a separate section of the present report.

In May, June, and July 1953, five test holes were drilled under contract for the Corps of Engineers, to determine the nature and thickness of the bolson deposits and the chemical quality of the ground water in particular areas. The test holes were located on the basis of information gained from the resistivity survey and other geological evidence available at that time. Formation samples were obtained from the test holes and were correlated with electric logs of the holes.

During the summer of 1953, several pumping tests were made to determine the characteristics of the supply wells and to determine roughly the permeability of the water-bearing materials at the Proving Ground. Several difficulties were encountered, with the result that the tests were less useful than had been expected. Because of the high consumption of water at the Proving Ground during the summer, no pump could be shut off for more than a short period; water levels in the pumped wells could be determined only by means of air-line gages; and the wells are so spaced that, in most tests, the effects of pumping did not reach the adjacent wells.

In the fall of 1953, two production wells were drilled under contract for the Corps of Engineers at locations believed to be favorable, on the basis of data obtained before that time. Formation samples and electric logs of those wells were obtained, and pumping tests were made in January and February 1954. A third production well was completed in September 1954. The data obtained from these three wells have been included in this report.

Intensive field work was concluded in the latter part of 1954, but additional data are still being acquired.

Well-Numbering System

The system of numbering wells in this report is that used by the Geological Survey in New Mexico and is based on the common subdivisions of 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; the third denotes the section; and the fourth, which consists of three digits, denotes the particular 10-acre tract in which the well is situated.

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 indicates 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 22.4.24.222 at White Sands Proving Ground is in the NE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 24, T. 22 S., R. 4 E., as shown in figure 2. If a well cannot be located accurately within a 10-acre tract,

Figure 2.--Plat illustrating method of numbering wells in New Mexico.

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, etc., are added to the last segment to designate the second, third, fourth, and succeeding wells in the same 10-acre tract.

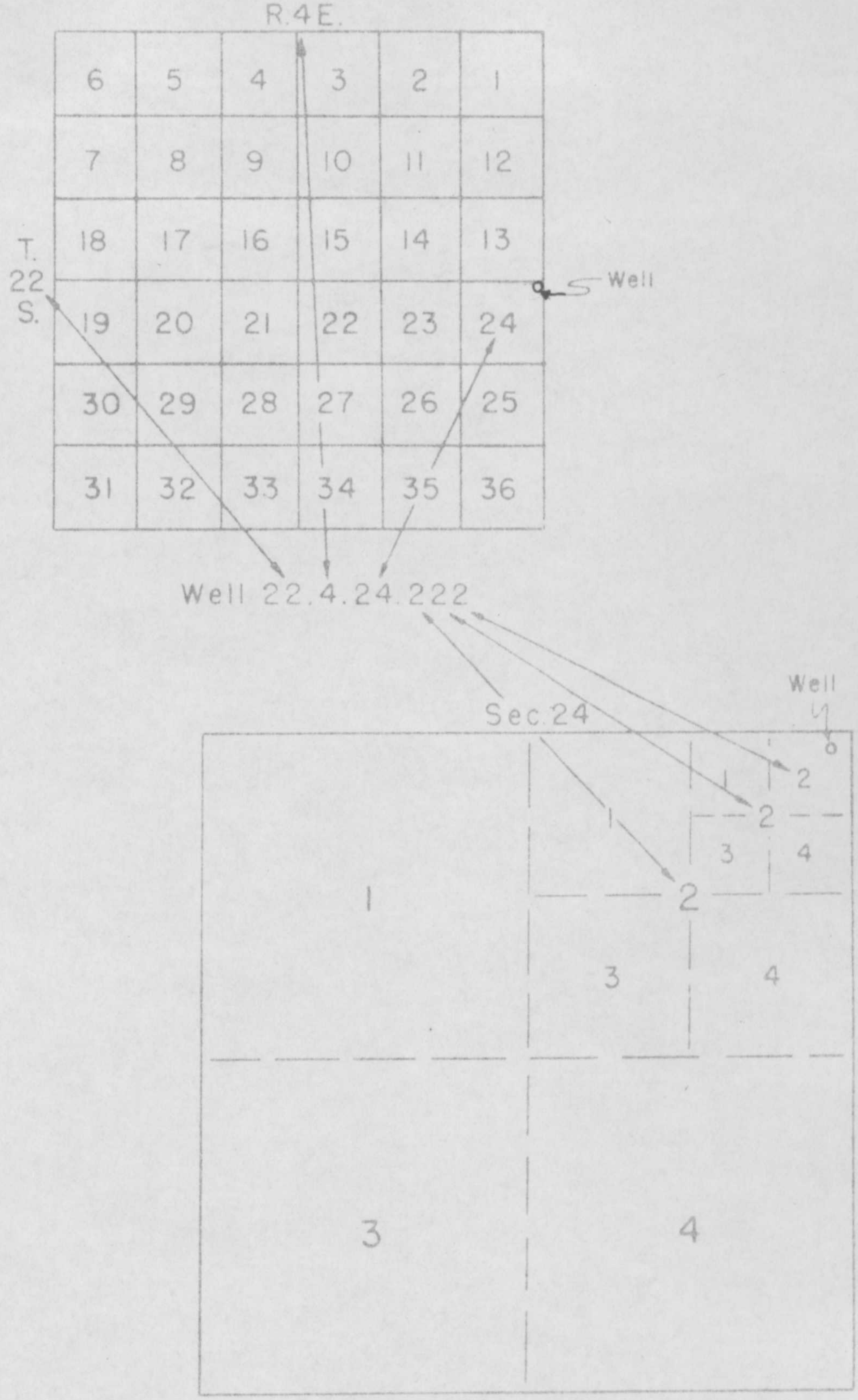


Figure 2--Plat illustrating method of numbering wells in New Mexico

Acknowledgments

The study was made under the general supervision of A. N. Sayre, then chief of the Ground Water Branch of the U.S. Geological Survey, and under the direct supervision of C. S. Conover, at that time district engineer in charge of ground-water investigations in New Mexico.

Generous and helpful cooperation was received from the Albuquerque District, U.S. Army, Corps of Engineers, and from the offices of the Post Engineer and Project Engineer at White Sands Proving Ground. Personnel of the Water and Sewerage Department at the Proving Ground were particularly helpful in furnishing well data and pumping records and aided materially in conducting pumping tests. Mr. James Cox, rancher, has made available useful precipitation records and other pertinent data.

Several members of the New Mexico district of the Ground Water Branch assisted in the collection and interpretation of field data and critically reviewed the manuscript of this report.

GEOGRAPHY

Location and Extent of the Area

White Sands Proving Ground is in the western part of the Tularosa Basin in eastern Dona Ana County and western Otero County, New Mexico. The housing and cantonment areas of the Proving Ground are principally in sec. 24, T. 22 S., R. 4 E., in Dona Ana County, about ~~25~~ 18 miles east of Las Cruces, about 50 miles southwest of Alamogordo, and about 40 miles north of El Paso, Texas.

The area discussed in this report is primarily that in the immediate vicinity of the headquarters but includes in general most of Tps. 21-23 S., Rs. 4 and 5 E. as shown in figure 1. Surrounding areas were investigated in order to relate the local ground-water conditions to general areal conditions.

Topography and Drainage

The headquarters area of White Sands Proving Ground lies within a reentrant in the mountains bordering Tularosa Basin on the west. Tularosa Basin is a bolson, or closed basin. The reentrant encompasses an area of about 40 square miles and is bounded on the south and southwest by the Organ Mountains, on the northwest by the San Augustin Mountains, and on the north by the San Andres Mountains. (See ~~pl. 1~~ fig. 2A.)

Figure 2A.--Headquarters area, White Sands Proving Ground, Dona Ana County, New Mexico--Geology, wells, and altitude of the water table, 1953-54

The Organ Mountains reach an altitude of 9,000 feet at Organ Needle, about $5\frac{1}{2}$ miles southwest of and 4,750 feet above the Administration Building. Organ Needle is the highest point inthe Organ Mountains, but many of the peaks reach altitudes above 8,000 feet. From Organ Needle north 3 miles to Baylor Pass, the Organ Mountains present a succession of almost inaccessible jagged spires and crags, whose resemblance to organ pipes probably accounts for the name given the range. From Baylor Pass north to San Augustin Pass, the relief is more subdued, more nearly resembling the San Augustin Mountains, to which the Organ Mountains are geologically related. San Augustin Pass, through which passes U.S. Highway 70 at an altitude of 5,700 feet, is the lowest part of the mountain rim separating the reentrant from the Rio Grande Valley to the west.

The San Augustin Mountains north of San Augustin Pass are geologically related to the Organ Mountains and the San Andres Mountains, between which they form a connecting link of rounded peaks reaching altitudes of 6,000 to 7,000 feet. The south end of the San Andres Mountains forms the northern boundary of the reentrant.

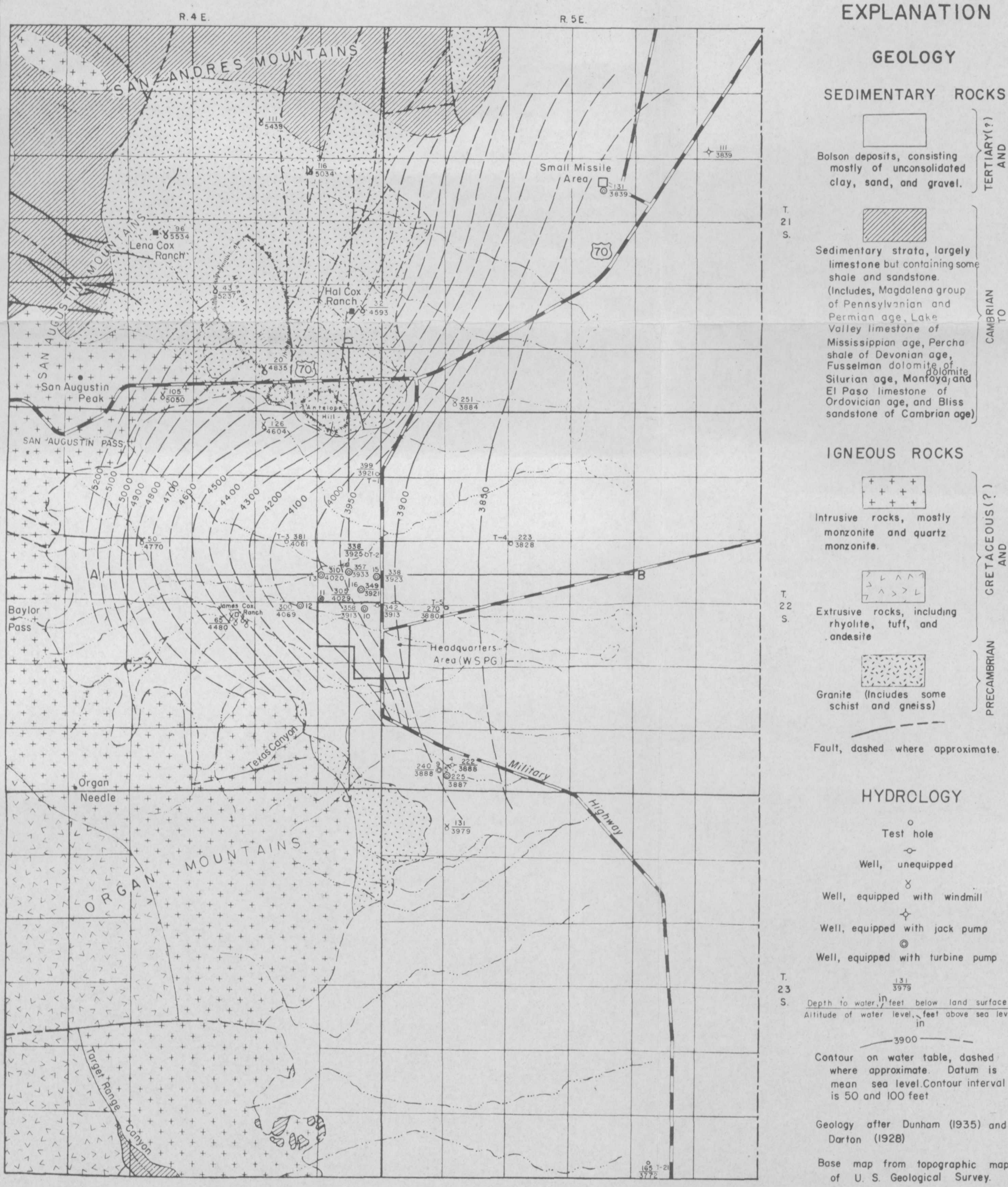


Figure 2A.

HEADQUARTERS AREA, WHITE SANDS PROVING GROUND, DONA ANA COUNTY, NEW MEXICO

Geology, wells, and altitude of the water table, 1953-54

1 0 1 2 3 4 miles

SCALE

A pediment surface that is developed on a Precambrian basement complex forms the floor of the northern half of the reentrant. Above the pediment surface rise several hills, the largest of which is Mineral Hill, about 1,000 feet high. South of U.S. Highway 70, resistivity measurements indicate that the unconsolidated bolson deposits forming the floor of that part of the reentrant are as much as 1,500 feet thick. Extensive talus slopes and alluvial fans are developed at the foot of the Organ and San Augustin Mountains. The eastward slope of the land surface in the south half of the reentrant ranges from 100 feet per mile at the mouth of the reentrant to between 300 and 400 feet per mile near the mountains. The altitude at the Administration Building is about 4,250 feet, and that of the land surface in the lower part of Tularosa Basin about 4 miles east of the Administration Building is about 3,950 feet.

Although generally well defined arroyos extend from the mountains to the playas east of the headquarters area, there are no perennial streams. Several small springs occur in the mountains, but some springs at lower altitudes have ceased to flow in recent years. The arroyos flow only immediately after the infrequent hard showers that occur mostly in the late summer. Water in the playas after heavy showers eventually evaporates or infiltrates through permeable floors.

Climate

The climate is typical of the continental arid regions of southwestern United States. The days are generally clear and warm even in the winter, but the diurnal range in temperature is large because of the high altitude (4,250 feet above sea level at the Air Weather station) and the clear atmosphere. High winds and sandstorms are common in the spring.

Climatological data have been recorded by the Air Weather Service at White Sands Proving Ground since August 1947. Mr. James Cox, local rancher, has recorded precipitation at the Cox Ranch, about 2 miles west from and 300 feet higher than the Air Weather station, since 1923.

The average annual precipitation at the Air Weather station for the period 1948-53 was 8.31 inches, compared with an average annual precipitation at the Cox Ranch of 10.06 inches. The average annual precipitation at the Cox Ranch for the period 1923-53 was 12.91 inches. There are no records of precipitation in the Organ Mountains west of Cox Ranch, but the average annual precipitation at higher altitudes (8,000 feet above sea level) probably exceeds 18 inches. A large part of the precipitation in the area occurs in heavy showers of local extent, largely in July, August, and September.

The average annual temperature at the Air Weather station for the period 1950-53 was 65°F. The average humidity probably is less than 40 percent. The annual evaporation probably exceeds 90 inches, as the average annual evaporation at the Jornada Experimental Range, west of the San Andres Mountains, at an altitude of 4,265 feet and a mean annual temperature of 59° F is 96 inches. The average monthly maximum and minimum temperatures for the period 1950-53 and the average monthly precipitation for the period 1948-53 at the Air Weather station are given in figure 3. Table 1 ~~and figure 4~~ gives the precipitation at the Air Weather station by months for

Figure 3.--Average monthly temperatures and precipitation at the Air Weather station, White Sands Proving Ground.

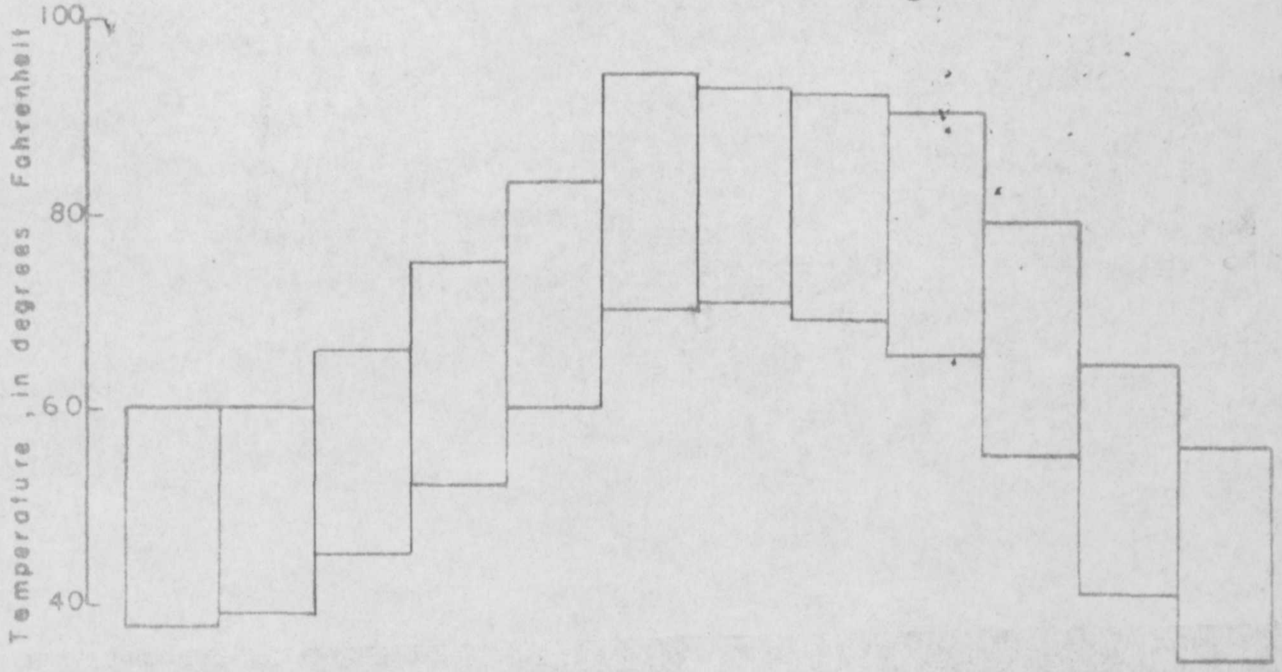
Monthly

~~Figure 4.--Precipitation by months at the Air Weather station, White Sands Proving Ground, 1947-53.~~

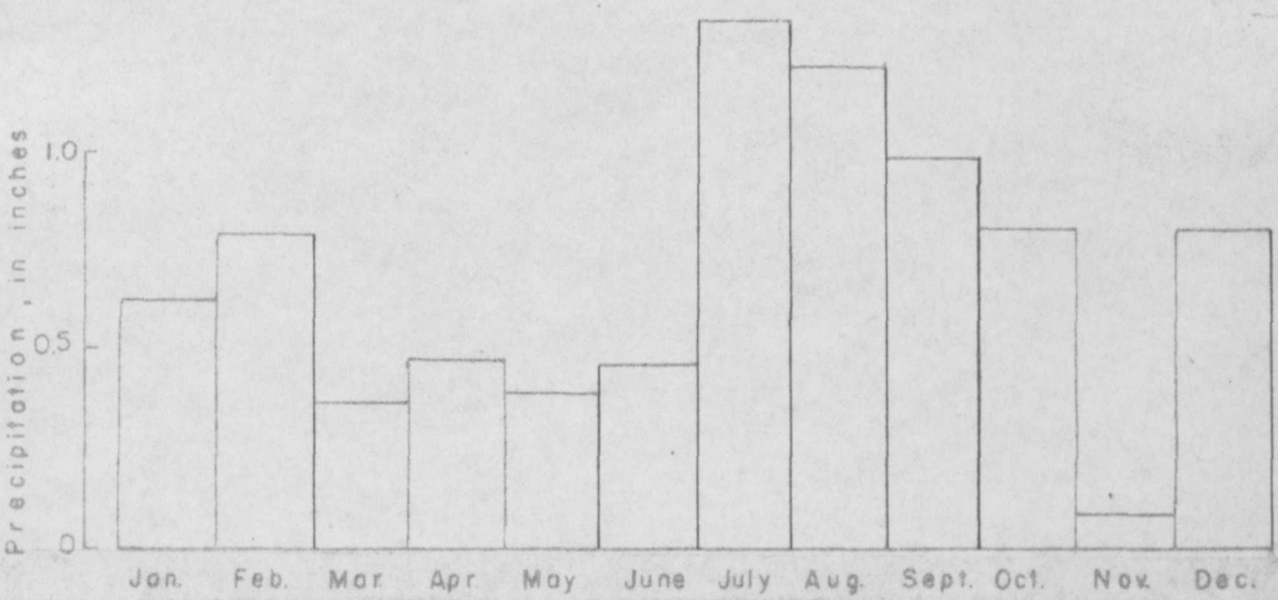
the period of record. Figure 5 gives the annual precipitation at the

Figure 5.--Annual precipitation at the James Cox Ranch, 1923-53.

Cox Ranch from 1923 to 1953.



Average monthly maximum and minimum temperatures, 1950-53



Average monthly precipitation, 1948-53

Figure 3.--Average monthly temperatures and precipitation at the Air Weather station, White Sands Proving Ground

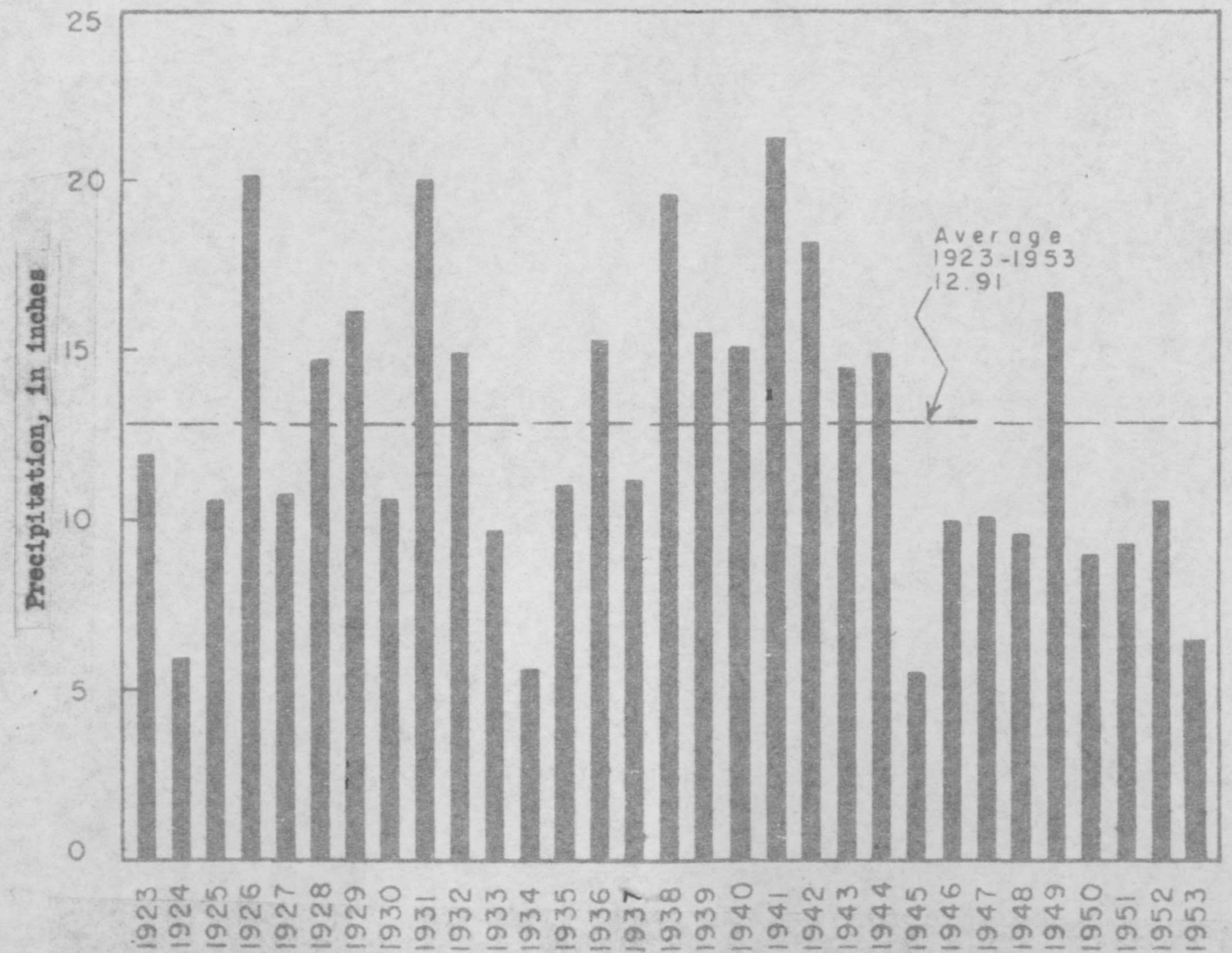


Figure 5.--Annual precipitation at the James Cox Ranch, 1923-53

Table 1.--Monthly precipitation, in inches, at the Air Weather station, White Sands Proving Ground, N. Mex., 1947-54

Month	1947	1948	1949	1950	1951	1952	1953	1954
Jan.	-	1.19	1.98	0.00	0.14	0.40	0.00	0.08
Feb.	-	1.06	.57	.28	.36	1.21	1.28	T
Mar.	-	.46	.00	.00	.28	1.34	.09	.31
Apr.	-	.00	.16	.00	.80	1.37	.48	T
May	-	.31	.78	.25	.10	.49	.15E	.27
June	-	1.51	.05	.11	.00	.65	.47E	.15
July	-	.22	1.68	3.46	.04	1.42	1.35	1.21
Aug.	0.83	2.79	.09	.01	2.68	1.48	.24	1.28
Sept.	.00	.41	3.85	1.20	.04	.26	.14	1.18
Oct.	.04	.36	2.05	1.04	.67	.00	.70	1.38
Nov.	1.35	.00	.00	.00	.19	.32	.02	.00
Dec.	1.77	1.56	~~.35~~ .85	.00	1.78	.38	.23	.05
Total	-	9.87	~~11.56~~ 12.06	6.35	7.08	9.32	5.15E	5.91

E - Estimated.

T - Trace.

GEOLOGY

Stratigraphy

The rocks exposed in the area range in age from Precambrian to Recent and consist of igneous and sedimentary rocks in the mountains and igneous rocks on the pediment surface in the north half of the reentrant. In the south half of the reentrant, between U.S. Highway 70 and the central part of the Organ Mountains, unconsolidated bolson deposits of Quaternary age, and, perhaps, partly of late Tertiary age extend to depths greater than 1,500 feet, probably overlying mainly Precambrian granite. The bolson deposits are the only important source of ground water in the Proving Ground, and these deposits were studied in much greater detail than the other rocks of the area, which have been described in detail previously by Dunham (1935).

The areal distribution of the rocks is shown on ~~plate 1~~ Figure 2A, and more

~~Plate 1~~ Figure 2A.--Headquarters area, White Sands Proving Ground, Dona Ana County, New Mexico--Geology, wells, and altitude of the water table, 1953-54.

detailed descriptions, including logs of holes drilled in the bolson deposits (table 2), and mechanical analyses of drill cuttings (table 3), appear in the following pages.

Precambrian Rocks

Precambrian rocks are exposed principally in Antelope Hill and Mineral Hill and the rock pediment north of U.S. Highway 70. They are well exposed also on the east side of the Organ Mountains in the northeastern part of T. 23 S., R. 4 E., and the northwestern part of T. 23 S., R. 5 E. Precambrian rocks are exposed in a small inlier southwest of the James Cox ranch.

The predominant Precambrian rock in the area is granite, but xenoliths composed of metamorphic rocks are contained in the granite. Particularly prominent is a large outcrop of chlorite schist at the north end of Mineral Hill. Small pegmatite dikes and epidiorite dikes of late Precambrian age are numerous in the granite.

Dunham (1935) concluded that "the basement complex of the Organs forms part of a large composite batholith, which was eroded to the hypobatholithic state in late Precambrian time. The granite occurring in the batholith is of two types, an older coarse-grained granite and a younger medium-grained granite, which is particularly well exposed in the pediment area northwest of Mineral Hill."

The Precambrian rocks are poor aquifers, although they furnish water to a few stock wells in the northern part of the area. Windmill pumps to furnish water to stock have been installed also at some abandoned mine shafts sunk in Precambrian rocks. Chemical analyses of water from wells in the Precambrian rocks indicate a somewhat high concentration of fluoride; otherwise, the water chemically is generally potable.

Paleozoic Rocks

Sedimentary rocks of Paleozoic age are well exposed north of San Augustin Peak and along the west side and at the south end of the Organ Mountains. A series of quartzites and shales, representing the Bliss sandstone of Late Cambrian age, rests upon Precambrian granite north of San Augustin Peak and along the east side of the Organ Mountains at their south end. The series ranges in thickness from 120 to 140 feet. Overlying the Bliss sandstone in both localities are dolomitic beds having a total thickness of 750 to 800 feet and belonging to the El Paso limestone of Early Ordovician age. The Montoya dolomite, Late Ordovician in age and ranging in thickness from 240 to 300 feet, overlies the El Paso limestone. Comformably overlying the Montoya is the Fusselman dolomite, Silurian in age and ranging in thickness from 180 to 210 feet. North of San Augustin Peak, the Fusselman is overlain by a series of dark-colored shale, which Dunham (1935) tentatively identified as the Percha shale of Devonian age. The series is about 115 feet thick north of San Augustin Peak and ~~north~~ crops out at the north end of Target Range Canyon in the southern part of the Organ Mountains, where it apparently pinches out. North of San Augustin Peak, Dunham (1935) mapped a limestone, the Lake Valley limestone of Mississippian age, about 300 feet thick, which overlies the Percha shale. Overlying the Lake Valley limestone are beds of limestone, shale, and some thin sandstone belonging to the Magdalena group of Pennsylvanian and Permian age. At the south end of the Organ Mountains, limestone beds of the Magdalena group rest directly on top of the Fusselman dolomite.

The Paleozoic rocks do not crop out within the reentrant and are not sources of water to the Proving Ground. A few domestic wells in the vicinity of Organ, west of San Augustin Pass, reportedly tap rocks of the Magdalena group.

Cenozoic Rocks

Extrusive rocks

Extrusive rocks, including basal tuff, rhyolite, and andesite, crop out extensively in the southwestern part of the Organ Mountains. Andesite also crops out about 3 miles north of Organ west of the San Augustin Mountains. The exact age of these rocks has not been determined, but they probably were extruded in early Tertiary time.

The extrusive rocks are not known to yield water to wells in the area, although they yield water to a few springs in the southwestern part of the Organ Mountains.

Intrusive rocks

Crystalline intrusive rocks form the rugged eastern and northern parts of the Organ Mountains and crop out over an area of more than 40 square miles from north of San Augustin Peak south to the head of Target Range Canyon. Before the geology of this area had been studied in detail, the intrusive rocks were thought by some (Keyes, 1905) to be of Precambrian age. Lindgren (1906) and Darton (1928a), among others, noted that the intrusive rocks are post-Carboniferous, and Dunham (1935) demonstrated that they definitely are younger than some of the extrusive rocks and therefore probably are of Tertiary age.

Three major rock types are represented among the intrusive rocks. A monzonite rich in ferromagnesian minerals crops out at the head of Texas Canyon in secs. 34 and 35, T. 22 S., R. 4 E.; a quartz monzonite forms the higher parts of the Organ Mountains from the head of Target Range Canyon north almost to San Augustin Pass; and a quartz-bearing monzonite forms San Augustin Peak and crops out in the area surrounding the peak. The quartz-bearing monzonite is coarse grained and readily distinguishable from the other Tertiary intrusive rocks. However, it closely resembles some of the Precambrian granite, and in the field the two can be distinguished only with difficulty. Aplite and quartz-feldspar porphyry dikes occur irregularly in the monzonites, and several porphyry sills were noted by Dunham (1935) in the sedimentary rocks at the northern end of the Organ Mountains and west of San Augustin Peak. Numerous rhyolite dikes cut both the major Tertiary intrusive rocks and the Precambrian granitic rocks.

The Tertiary intrusive rocks are not major sources of ground water, although they yield water to a few small springs in the mountains.

Bolson deposits

All the unconsolidated deposits of clay, sand, and gravel in the reentrant between the San Andres and Organ Mountains are considered as a unit in this report. Because the Tularosa Basin is a bolson, as the term is generally used (Fenneman, 1931, p. 385-386), it seems proper to refer to these unconsolidated materials as bolson deposits. They include not only the older materials at considerable depths but also the younger talus and outwash deposits.

The unconsolidated deposits in the headquarters area have been derived from the nearby mountains and are not gypsiferous, as are most of the sediments in the main part of the Tularosa Basin. Most of the unconsolidated material in the reentrant probably is of Quaternary age, although some of the deeper material may have been deposited in late Tertiary, possibly Pliocene, time.

<u>Distribution and thickness</u>.--Throughout almost all the pediment area north of Antelope Hill, the crystalline bedrock is exposed or is covered by only a few feet of unconsolidated material. However, most of the south half of the reentrant between Antelope Hill and the central part of the Organ Mountains is floored with a considerable thickness of unconsolidated bolson deposits, as shown on ~~plate 1~~ figure 2A. It is these deposits, underlying more than 25 square miles of the reentrant, that contain the principal ground-water resources of the headquarters area of the Proving Ground.

In order to estimate the quantity of available ground water in the headquarters area, it was necessary to determine as accurately as possible the thickness of the bolson deposits. Consequently, during the early part of the study electrical-resistivity measurements were made throughout the south half of the reentrant. A more detailed discussion of the resistivity survey is contained in a subsequent section of this report (p. 42). Drillers' logs of many of the wells drilled prior to 1953 were available for study, but these provided information on only the upper few hundred feet of the deposits. During the summer of 1953, five test holes were drilled. These not only furnished an opportunity to examine the character of the materials in detail but also permitted a check on the thickness of the bolson deposits indicated by the resistivity measurements.

Figure 6 shows the thickness of the bolson deposits in the south

Figure 6.--Thickness, in feet, of the bolson deposits in the headquarters area, White Sands Proving Ground.

half of the reentrant, as interpreted from resistivity measurements. These measurements indicate that the deposits in the western half of that part of the reentrant are less than 500 feet thick. Northeast and north of the cantonment area, almost all of sec. 18 and the southeast cor. sec. 7, T. 22 S., R. 5 E., is underlain by more than 1,500 feet of unconsolidated material, as in the northeast cor. sec. 13, the south half of sec. 12, and the east half of sec. 11 in T. 22 S., R. 4 E. An area of about 7 square miles north and northeast of the cantonment area is underlain by bolson deposits to a depth of more than 1,000 feet.

Test holes T-1 (22.4.1.444), T-2 (22.4.13.~~232~~ 223), T-4 (22.5.16.111), and T-5 (22.5.20.111) were drilled to a depth of 1,000 feet without reaching bedrock. The resistivity data indicate that test holes T-1 and T-5 probably were drilled almost to bedrock, although this was not apparent from the drill cuttings. Test hole T-3 (22.4.14.~~122~~ 211) penetrated fractured igneous rock at a depth of 770 feet. No other holes drilled in the area have completely penetrated the bolson deposits.

The interpretation of the thickness of the bolson deposits from resistivity measurements is subject to limitations, as explained on p. 47-51, and it cannot be assumed that figure 6 is accurate in detail. However, the interpretation of the data as presented by the figure is approximately correct. Additional exploratory drilling in the area will provide more detailed supplementary data.

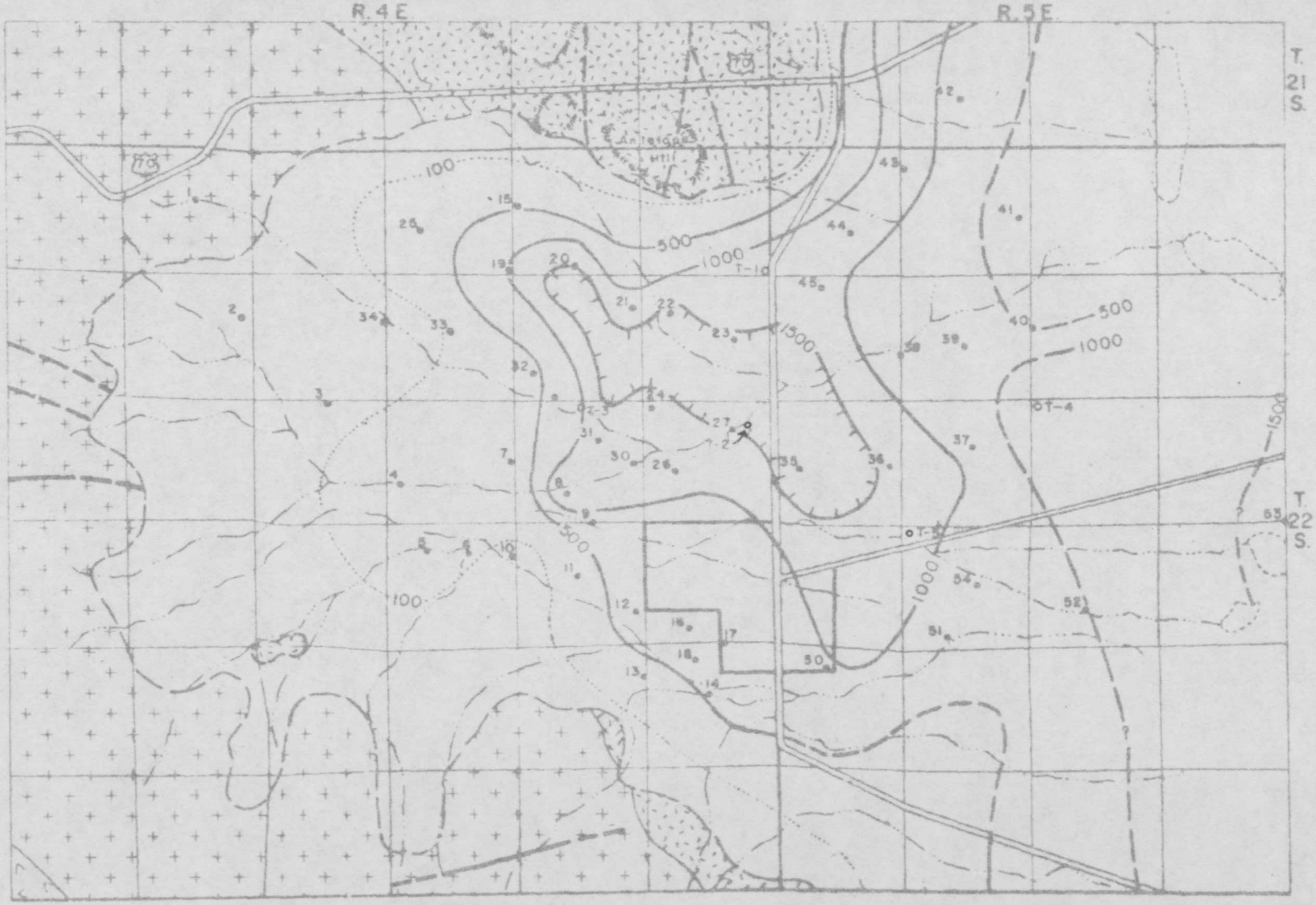


Figure 6 -- Thickness, in feet, of the bolson deposits in the headquarters area, White Sands Proving Ground

0 1 2 miles

EXPLANATION

Contour interval - 500 feet.

•23 Resistivity station

○T-2 Test hole

(For explanation of geology, see figure 2A)

Character.--The bolson deposits are not well exposed in section in the headquarters area, as cuts penetrate the deposits only a few feet. However, the drill cuttings and electric logs obtained from the 5 test holes and 3 wells drilled during this investigation furnish data regarding the character of the deposits to a depth of 1,000 feet. Sample logs of these test holes and wells and drillers' logs of other wells in the area are contained in tables ~~7~~ 2 and ~~8~~ 3.

The bolson deposits consist of alternating layers of clay and sand and some gravel. Most of the sand and gravel layers contain some clay, and much of the clay is sandy. Well-defined layers of sand generally are less than 20 feet thick. The granitic particles that make up a large part of the unconsolidated material of the reentrant disintegrate readily, and the feldspar weathers to clay. For that reason, gravel is confined generally to the upper few hundred feet of the bolson deposits, and clay makes up a large proportion of the deeper deposits. Well-sorted gravel was not penetrated below the water table in any of the test holes or wells.

The sands and gravels in the reentrant are composed principally of feldspar and quartz, derived from the granite, monzonite, and related igneous rocks of the Organ and San Augustin Mountains. In the northern part of the reentrant, limestone and sandstone particles are common. Lenticular deposits of caliche ranging in thickness from 1 to 3 feet are common in the higher terrace gravels in the northern part of the reentrant, and several layers of gravel cemented with calcium carbonate were penetrated in test hole T-1. Caliche is almost completely absent from the bolson deposits throughout the southern part of the reentrant.

Drillers' logs indicate that the deposits in the old well field contain mostly clay and practically no clean sand or gravel. It is reported that a large number of boulders were encountered in wells 10, 11, 12, and 13. Although the drillers' logs indicate that very little clay was penetrated in these wells, the performance of the wells suggests that the deposits contained much more clay than was noted. Well-defined layers of sand were penetrated in wells 15 and 16 and in test holes T-2 and T-3. Test holes T-4 and T-5 penetrated more clay than was observed in the test holes and wells north of the cantonment area. The sand penetrated in the former two test holes occurred in fairly well-defined layers ranging in thickness from less than a foot to almost 5 feet. Very little gravel was penetrated below the water table in test holes T-4 and T-5, and most of the sand ranged from very fine to medium.

The wells and test holes were not drilled close enough to each other to permit a definite correlation of beds between adjacent holes, but the various beds probably change character or completely pinch out within a few hundred feet.

In general, the coarsest material of the bolson deposits occurs near the mountains; however, the deposits in that area are poorly sorted and therefore relatively impermeable. Beyond the alluvial fans and throughout much of the central part of the reentrant, the deposits are better sorted but still contain a considerable amount of coarse material. East of the access highway, several miles from the mountains, the bolson deposits are well sorted but contain a large amount of fine material, including much clay. These deposits are less permeable than those in the central part of the reentrant. Thus, there appears to be a general transition from material having a low permeability near the mountains to material having the greatest permeability beyond the alluvial fans, and then to fine, relatively impermeable material in the main part of Tularosa Basin.

Geologic History

Dunham (1935) reconstructed much of the geologic history of the region, which earlier had been described by Lindgren (1910) and others. The following discussion is based principally on the work of Dunham.

Precambrian Time

The earliest known event of Precambrian time in the White Sands area was the deposition of clastic and pelitic sediments. Those sediments later were metamorphosed and subjected to lit-par-lit injection by a granite magma, producing quartzite, schist, and gneiss. Only small remnants of these oldest rocks remain in the form of xenoliths in younger intrusive rocks.

A large granite batholith was intruded into the metamorphosed rocks in at least two stages. The first stage is represented by a coarse-grained granite containing large phenocrysts of orthoclase feldspar. The coarse-grained granite was intruded by a medium-grained granite, which is well exposed on the pediment northeast of Mineral Hill. The two bodies of granite then were intruded by many small pegmatite sheets and dikes. The youngest Precambrian rocks in the area are diabase intrusions, which form several widely scattered dikes that cut only Precambrian rocks.

Toward the end of Precambrian time, the area was uplifted and subjected to extensive erosion. At the end of the cycle of erosion, the upper part of the batholith had been removed, and the central core was exposed as a smooth peneplained surface.

Paleozoic Era

During Late Cambrian and Early Ordovician times this area was inundated by epicontinental seas, and the Bliss sandstone and El Paso limestone were deposited. A regression of the sea during Middle Ordovician time was followed by another transgression in Late Ordovician time, and the dolomitic beds of the Montoya dolomite were deposited. A more restricted sea in Middle Silurian time is indicated by the more limited distribution of the Fusselman dolomite. The absence of the Percha shale of Devonian age and the Lake Valley limestone of Mississippian age from the southernmost parts of New Mexico indicates that a gentle warping at the end of the Silurian period had uplifted that area south of the Organ Mountains above sea level. Both formations are absent from the southern Organ and the Franklin Mountains. During the Pennsylvanian and Permian periods, marine conditions were widespread, as is indicated by the large area occupied by rocks of the Magdalena group. Permian rocks are present also in the nearby San Andres Mountains.

Mesozoic Era

Mesozoic rocks are absent from the Organ Mountains, but probably they were deposited and later eroded from the area. Near the end of Cretaceous time, the region was uplifted and the beds were gently tilted to the west. Extensive erosion probably accompanied and followed the uplift.

Cenozoic Era

The extrusive rocks in the southern part of the Organ Mountains probably are of Tertiary age, although the volcanism may have begun in Late Cretaceous time. Basal tuff resting on a thin conglomerate at the head of Target Range Canyon indicates that the volcanism began with explosive eruptions and was followed by a period of quiet extrusion, during which andesite lavas were deposited. After the deposition of the andesite, explosive eruptions began again. Finally, rhyolite lava was deposited. The rhyolite is more than 2,500 feet thick.

The crystalline rocks that form the greater part of the Organ Mountains were intruded in Tertiary time as a composite batholith. ~~It has been demonstrated that~~ the batholith ~~definitely~~ is younger than the andesite flows and probably is younger than the rest of the lava series. Lindgren (Lindgren and others, 1910) suggested that the structure might be laccolithic, but no evidence of a floor to the body has been discovered. Dunham (1935) has described in great detail the various rock types, mainly monzonites, of the batholith and the related intrusive rocks.

By the beginning of Miocene time, the intrusive cycle was completed. The region of the Organ Mountains had been uplifted high above sea level by tectonic processes which had been taking place since the end of the Cretaceous period. During late Tertiary and probably early Quaternary time, extensive erosion reduced the mountains of the Rio Grande region, and the Santa Fe group accumulated in basins along the present course of the Rio Grande. Dunham (1935) has conjectured that the Organ Mountains batholith was unroofed before the end of the Tertiary. The Organ-San Andres mountain chain ~~probably~~ was uplifted relative to the Tularosa Basin probably during late Tertiary time. On the west side of the San Andres Mountains, the rocks dip under the plain of the Jornada del Muerto; the prominent east-facing scarp of those mountains appears to be chiefly a result of extensive north-south faulting. It is reasonable to conclude that both the Organ and the Franklin Mountains are part of the same great fault block.

The present topography was produced by faulting and erosion during Tertiary and Quaternary time. A pronounced scarp in the bolson deposits extends along much of the eastern base of the Organ Mountains; Sayre (and Livingston, 1945, p.18) concluded that a similar feature along the eastern base of the Franklin Mountains is "... undoubtedly a fault scarp." Resistivity measurements across a similar escarpment near the James Cox ranch did not indicate a displacement of the underlying bedrock. It is difficult to explain the escarpment by other than faulting, and it is likely that more intensive investigation than was possible during this study will prove its tectonic origin.

ELECTRICAL-RESISTIVITY MEASUREMENTS

By C. B. Yost, Jr.

In the reentrant occupied by the headquarters of White Sands Proving Ground, alluvium is underlain at various depths mostly by granite and quartz monzonite. The alluvium and the granitic rocks are of contrasting resistivity. Consequently, an electrical-resistivity survey should indicate the depth to bedrock and hence the thickness of the alluvium at various places in the area. Arrangements were made for such a survey, and measurements were made at 57 locations shown on figures 6 and 7 during February, March, and April 1953. The results

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Figure 7.--Altitude, in feet, of the bedrock surface in the headquarters area, White Sands Proving Ground.

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of this work, supplemented by test-hole and well data, indicated subsurface conditions fairly well.

~~Of the~~ Several factors considered in the selection of sites for resistivity measurements, priority was given to the need for information at a particular site; however, it was necessary to compromise the need for information with the practicability of measuring the resistivity at the site. Rough terrain made access and operation difficult in some areas. Other areas were unsatisfactory because of grounded power lines, buried pipelines and other cultural features capable of interfering with resistance measurements.

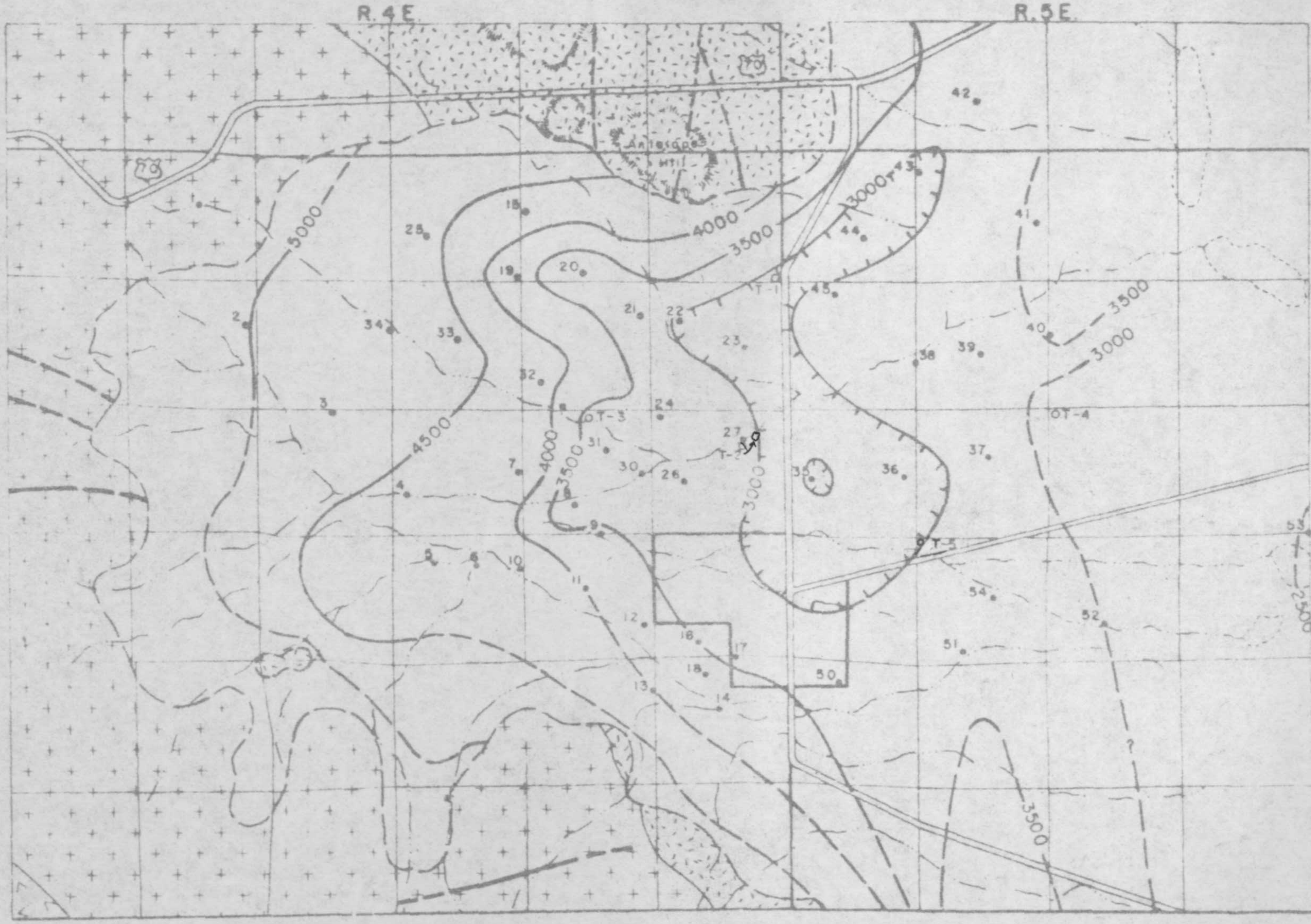

Figure 7.--Altitude, in feet, of the bedrock surface in the headquarters area, White Sands Proving Ground

EXPLANATION

Contour interval- 500 feet

0 1 2 miles

•23 Resistivity station

○T-2 Test hole

(For explanation of geology see figure 2A.)

Most of the resistivity stations were concentrated within the reentrant, where information would be most useful in locating wells reasonably close to the housing area. In particular, an attempt was made to locate deep bedrock areas and then to delineate the boundary between the deep and shallow areas. A smaller number of stations were located at sites east of the reentrant, where supplemental information was desired.

In order to obtain control information for use in interpretation, the resistivity of granitic rock was measured directly on the outcrop at station 1 and indirectly along a profile between stations 1 and 6. The profile measurements indicated that bedrock of very high resistivity lay at relatively shallow depth beneath the alluvium. Station 6 was near the site of a water well, which reportedly entered bedrock at a depth of 118 feet. The resistivity measurement at that station indicated that the top of highly resistive bedrock was at a depth of 115 to 120 feet. Test holes or wells drilled in the future will provide control for additional interpretation of the resistivity survey.

Field Work and Method Used

The field equipment used to make the resistivity measurements consisted chiefly of instruments to measure a commutated direct current flowing in the earth between two electrodes on the surface and to measure the difference in electrical potential between two additional electrodes. By using a commutated direct current, reversed about 20 times per second, the effects of natural earth currents and stake-to-ground contact potentials were eliminated. The reversing potential that resulted from the commutated current flow was converted to a unidirectional potential by a second commutator prior to measurement with a direct-current potentiometer.

The two current electrodes and the two potential electrodes were arranged as shown in figure 8. This configuration requires that

Figure 8.--Diagram of electrode configuration and corresponding electrical condition.

three of the electrodes be equally spaced on a straight line. The center electrodes at the instrument site is not moved during the measurements; the two adjacent electrodes are moved to increasing but equal distances, a, from the center electrode in order that resistivity determinations can be determined at greater depths. A fourth electrode is located at a distance of approximately 2 miles from the center electrode, and, from the standpoint of influence upon the potential measurements, is considered to be at an infinite distance. The "infinite electrode" is always a current electrode; the one at the site is always a potential electrode. Two sets of current-potential readings are made for each electrode interval a. For the first set of readings, one of the electrodes at a distance from the center is used as a potential electrode and the other as a current electrode; for the second set of readings the relation is reversed.

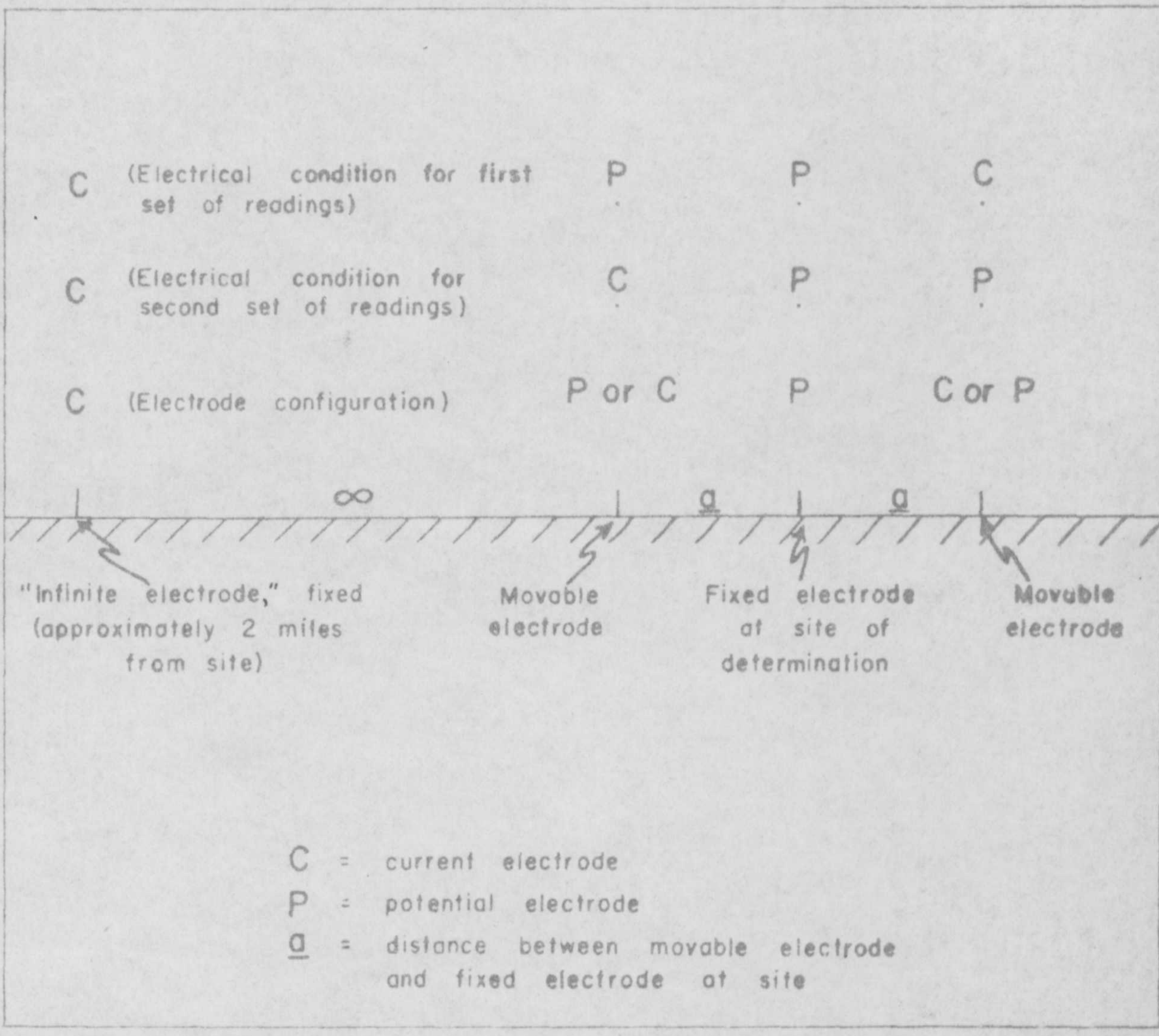

Figure 8--Diagram of electrode configuration and corresponding electrical condition

A curve of apparent resistivity, p, in ohm centimeters, and electrode separation distance, <u>a</u>, in feet, was plotted on logarithmic paper. The values of apparent resistivity were computed from the formula $p = 4 \;\; \underline{a} \; V/I$ in which V is the measured potential and I is the measured current.

Interpretation of Data

The curves of apparent resistivity were interpreted in terms of resistivity and thickness of subsurface layers by comparison with theoretical type curves (~~Tagg, 1934,~~ Wetzel and McMurry, 1937), supplemented when necessary by an empirical method. Further interpretation, in terms of geology, is possible if the resistivities of the rock types in the area are known or can be reasonably assumed on the basis of geologic knowledge.

In order to cause a change in the resistivity curve, a geologic formation must have a resistivity that contrasts with the resistivity of adjacent formations; it must be of appreciable thickness; or, if thin, it must be near the surface. The effect of a thin layer usually is masked by the effects of adjacent layers, especially at depth or where the adjacent layers are thick. Rocks have different resistivities in accordance with their composition, porosity, and contained moisture. Clay commonly has a low resistivity; dense granitic, metamorphic, and volcanic rocks normally have high to very high resistivities; sand and gravel usually have intermediate resistivities. Many porous volcanic rocks have resitivities similar to that of alluvial material, in which case they can not be differentiated by resistivity methods.

Bedrock Configuration

The configuration of the bedrock is presented on two accompanying maps (figs. 6 and 7), one showing the depth of the bedrock surface below the land surface, the other showing ~~elevation~~ altitude of the bedrock surface above sea level.[1] The positions of the contour lines have been determined primarily by straight-line interpolation between depths indicated at each of the 57 resistivity sites. The accuracy of the maps as indicators of depth to bedrock at any particular site depends upon the number and quality of controlling measurements and the amount of relief of the basement surface between control points. At places where control was lacking, a relatively shallow depth to bedrock was assigned in order to keep the indicated deep bedrock areas as small as the available control would permit. This was done so that drilling would be encouraged only at places where there is the least chance of encountering unexpectedly shallow bedrock.

The positions of the contours near the margins of the reentrant were influenced by the location of the surface contact between bedrock and alluvium. Test holes 1 and 4 supplied control that permitted adjustment of the 1,000-foot isodepth line in a direction that enlarged the deeper bedrock area. Information from test holes 2 and 3 did not show a need for altering the position of the interpolated depth lines.

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[1] For the purpose of discussion, many general statements concerning the depth-to-bedrock map apply also to the bedrock-~~elevation~~ altitude map. This is permissible because of their similarity.

In the interpretation of depth to bedrock it was assumed that the buried bedrock is similar to the nearby outcrops and therefore has a very high resistivity. Granitic rocks, such as the quartz monzonite and granite cropping out along the border of the alluvial surface of the reentrant, normally have resistivities of several hundred thousand ohm-cm (ohm-centimeters). In the Basin and Range province, alluvium consisting of boulders, gravel, sand, and clay usually has a resistivity of less than 50,000 ohm-cm.

The generally large resistivity contrast between granitic bedrock and alluvium assumed to be present within the reentrant is favorable for bedrock-depth determination by surface-resistivity methods; therefore, the measurements within the reentrant are thought to be fairly reliable in their indication of the depth to bedrock. The measurements in shallow bedrock areas probably are most accurate. Many depth determinations of 1,000 to 1,500 feet required an extrapolation of the graph past the 1,500-foot stake-separation limits of the measurements. Several curves showed no bedrock effect, and bedrock depth, therefore, was interpreted to be greater than 1,500 feet.

Some bedrock, for example, interbedded limestone and gypsum, may have a resistivity that is roughly similar to that of alluvium. Conversely, a material having a resistivity higher than typical alluvium, under certain conditions, may simulate the effect of granitic basement rock. Data obtained in future drilling, when correlated with the resistivity curves, can be the basis for obtaining new information from the curves as well as for adjusting past interpretation.

The maps (figs. 6 and 7) indicate a deep bedrock area near the mouth of the reentrant. The deepest parts of this bedrock basin are about a mile north of the headquarters and are more than 1,500 feet below the ground surface. To the west, toward the head of the reentrant, a large area is underlain by bedrock at depths of less than 500 feet. More than half the reentrant is within this shallow-bedrock area. From west to east, the transition from the shallow to deep areas, near the west lines of secs. 11 and 14, T. 22 S., R. 4 E., is abrupt. Faulting could be responsible for this sharp increase in depth to the bedrock surface. To the south in secs. 23, 24, and 25, the transition is more gradual.

Outside the reentrant toward the east where there were relatively few resistivity measurements, a general north-south highly resistive ridge of material, which may be bedrock separating the deeper parts (below a 3,000-foot elevation) of the bedrock basin within the reentrant from the main part of the Tularosa Basin, is indicated in secs. 8, 17, and 20, T. 22 S., R. 5 E. (See fig. 7.) This area is considered to be too far from outcrops or other geologic control for the identity of subsurface rock types to be assumed, as was done within the reentrant. This high resistivity may be caused by bedrock, or it may be aberrant. This material is tentatively designated bedrock in this report, and its upper surface is shown on the bedrock maps by dashed and questioned contours.

Resistivity of the Alluvium

Although the primary purpose of the geophysical survey was the determination of the depth to bedrock, the resistivity variations within the alluvium may have significance in determining areas having less clay and where the chemical quality of ground water is good.

In many areas of the Basin and Range physiographic province, very low resistivities of saturated alluvium may indicate clay or highly mineralized water. Higher resistivities may indicate more permeable sand and gravel or water of better quality. Consolidated rocks generally have resistivities higher than those of sand and gravel. Granitic, metamorphic, and volcanic bedrock generally have the highest relative resistivity.

If these typical Basin and Range relations prevail in the headquarters area at White Sands Proving Ground, permeability and chemical-quality factors generally are more favorable within the reentrant than immediately outside the reentrant toward the east.

High resistivity of the alluvium was indicated at stations 19, 20, and 21, near the north line of sec. 11, T. 22 S., R. 4 E. This may indicate that the alluvium in this area contains relatively little clay and that the ground water is not highly mineralized. A test hole in this area would be desirable.

East of the reentrant nearly all the resistivity determinations show the presence of a second layer of material, below a medium-high near-surface layer, and a high third layer which may be bedrock. This second layer, having a resistivity of less than 1,000 ohm-cm and being fairly thick, indicate a large proportion of clay or a greater than normal salt content of the water.

The resistivity data do not obviate the possibility of obtaining ground water of good quality outside the reentrant east of the access highway. However, they do indicate that some areas within the reentrant west of the highway are relatively free of clay, that the ground water west of the highway is not highly mineralized, and that the alluvium is relatively thick.

GROUND WATER IN THE BOLSON DEPOSITS

~~General Features~~

The heterogeneity of the bolson deposits has been discussed in a previous section of this report (p. 35-37). Because the character of the deposits changes markedly within short distances, the occurrence of ground water in the deposits also varies considerably in different parts of the area.

The direction of slope and the gradient of the water table within the reentrant are shown by means of contour lines on ~~plate 1~~ figure 2A. The contour lines indicate that within that part of the reentrant between Antelope Hill and the central part of the Organ Mountains the ground water moves eastward through the bolson deposits. The gradient of the water table ranges from about 450 feet per mile near the mountains to about 50 feet per mile in the vicinity of the access highway at the mouth of the reentrant. Information relating to the altitude of the water table east of the reentrant is meager, but according to the information available, the water table in the lower part of the Tularosa Basin slopes southeastward toward the Hueco bolson at a gradient estimated to be less than 5 feet per mile.

The depth to water within the reentrant, as shown in figure 9,

Figure 9.--Depth to water, in feet below land surface, in the headquarters area, White Sands Proving Ground, 1954.

ranged from a few feet near the mountains to about 400 feet in the vicinity of test hole T-1 (22.4.1.444). The water table is more than 350 feet below the land surface in half of sec. 11, most of sec. 12, and parts of secs. 1, 13, and 14, T. 22 S., R. 4 E., north of the well field. West of that area, the slope of the water table is steeper than the slope of the land surface; consequently, the depth to water decreases toward the west. East of that area, the slope of the water table is less steep than the slope of the land surface; therefore, the depth to water also decreases toward the east. The depth to water in test hole T-4 (22.5.16.111) is about 225 feet, and it is estimated that the depth to water below the playas east of T-4 is about 150 feet.

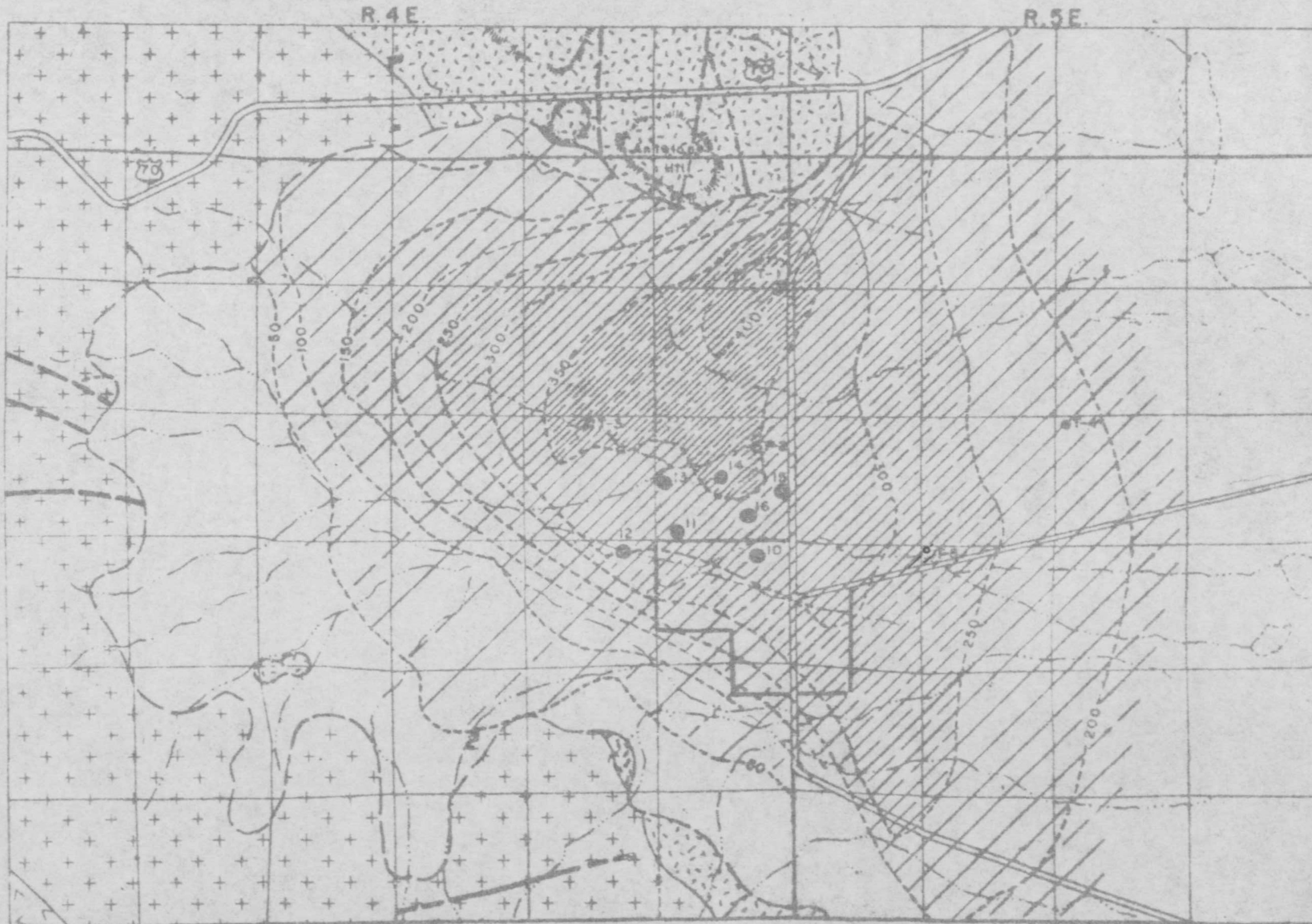


Figure 9.—Depth to water, in feet below land surface, in the headquarters area, White Sands Proving Ground, 1954
(For explanation of geology and well symbols, see Figure 2A. Contour interval 50 feet.)

0 2 Miles

The thickness of the saturated part of the bolson deposits within the reentrant, the difference between the altitude of the water table and the altitude of the bedrock in the area, is shown on figure 10.

Figure 10.--Thickness, in feet, of saturated bolson deposits in the headquarters area, White Sands Proving Ground, 1954.

The total volume of saturated materials underlying that part of the reentrant west of the access highway is computed to be about 4 million acre-feet. If an average porosity of 25 percent is assumed, the total quantity of ground water within the reentrant area is approximately 1 million acre-feet. A large part of this water is not available to wells, of course. The specific yield (ratio of volume of water a saturated rock will yield by gravity to its own volume) of the unconsolidated deposits is less than the porosity and probably is about 15 percent. Furthermore, the ground water in the lower part of the bolson deposits east of the access highway is highly mineralized (fig. 11), and overpumping of wells could induce migration of the highly mineralized water toward the wells. Such a possibility is discussed in a later section of this report ~~(p. 98)~~.

The sections in figures 11 and 12 show the general relation between

Figure 11.--Generalized section along line A-B on ~~plate 1~~ figure 2A.

Figure 12.--Generalized section along line C-D on ~~plate 1~~ figure 2A.

land surface, water table, and bedrock within the reentrant at the headquarters area.

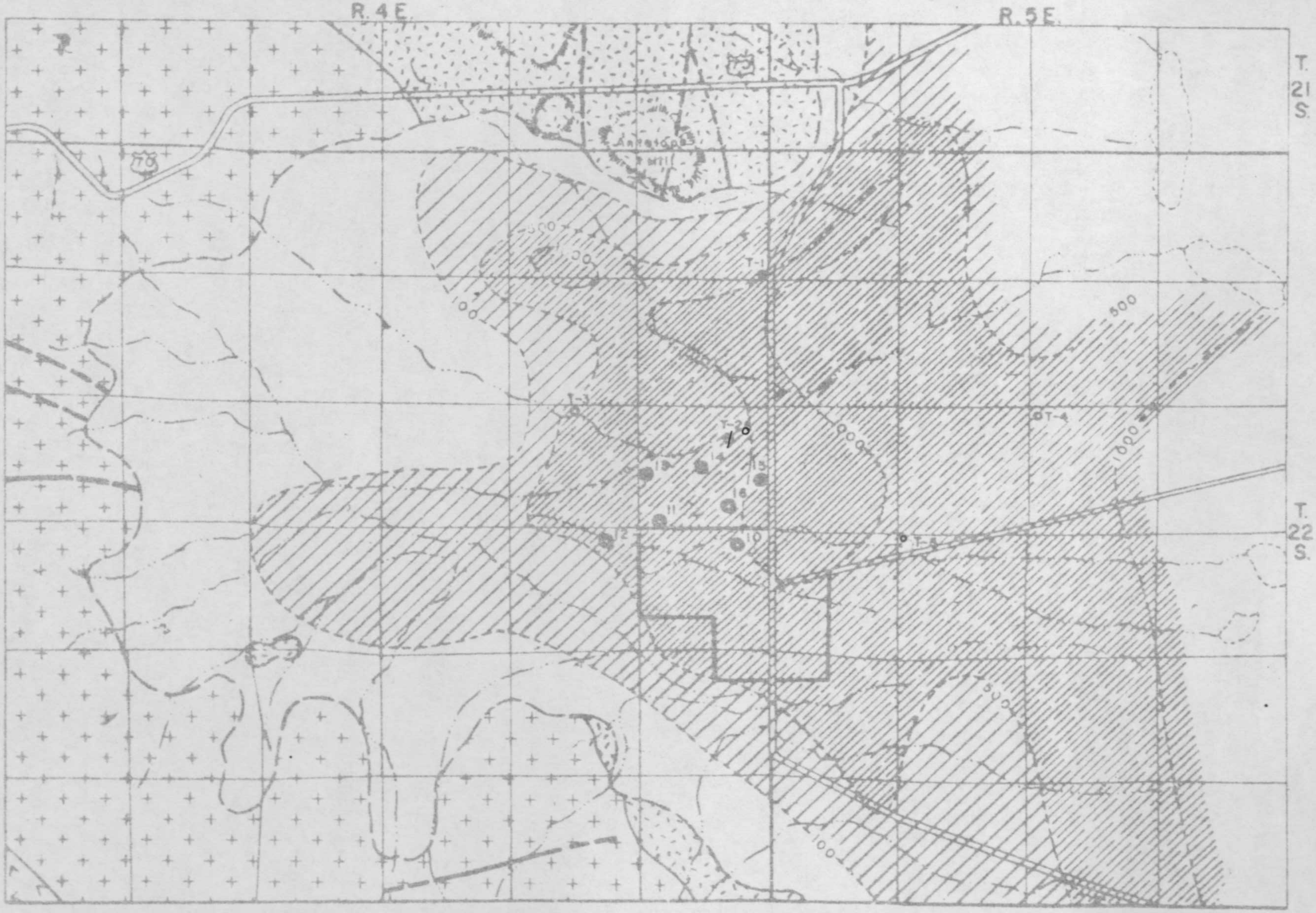
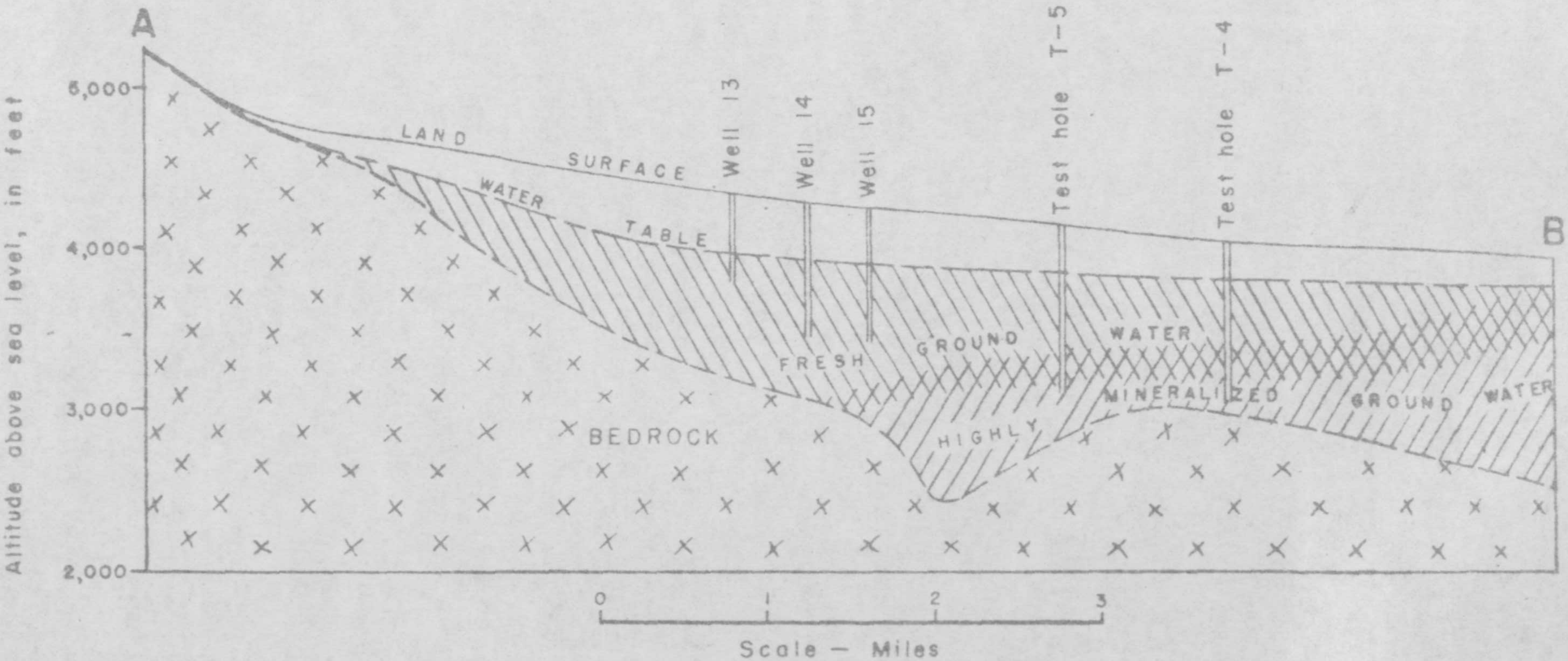


Figure 10 -- Thickness, in feet, of saturated bolson deposits in the headquarters area, White Sands Proving Ground, 1954

(For explanation of geology and well symbols, see Figure 2A. Contour interval 400 and 500 feet.)



Vertical exaggeration = 5.3

Figure 11 -- Generalized section along line A-B on figure 2A.

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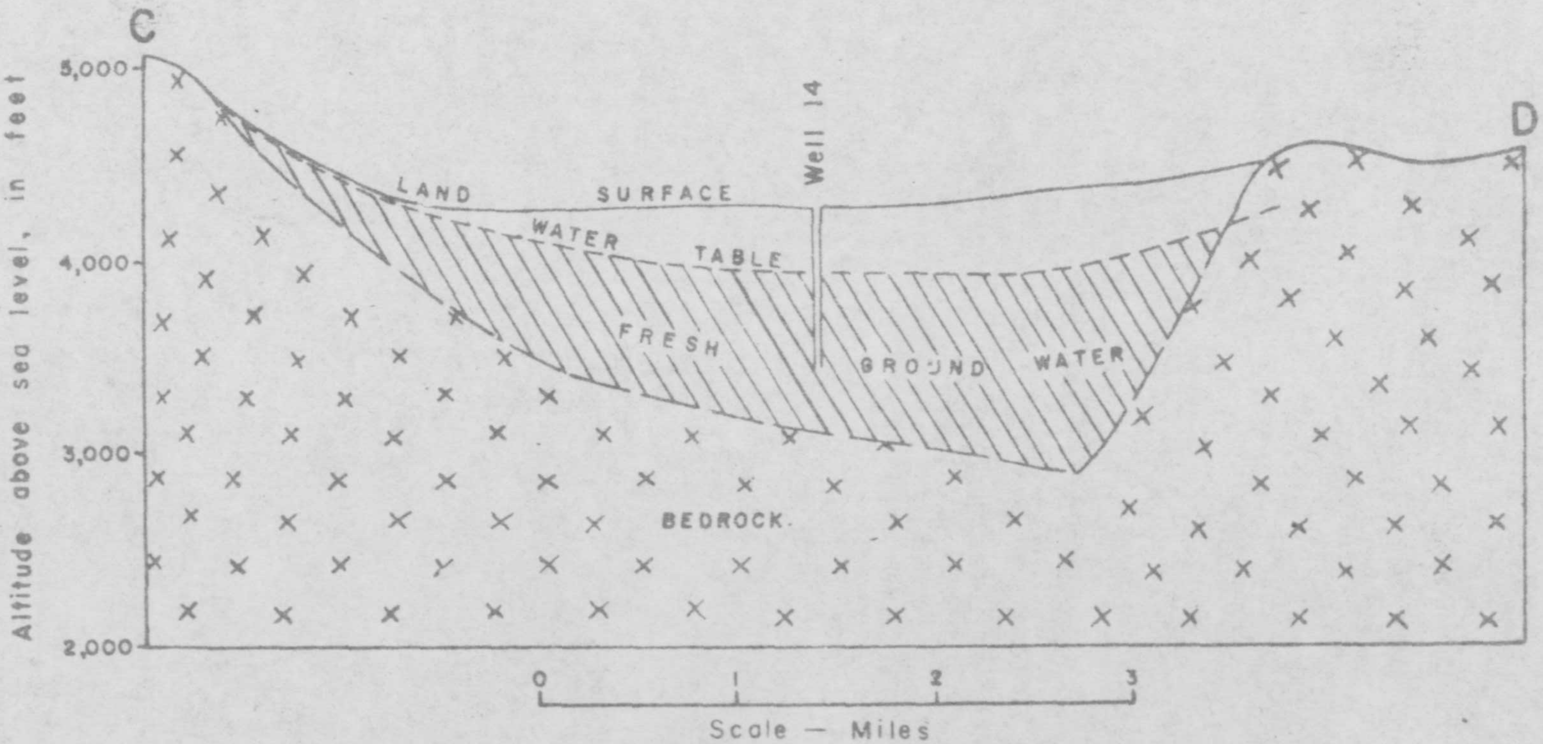

Vertical exaggeration = 5.3

Figure 12 -- Generalized section along line C-D on figure 2A.

Recharge

The source of all ground water in the headquarters area is precipitation within the reentrant and in the nearby mountains. Recharge to the unconsolidated materials in the south half of the reentrant is contributed from an area that coincides approximately with that delineated by the drainage divide of the reentrant, an area of about 40 square miles. Of this total area, about 25 square miles is underlain by unconsolidated materials, mainly sand and gravel at the surface, and in about 15 square miles the bare rock of the mountains is exposed.

The average annual precipitation ranges from 8.31 inches at the Air Weather station (for the period 1948-53) to 18 inches or more (estimated) in the higher parts of the mountains. The average annual precipitation at the Cox ranch for the period 1923-53 was nearly 13 inches, compared to 10 inches for the period 1948-53. Therefore, it can be assumed that precipitation during 1948-53 was below normal and that the average annual precipitation at the Air Weather station probably is closer to 10 inches. It is estimated that the average annual precipitation of the reentrant west of the access highway is 13 inches.

Only a small part of the precipitation infiltrates below the ground surface in the mountains; most is either evaporated or runs off the bare rock surface through the canyons and onto the unconsolidated material of the reentrant. Some of this water percolates to the water table. Most of the direct precipitation on the unconsolidated material is evaporated and transpired. During exceptionally heavy showers, infrequent in this area, some of the precipitation runs off to the lower elevations east of the reentrant. Probably the greatest recharge to the ground-water body of the bolson deposits occurs in the area closest to the mountains. Precipitation is somewhat greater in that area than it is in the central part of the reentrant, and runoff from the mountains reaches that area first.

It is not possible during this study to determine the amount of recharge to the ground-water body. Whenever possible, observations were made of the rate at which surface waters were absorbed by the sand and gravel. In October 1954, well 16 was pumped for 48 hours at an average rate of 600 gpm (gallons per minute), and the water was discharged to a natural drainageway leading to the playa area 3 to 4 miles east of the well. At the end of the pumping period, the drainageway contained water only to a point about 1½ miles east of the well. Much of the water, of course, was evaporated; however, the flow in the drainage decreased rapidly within a short distance of the well, and within a few minutes after pumping was stopped the drainageway contained no water. The unconsolidated materials near the sides of the reentrant are similarly permeable at the surface and absorb natural floodwaters in a similar fashion.

Some idea of the amount of recharge can be gained from a study of water-level fluctuations, but at this time few conclusions regarding the amount of recharge in the headquarters area can be drawn from these data because of the brief period of record.

The amount of recharge in the area may be estimated by computing the amount of water flowing through a cross section of the area. The average transmissibility of the alluvial fill in the vicinity of the wells north of the cantonment area has been estimated from pumping tests ~~(p. 103)~~ to be about 15,000 gpd (gallons per day) per foot. The reentrant in the vicinity of the wells is about $4\frac{1}{2}$ miles wide, and the average gradient of the water table in that vicinity is about 80 feet per mile. The quantity of water moving through a cross section of the aquifer in that part of the reentrant is approximately $15,000 \times 4\frac{1}{2} \times 80$, or 5,400,000 gpd. This is equal to about 6,000 acre-feet per year.

Sayre (1945, p. 72) assumed that 25 percent of the precipitation in the catchment area in and near the Franklin and Organ Mountains at the west side of the Hueco bolson becomes recharge to the ground-water body. That area and the reentrant at the headquarters area are similar geologically and topographically, and it is probable that the recharge conditions also are similar. ~~Although the results of studies in other areas indicate that this estimate may be high for the headquarters area,~~ it probably is safe to assume that 25 percent represents the maximum amount of precipitation that becomes recharge in the headquarters area. Unconsolidated sediments cover only about 25 of the 40 square miles within the reentrant drainage, but a considerable amount of the precipitation within the mountain flows into this area. Therefore, if it is assumed that 25 percent of the precipitation within the entire recharge area of 40 square miles is the volume of the recharge, the maximum average annual recharge to the area is approximately 6,~~500~~900 acre-feet.

These estimates are based upon a meager amount of data and many assumptions and that they represent the maximum amount of recharge in the area. Additional data as they become available, will permit a reevaluation.

Discharge

Water moves vertically through the rocks at the earth's surface unit it reaches the water table or an impermeable barrier. When it reaches the water table, it moves in the direction of the slope of the water table toward areas of discharge at lower altitudes. The water-table contours on ~~plate 1~~ figure 2A indicate that ground water moves eastward out of the reentrant at the headquarters area to the lower part of the Tularosa Basin, where it mixes with ground water moving southward and southwestward through the main part of the basin. In the lower part of the basin east of the reentrant, the ground water moves southward toward the Hueco Bolson.

Within the area of this study the only appreciable discharge of ground water in the bolson deposits is by transpiration and pumping from wells. Most of the ground water is discharged outside the area.

Formerly, springs discharged some ground water from the fan deposits in the vicinity of the Cox ranch; San Augustin Springs, as they were called, have not flowed for several years. Other springs near the mountains reportedly discharged small quantities of water in past years.

No attempt has been made to determine the amount of ground water transpired by plants in the area, but it is relatively small. In the higher elevations of the mountains, pinon pine and juniper along with various other representatives of Upper Sonoran flora are common. Native vegetation on the alluvial deposits in the reentrant includes mainly mesquite, creosote bush, some native grasses, several varieties of cactus, and yucca. In some parts of the reentrant where the water table is shallow, mesquite and other plants probably transpire significant amounts of ground water. In other parts of the area, plants depend largely upon soil moisture from precipitation and floodwaters and intercept water that otherwise might percolate to the water table to become recharge.

Ground-Water Levels and Their Significance

Under natural conditions over a long period of time, the average discharge from an aquifer is equal to the average recharge to the aquifer, and the flow of ground water in an area is in an approximate state of equilibrium. Small variations in natural discharge and recharge cause temporary changes in the amount of water stored in the aquifer, and these changes in storage are reflected by minor fluctuations in the water table. If recharge exceeds discharge, the water table rises, and if discharge exceeds recharge, the water table declines. Such natural fluctuations generally balance each other over a complete season or climatic cycle (Theis, 1940).

From 1946 until 1949, all the water used at White Sands Proving Ground was pumped from wells in secs. 31 and 32, T. 22 S., R. 5 E.; since 1949 an increasing amount of ground water has been pumped from wells in secs. 13, 23, and 24, T. 22 S., R. 4 E. At the present time the newer wells are supplying most of the water used at the headquarters area. Water levels in the area of the wells are declining and will continue to decline, if the present rate of pumping is maintained, until the water table has become adjusted to the new discharge and approximate equilibrium is again established. Equilibrium can be reestablished only if recharge is increased or discharge is decreased, or both, by an amount equal to the quantity of water pumped from the wells. Until equilibrium is reestablished, the water pumped must come chiefly from storage. Reduction in storage is reflected by a declining water table. Continuous records of water-level fluctuations in wells, therefore, may indicate the rate at which the ground-water reservoir is depleted.

Fluctuations of the Water Table

The fluctuations of the water table in the bolson deposits of the headquarters area since the summer of 1953 have been determined by periodic measurements of water levels in wells and test holes and by the records obtained from recording gages. The conclusions to be drawn from those data are limited, of course, by the short period of record. A program of water-level observations should be continued.

Test holes

The five test holes drilled in the summer of 1953 were partly cased and cleaned so that they could be used as observation wells. About 2 months after test hole T-2 was completed, it was found to be filled with sand above the water level; therefore, measurements of the water level in the well have not been made since July 1953. Water levels in the remaining 4 test holes have been measured an average of every 2 months since they were completed. Hydrographs prepared from the measured water levels in those test holes appear in figure 13.

Figure 13.--Hydrographs of test holes at White Sands Proving Ground.

Test hole T-1 is nearly 2 miles north of the center of the well field and more than 1.5 miles from the closest pumped well. As shown by the hydrographs, the water level in that test hole declined about 1 foot from July 1953, when the test hole was completed, to the end of 1954.

The water level in test hole T-3, about a mile northwest of the center of the well field and about half a mile from the closest pumped well, declined about 9 feet from June 1953 to the end of that year. From the end of 1953 to February 1954 the water level rose about 2.5 feet. In May 1954 it declined about 1.5 feet, and by November it had risen about 1 foot.

Test hole T-4 is nearly 3 miles east of the center of the well field and about 2½ miles from the closest pumped well. The water level in it has fluctuated only slightly since the hole was completed in June 1953. The water level rose less than 0.2 foot in September 1953, and it declined about the same from May to August 1954. It rose slightly again in October 1954 but has continued to decline since then.

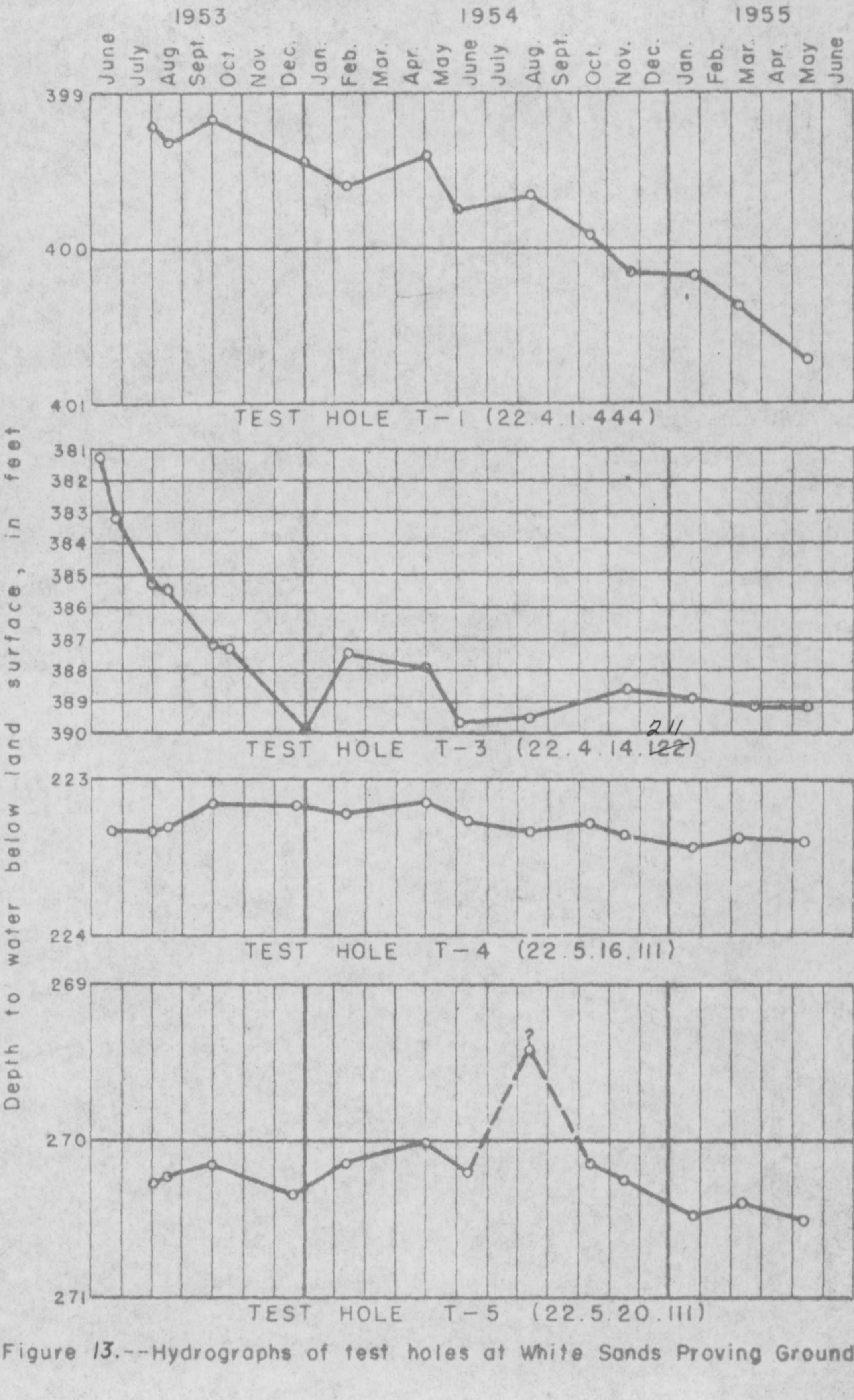

Figure 13.--Hydrographs of test holes at White Sands Proving Ground

Test hole T-5 is about 2 miles east of the center of the well field and less than $1\frac{1}{2}$ miles from well 10, the closest pumped well. The water level in that test hole fluctuated only slightly from July 1953 until August 1954, when it apparently rose nearly a foot from the level observed in June of that year. It is possible that the high measurement obtained in August is in error, although all measurements were carefully checked in the field. Since October 1954, the water level in the test hole has declined steadily, but in January 1955 it was only about 0.2 foot below the level of July 1953.

Supply wells

Until rehabilitation of the wells in 1955, it had not been possible to measure the depth to water with a steel tape in any of the older wells at White Sands Proving Ground. In addition to this difficulty, throughout most of the period of this investigation it has not been possible to stop the pumps in most of the wells long enough to determine accurately the nonpumping water levels. However, the approximate changes in water levels in the supply wells can be estimated from the available data.

In the old well field, the air line in well 5 is broken, and it has been impossible to determine the depth to water in that well. When the well was completed, in April 1946, the water level reportedly was 221 feet below the land surface. When well 9 was completed in June 1946, the depth to water reportedly was 234 feet below the land surface. In April 1953 it was approximately 240 feet by air-line gage, representing an apparent decline of about 6 feet in 7 years.

Well 10 was equipped in August 1948, and the depth to water at that time was reported to be 345 feet below the land surface. In August 1953, static water level in the well, according to an air-line gage, was at a depth of 358 feet. In February 1955, the pump was removed from the well and the static water level was determined by steel tape to be 355 feet below the land surface. This represents a decline of about 11 feet in 6½ years.

Well 11 was completed in May 1950, and the depth to water at that time was reported to be 296 feet. In March 1953 it was 305 feet, and in March 1955 it was 312 feet, according to an air-line gage. In April 1955, after the well was rehabilitated, the depth to water in the well was determined, by a steel tape, to be 303 feet below the pump base, or about 300 feet below the land surface. Except for a few days during the rehabilitation of the well in April 1955, well 11 had not been pumped since August 1954. Apparently the water level in the well is now about 6 feet lower than the reported original depth, but there are indications that rehabilitation procedures may have opened semiconfined water-producing strata that formerly were plugged. This may account for the rise in the water level from March 1955 to April 1955, as indicated by the air-line gage determinations.

The depth to water in well 12 upon completion of the well in January 1952 was reported to be 291 feet. It has not been possible to measure the depth to water in that well. However, for the purpose of constructing a water-table map, it was estimated to have been about 300 feet in April 1953.

Well 13 was completed in August 1951, and the original depth to water reportedly was 300 feet. In September 1953 the depth to water by air line gage was 312 feet below the pump base, or about 310 feet below the land surface. In May 1955, at the start of rehabilitation work on the well, the depth to water by air-line gage was still 310 feet below the land surface. The water level in well 13 apparently declined about 10 feet between August 1951 and May 1955.

Records of recording gages

Recording gages were installed on an unused well (22.4.24.222) near the principal production wells in April 1953 and on well 4 in the old well field in May 1954. Almost continuous records of the water-level fluctuations in those wells have been obtained since the records were installed. Hydrographs of the wells appear in figures 14 and 15.

Figure 14.--Hydrograph of well 22.4.24.222 at White Sands Proving Ground.

Figure 15.--Hydrograph of well 4 at White Sands Proving Ground.

The water level in well 22.4.24.222 declined nearly 3 feet from April to September 1953, but by March 1954 it had risen above the level of April 1953. By September 1954 it had declined about 5 feet and was about 2 feet below the lowest level of 1953. By the end of 1954 it had risen about 2 feet but was about 1 foot below the level in December 1953.

The water level in well 4 in the old well field rose almost continuously from May 1953 to the end of February 1954. Since that time it has fluctuated slightly, although the average water level remained about the same from March 1954 to the end of the year.

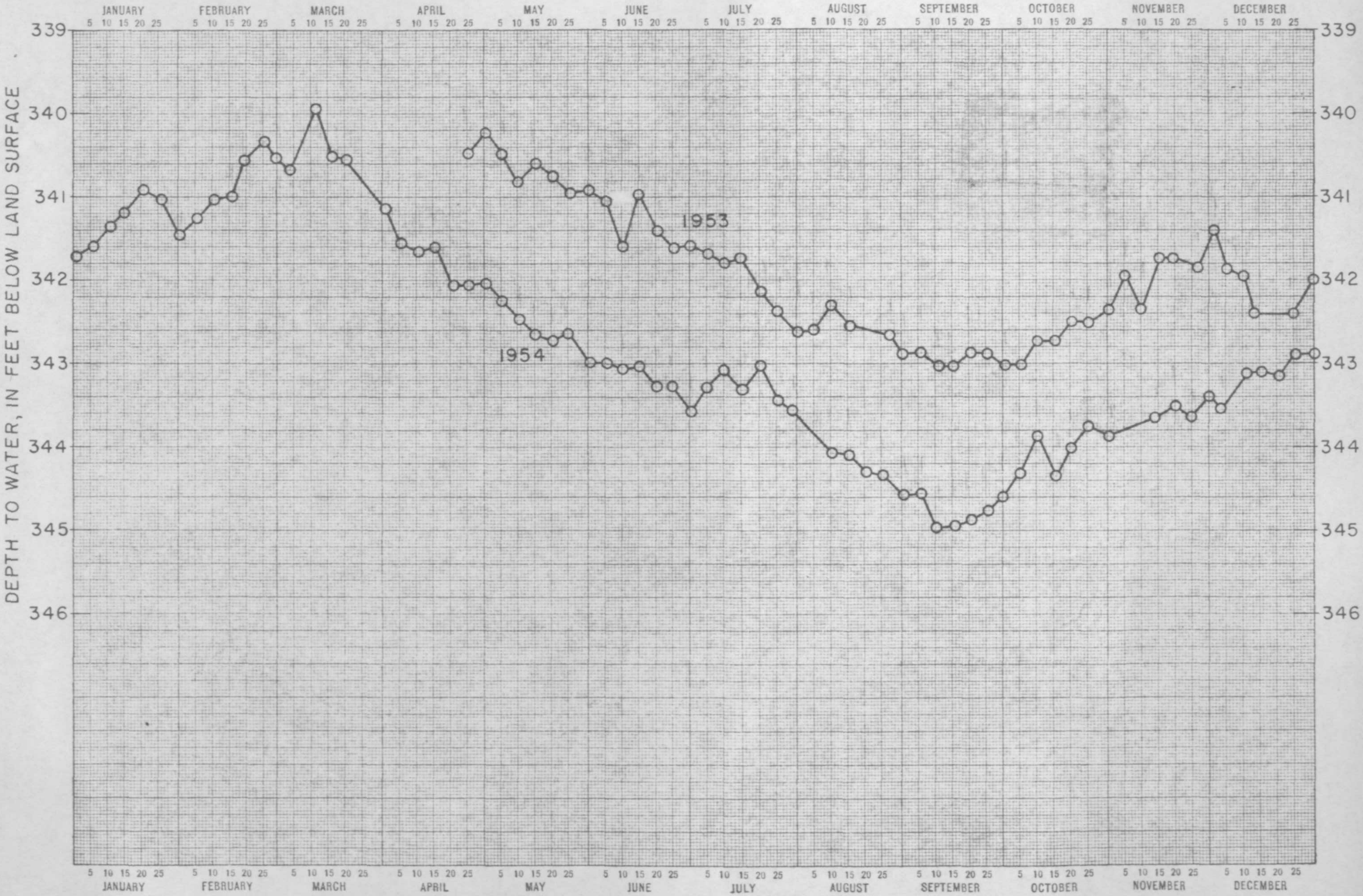

Figure 14.--Hydrograph of well 22.4.24.222 at White Sands Proving Ground.

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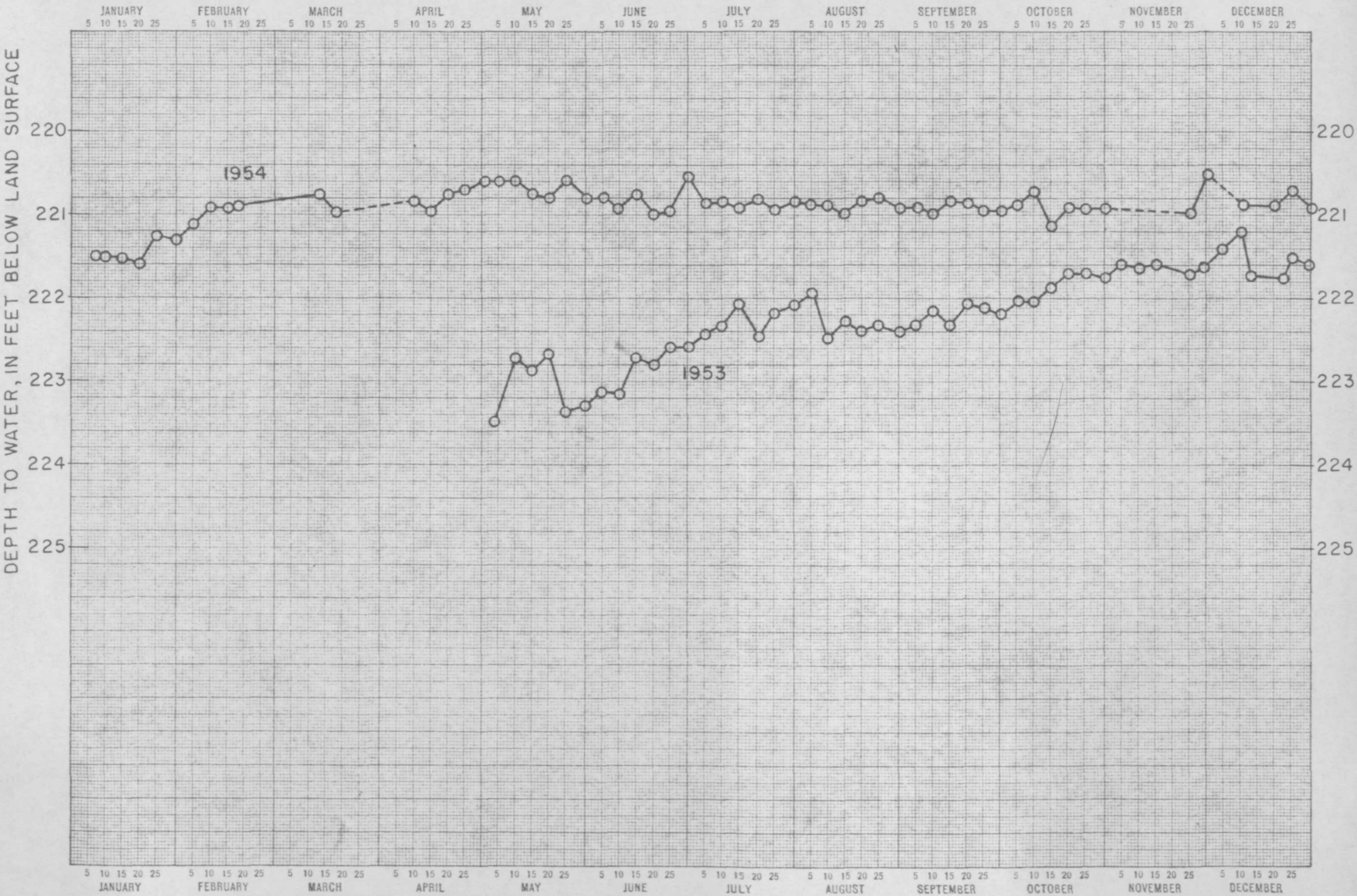

Figure 15.--Hydrograph of well 4 at White Sands Proving Ground.

Interpretation of fluctuations

The 1-foot decline of the water level in test hole T-1 from July 1953 to the end of 1954 probably is almost entirely a result of pumping the wells north of the cantonment area and was predictable on the basis of the amount of water pumped in the well field and the aquifer characteristics. If the average transmissibility of the aquifer is about 15,000 gpd per foot, the specific yield is about 0.15, and the pumpage is from storage, the water level at test hole T-1 should have declined about 3 feet since the wells north of the cantonment area were placed in production.

The large decline (almost 9 feet) of the water level in test hole T-3 from June 1953 to the end of 1953 is difficult to explain. If it is entirely a result of the pumping of wells more than half a mile distant, then pumping effects are transmitted much more readily northwestward from the wells than has been observed elsewhere in the area. A longer record of the water levels in that test hole will be necessary to analyze fully the fluctuations thus far observed.

The water levels in test holes T-4 and T-5 apparently have not yet been affected to any appreciable degree by pumping. This is to be expected because the bolson deposits become considerably finer grained eastward from the well field, and the transmissibility of the aquifer in the vicinity of test holes T-4 and T-5 probably is considerably less than the average transmissibility of the bolson deposits in the area of the well field. Therefore, the cone of depression caused by pumping from the well field would not expand as rapidly toward the two test holes.

The decline of water level in well 22.4.24.222 is a result mainly of the pumping of well 10, 1,200 feet distant. The water level has been affected somewhat by the pumping of other wells also, and will be affected by the pumping of wells 15 and 16 and, eventually, well 14. The seasonal fluctuation observed on the hydrograph is due to the heavier pumping during the summer. From March to September 1954, the water level declined about 5 feet. During January, February, and March, 1954, well 10 yielded less than 9 million gallons of water compared to about 27 million gallons in April, May, and June, 1954.

It is not known to what extent the water level in well 22.4.24.222 has declined since production wells were drilled in the area. When the original windmill pump was removed from the well in 1953, what appeared to be a fairly well defined old water mark was observed on the pump rods at a point that indicated that the static water level was at a depth of about 335 feet, which probably represents the depth to water in the well prior to the pumping of well 10. If so, the water level in the well declined about 8 feet from 1948, when well 10 was drilled, to the end of 1954.

Water levels in the center of the present well field apparently have declined about 10 feet since well 10 was completed. Even though the accuracy of the reported original water levels in the supply wells is somewhat questionable, it should be possible to maintain an accurate record of water levels in those wells in the future, as alterations to the pump bases are being made that will allow measurement by steel tape.

The rise of the water level in well 4 in the old well field probably is a reflection of the recovery of the water table in that area, as pumping in the old well field was greatly reduced in 1951 and still more in 1952. No data on the water level in the well prior to this investigation are available; therefore, a comparison of the present water level with the original water level in the well cannot be made. Since the early part of 1954 the water level in the well has fluctuated only slightly, owing partly to changes in atmospheric pressure and partly to the intermittent pumping of wells 5 and 9 nearby. A temporary equilibrium probably has been established; however, water levels in that area probably will decline somewhat in the future if wells 5 and 9 continue to be pumped.

Chemical Quality

All natural waters contain varying amounts of mineral matter that have been dissolved from the material through which the waters have moved. Chemical analyses not only indicate whether the water is chemically suitable for various uses but also may provide information regarding the source, movement, and discharge of the water and the character of the containing rocks.

The most important of dissolved solids in ground water are the cations calcium, magnesium, and sodium and the anions bicarbonate, sulfate, and chloride. In a chemical analysis, the concentration of dissolved constituents may be expressed in parts per million, equivalents per million, or tons per acre-foot.

In an analyses in which the concentration of dissolved solids is given in parts per million, 1 ppm (part per million) equals 1 part, by weight, of the constituent per 1 million parts, by weight, of the water.

The unit "equivalent per million" (epm) is defined as 1 equivalent weight of an element, ion, or salt in 1 million weights of solution. The equivalent or combining weight in grams is the weight of an element or compound that will react with 8 grams of oxygen or its equivalent. In other words, the equivalent weight of a constituent is its atomic weight divided by its valence. In any solution, the sum of the anions must equal the sum of the cations in terms of equivalents.

To change an analysis reported in parts per million to equivalents per million, the concentration of each constituent in parts per million is divided by its equivalent weight. To change an analysis reported in equivalents per million to parts per million, the concentration of each constituent in equivalents per million is multipilied by its equivalent weight.

Results of analyses of water for irrigation are sometimes reported in tons per acre-foot. Such analyses indicate the amount, by weight in tons, of dissolved salts in 1 acre-foot (about 326,000 gallons) of water.

Principal Mineral Constituents of Water

A standard chemical analysis of water generally gives the following constituents and characteristics of the water.

Silica (SiO_2).--Silica is dissolved from practically all rocks and usually is present in both surface and ground waters in concentrations of less than 60 ppm. It is practically inert so far as soils and plants are concerned, but it contributes to the formation of boiler scale.

Iron (Fe).--Iron is a common constituent of ground water, as it is dissolved from many rocks and soils. Small quantities (more than 0.3 ppm), which may stain cooking utensils and clothing washed in the water, usually can be removed from the water by aeration and filtration.

Calcium (Ca) and magnesium (Mg).--Calcium is dissolved from practically all rocks and magnesium from many. Hence, both minerals are usually present in ground water. They cause nearly all the hardness of ordinary water and are largely responsible for the formation of boiler scale. More than 125 ppm of magnesium are not recommended for drinking water by the U.S. Public Health Service (1946).

Sodium(Na) and potassium (K).--Sodium and potassium also are dissolved from practically all rocks. As the total quantity of the two constituents increases, the proportion of sodium to potassium becomes greater, and sodium is often the predominant cation in highly mineralized waters of western United States. Concentrations of less than 50 ppm of sodium and potassium generally do not affect the usefulness of water for most purposes. Water that contains a large proportion of sodium salts may be unsatisfactory for irrigation. (See "percent sodium.")

Bicarbonate (HCO_3) and carbonate (CO_3).--Carbon dioxide in water enables the water to dissolve carbonates of calcium and magnesium, thus producing bicarbonates. Bicarbonates of those two metals are responsible for so-called "temporary" hardness. Most water does not contain carbonate in appreciahle quantities but almost all waters contains bicarbonate.

Sulfate (SO_4).--Sulfate is dissolved in large quantities from deposits of gypsum and sodium sulfate. It is formed also by the oxidation of sulfides of iron and therefore is present in considerable quantities in mine waters. According to standards of the U.S. Public Health Service (1946), sulfate should not exceed 250 ppm in water for domestic use. Calcium or magnesium resulting from the solution of sulfates causes the water to have so-called "permanent" hardness, which cannot be removed by boiling.

Chloride (Cl).--Chloride in ground water is dissolved in small quantities from many rocks and may be dissolved in large quantities from rocks of marine origin. Water having a chloride concentration of more than 250 ppm has a salty taste and generally is considered unfit for domestic use. Calcium and magnesium resulting from the solution of chloride salts contribute to "permanent" hardness of water.

Fluoride (F).--Fluorides occur naturally in small quantities in many ground waters. Although fluoride in excess of 1.5 ppm may cause mottling of the enamel of children's teeth, several ~~recent~~ studies have indicated that concentrations less than 1.5 ppm in drinking water tend to inhibit tooth decay (Dean, 1936).

Nitrate (NO_3).--High nitrate concentrations in water usually indicate contamination by sewage or other organic matter or fertilizer, although small quantities may be dissolved from nitrate-bearing rocks. Studies indicate that water containing nitrate may contribute to cyanosis of infants ("blue babies ~~disease~~"), and such water should not be used for feeding formulas (Nelson, 1951). The amount considered to be dangerous ranges, according to different authorities, from 45 to 90 ppm.

Dissolved solids.--The residue after evaporation of a filtered sample of water is weighed and reported as dissolved solids, in parts per million or tons per acre-foot. According to standards adopted by the U.S. Public Health Service (1946), drinking water should contain not more than 1,000 ppm and preferably not more than 500 ppm of dissolved solids. Water containing several thousand parts per million of dissolved solids is commonly used for irrigation and for watering stock.

Hardness as $CaCO_3$.--Hardness of water is easily recognized by the difficulty with which soap lathers and by the precipitate or scale that forms in vessels in which hard water is heated or evaporated.

Hardness is caused principally by compounds of calcium and magnesium and is expressed as the calcium carbonate equivalent of all the significant cations except sodium and potassium. Carbonate hardness, caused by solution of calcium and magnesium bicarbonates, can be largely removed by boiling and is often called "temporary" hardness. Noncarbonate hardness, caused mainly by calcium and magnesium in excess of the bicarbonate and carbonate, cannot be removed by boiling and is often called "permanent" hardness. Both types of hardness produce the same effect with respect to use of soap in water.

Water having a total hardness of less than 60 ppm is considered soft; water having a hardness of 60 to 120 ppm is considered moderately hard and is suitable for most uses except in high-pressure steam boilers and some industrial processes; and water having a hardness of more than 200 ppm usually requires treatment.

Specific conductance.--The specific conductance of a water is the reciprocal of its resistance to an electric current. Generally at White Sands Proving Ground, the specific conductance of water in micromhos at 25° C multiplied by 0.7 is approximately equal to the dissolved solids in ppm -- useful in estimating the concentration of dissolved solids in a water when only its specific conductance is known. However, the conductance does not indicate the chemical nature of the dissolved solids.

Percent sodium.--Percent sodium is determined by dividing the quantity of sodium multiplied by 100 by the sum of the quantities of calcium, magnesium, sodium, and potassium in the water, all constituents being expressed in equivalents per million. Percent sodium is particularly useful in classifying water for irrigation. A percent sodium of less than 60 in irrigation water usually will not cause a deterioration of soil structure. Water having a higher percent sodium may react with soil so that the soil becomes increasingly less permeable, particularly if other salts are present in large quantities and drainage is poor.

Sodium-adsorption-ratio (SAR).--The sodium-adsorption-ratio has been developed as a useful index for designating the sodium or alkali hazard of waters used for irrigation. Sodium-adsorption-ratio is the ratio of Na^{+} to $\frac{Ca^{++} + Mg^{++}}{2}$, where Na^{+}, Ca^{++}, and Mg^{++} represent the concentration in milliequivalents per liter or equivalents per million of the respective ions. Water having a sodium-adsorption-ratio of less than 10 can be used for irrigation on almost all soils with little chance of soil deterioration. Water having a sodium-adsorption-ratio of 10 to 18 will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity, especially under conditions of relatively little leaching by fresh water unless the soil contains gypsum. Such waters may be used on coarse-textured or organic soils of good permeability. Water having a sodium-adsorption-ratio between 18 and 26 may produce harmful levels of exchangeable sodium in most soils, and the use of such water necessitates special soil management, except of gypsiferous soils. Water having a sodium-adsorption-ratio greater than 26 generally is unsatisfactory for irrigation except at low and perhaps medium salinity. The addition of gypsum may make the use of these waters feasible. (U.S. Department Agriculture, 1954.)

pH (Hydrogen-ion-concentration).--The pH of water indicates its degree of acidity or alkalinity; as pH increases to 7.0 (neutral point), acidity decreases; as pH increases beyond 7.0, alkalinity increases. The pH of a water indicates in a general way its ability to corrode metal surfaces. Acid waters are corrosive and may contain objectionable constituents, such as iron.

Chemical Quality of Ground Water in the Headquarters Area

Samples of water from all wells used by the Army at White Sands Proving Ground are collected at least once a year and analyzed by the Quality of Water Branch of the U.S. Geological Survey at Albuquerque. During this study, samples of water were collected also from each of the 5 test holes, the 3 new production wells, and several ranch wells in the area. The results of the chemical analysis are given in table ~~6~~ 5, and chemical analyses of water from several representative wells in the area are presented graphically in figure ~~16~~ 17.

Figure ~~16~~ 17.--Graphic representation of analyses of water from representative wells at White Sands Proving Ground.

All the wells supplying water to the housing and cantonments areas of the Proving Ground yield water of exceptionally good chemical quality from the unconsolidated bolson deposits. Wells 5 and 9 in the old well field yield water having less than 200 ppm of dissolved solids, and wells 10, 11, 12, and 13 yield water having an average concentration of 240 ppm of dissolved solids. None of the determined mineral constituents are present in objectionable quantities in the water from those wells, and the water is only moderately hard.

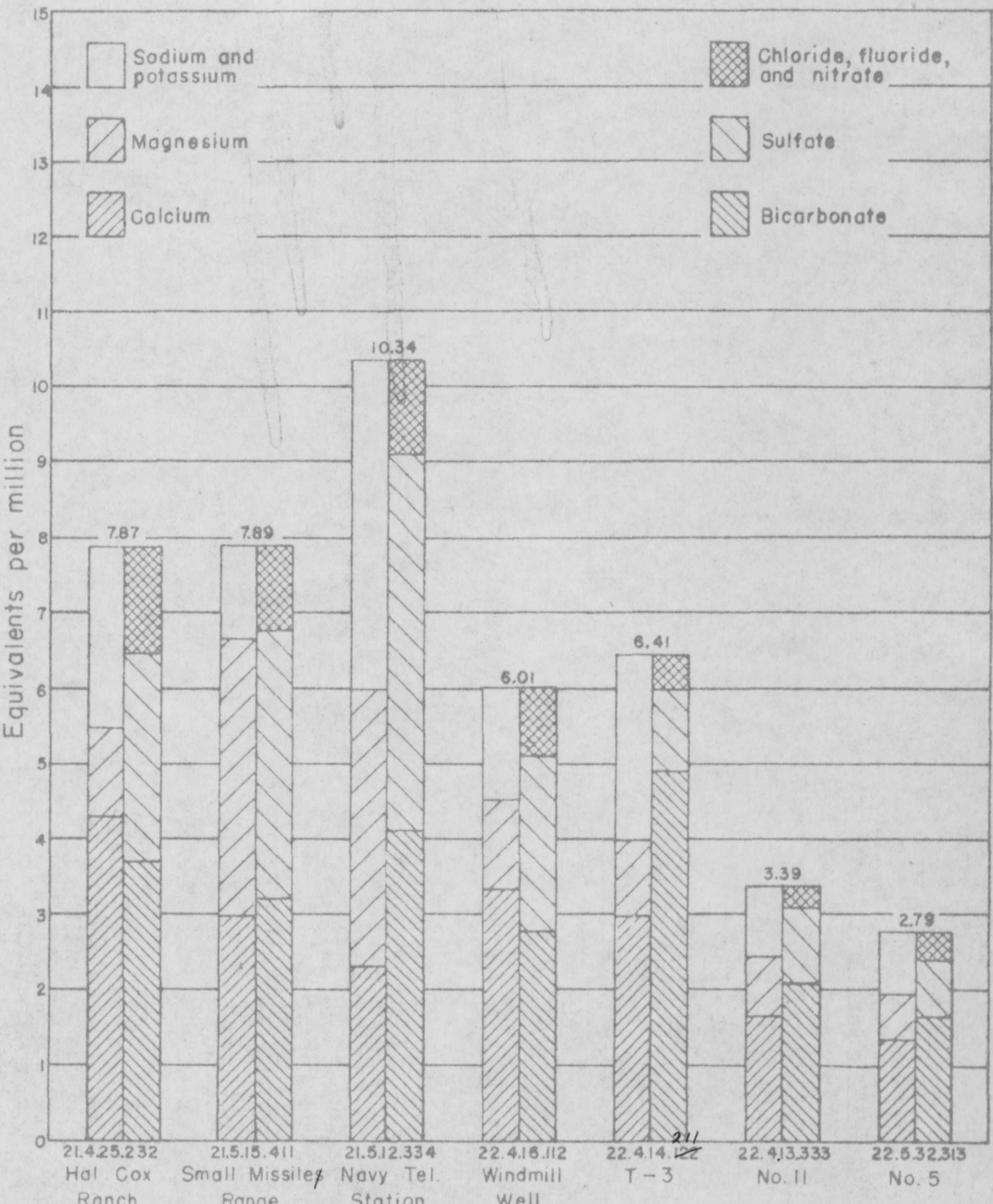

Figure 17.--Graphic representation of analyses of water from representative wells at White Sands Proving Ground

The pilot holes for wells 14, 15, and 16 were drilled to a depth of 1,000 feet, several hundred feet deeper than the other wells in the area. A sample of water obtained between depths of 953 and 1,000 feet in the pilot hole of well 14 had a specific conductance of 477, almost 50 percent higher than that of the shallower water from wells 10-13. The water contained very little calcium and practically no magnesium and had a hardness of only 28 ppm. Water from near the bottom of the pilot hole of well 15 had similar characteristics, although the water from between depths of 955 and 1,000 feet in that hole was of better quality than that obtained between depths of 755 and 800 feet. A deep water sample was not obtained from well 16. Wells 14 and 15 were completed to depths of 810 and 820 feet, respectively, and the water pumped after completion of the wells had specific conductances of 321 and 340, respectively, similar to that of water from wells 10-13. Water pumped from well 16 after its completion to a depth of 890 feet had a specific conductance of 337 and a hardness of 118 ppm.

Although the deeper water underlying section 13 is more highly mineralized than the shallow water, it is potable, at least to a depth of 1,000 feet. The higher specific conductance of the deep samples apparently are due principally to somewhat greater concentrations of sodium and sulfate.

The water from stock and domestic wells in the pediment area north of U.S. Highway 70 and near the mountains west of the cantonment area contains a greater concentration of dissolved minerals than ground water in the cantonment area. Water from a shallow stock well (22.4.16.112) about 4 miles west of the cantonment area contained 392 ppm of dissolved solids. Water from the shallow well (21.4.21.231) at the Lena Cox ranch, about 5 miles northwest of the cantonment area, contained 453 ppm of dissolved solids, and water from well 21.4.25.232 at the Hal Cox ranch contained 489 ppm of dissolved solids. Water from the two ranch wells contained 4.0 ppm fluoride. The well at the Hal Cox ranch appears to have been originally a shallow prospect shaft that was equipped with a windmill pump. The water is derived from porous zones or cracks in the granite. Well 21.4.21.231 is in an arroyo and probably yields water mainly from thin beds of gravel overlying Precambrian granite.

Well 21.5.15.411 at the Small Missile Range, 4 miles northeast of the Hal Cox ranch, taps beds of fine sand. A sample of water collected from that well in March 1953 contained 464 ppm of dissolved solids and 1.6 ppm of fluoride. Well 21.5.12.334, about 2 miles east of the Small Missile Range, also taps beds of fine sand in the bolson deposits. The water is considerably more mineralized than that from the well at the Small Missile Range, containing 663 ppm of dissolved solids in March 1953.

The dissolved-solids content of ground water increases eastward from the cantonment area, the deeper water having the higher concentrations. Shallow water from test hole T-5, 1 mile east of the access highway, contained only 241 ppm of dissolved solids. An attempt was made to obtain a sample of water from a depth between 900 and 1,000 feet in that test hole, but only a small amount of water mixed with drilling mud was recovered. The mixture had a specific conductance of 672, indicating that concentration of dissolved solids probably was about 500 ppm, but ground water at that depth probably has a considerably higher concentration than was indicated by analysis of the sample obtained. The electric log of the test hole indicates that the ground water is highly mineralized below a depth of approximately 880 feet. Shallow water from test hole T-4, 2 miles east of the access highway, contained 329 ppm of dissolved solids, but water from a depth between 956 and 1,003 feet in the same test hole contained 7,480 ppm of dissolved solids, 499 ppm of calcium, 2,210 ppm of sodium and potassium 568 ppm of sulfate, and 4,050 ppm of chloride. The electric log of test-hole T-4 indicates that the ground water at that site is highly mineralized below a depth of approximately 760 feet.

Even the shallow water farther east in the central part of Tularosa basin is reported to be highly mineralized and unfit for watering stock. Analyses of ground water from that area are not available. However, a test hole was drilled in March 1953 at the northwest cor. sec. 35, T. 23 S., R. 6 E., for the Army and the city of El Paso. Water from a depth of 450 feet in that test hole had a specific conductance of 19,000 micromhos and contained 6,710 ppm of chloride. Water from test-hole T-21 (23.5.35.300) ~~in the southwest cor. sec. 35, T. 23 S., R. 5 E.~~, also drilled in 1953 for the Army and the city of El Paso, was of potable quality to a depth of approximately 1,000 feet. Water from a depth between 1,162 and 1,216 feet in that test hole contained 3,280 ppm of dissolved solids.

The fresh ground water within the reentrant is derived from precipitation in the mountains and within the reentrant. It is evident from the chemical analyses that the ground water moving into the reentrant from the Organ Mountains south and southwest of the headquarters area is the least mineralized of the ground water in the area. The ground water in the crystalline rocks of the pediment area is considerably more mineralized, but most of that water moves southeastward to the main part of the basin and therefore does not reach the well field.

It is readily apparent from a comparison of the chemical analyses in table ~~6~~ 5 and the ground-water contour lines on ~~plate 1~~ figure 2A that the fresh water within the reentrant moves eastward, and east of the headquarters area it must mix with highly mineralized water that is moving south and southwest through the main part of the basin. Immediately east of the reentrant, the fresh water apparently overrides the highly mineralized water, as shown in the generalized cross section in figure 11. It is not definitely known how far east of the headquarters area the upper water is potable, but it is reported to be fresh about 4 miles east of the access highway near the playas. It is suspected, however, that highly mineralized water would be encountered a short distance below the water table in the area of the playas.

The ground water underlying the lower part of the basin east of the headquarters area moves south and southeast, and the available data indicate that immediately southeast of the headquarters area fresh water probably is confined to a narrow belt close to the base of the Organ Mountains.

Hydrologic Properties of the Bolson Deposits

In order to evaluate and develop a well field most efficiently, the hydrologic characteristics of the water-bearing formations must be determined. The most important of these hydrologic characteristics are the coefficients of transmissibility and storage.

Coefficient of Transmissibility

The coefficient of transmissibility of an aquifer is a measure of the ease with which the aquifer transmits water. It generally is expressed as the number of gallons of water that will pass in 1 day through a vertical section of the aquifer 1 foot in width under a unit hydraulic gradient. It is equal to the average field coefficient of permeability _/ multiplied by the saturated thickness of the aquifer, in feet.

The rate of recovery of the water level in a well after discharge from the well has stopped is related to the permeability of the aquifer. Thus, by observing the rate at which the water level recovers, the coefficient of transmissibility of the aquifer can be derived.

_/ The coefficient of permeability, as used by the U.S. Geological Survey, is defined as the number of gallons of water, at 60°F, passing through a cross section of 1 square foot under unit hydraulic gradient. The field coefficient of permeability is the same, except that it is measured at the prevailing temperature of the water rather than at 60°F.

Theis (1935) developed the following formula, later described by Wenzel (1942), for computing the coefficient of transmissibility of an aquifer from the rate of recovery of the water level after a well has been pumped at a constant rate for a known time:

$$T = \frac{264\,q}{s} \log_{10} t/t'$$

where: T = coefficient of transmissibility, in gallons per day per foot.

q = discharge of well, in gallons per minute.

t = time since pumping began.

t' = time since pumping stopped.

s = residual drawdown at the pumped well, in feet, at time t'.

The value of $\frac{\log_{10} t/t'}{s}$ can be determined graphically by plotting t/t' against corresponding values of s on semilogarithmic paper with t/t' on the logarithmic coordinate. Theoretically, the points should fall on a straight line that passes through the origin. The ideal curve is not always obtained, owing partly to the heterogeneity of the water-bearing sediments. The slope of the line represents $\frac{\log_{10} t/t'}{s}$, and, over one cycle of the semilogarithmic scale, $\log_{10} t/t'$ becomes unity and the formula is reduced to:

$$T = \frac{264\,q}{\Delta s}$$

where Δs is the change in depth to water over one cycle of the semilogarithmic scale.

The coefficient of transmissibility can be computed also from the rate of recovery of the water level after a well has been pumped at several different rates, as during a step-pumping test. For example, for a two-step test in which the well has been pumped for equal intervals at different ratés, without shutting down:

$$s = \frac{264}{T} \left[q_1 \log \frac{t_1 + t'}{t_2 + t'} + q_2 \log \frac{t_2 + t'}{t'} \right]$$

where: s = residual drawdown at the pumped well.

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

q_1 = discharge of well, in gallons per minute, during the first step.

q_2 = discharge of well, in gallons per minute, during the second step.

t = time since pumping started of the step indicated by the subscript to the time that pumping stopped.

t' = time since pumping stopped.

By transposition, the above equation becomes:

$$T = \frac{264}{s} \left[q_1 \log \frac{t_1 + t'}{t_2 + t'} + q_2 \log \frac{t_2 + t'}{t'} \right]$$

The values of s are plotted on linear graph paper against the values of the term in brackets for various intervals after pumping stopped. These points should theoretically fall along a straight line. By selecting two points on the line and dividing the difference in the two values of the term in brackets at those points by the difference in the two values of s at those two points and multiplying the quotient by 264, the coefficient of transmissibility is obtained. The same procedure applies to a computation of the coefficient of transmissibility from the recovery after any number of pumping steps, an additional term in brackets being added for each additional pumping step. Thus:

$$T = \frac{264}{s} \left[q_1 \log \frac{t_1 + t'}{t_2 + t'} + q_2 \log \frac{t_2 + t'}{t_3 + t'} + \cdots + q_n \log \frac{t_n + t'}{t'} \right]$$

Coefficient of storage

The coefficient of storage of an aquifer (S) ~~is~~ may be defined as the amount of water, expressed as a fraction of a cubic foot, that is released from storage in each vertical column of the aquifer having a base 1 foot square, when the water level declines 1 foot. The coefficient of storage of a nonartesian aquifer is nearly equal to the specific yield. ~~(See p. 83.)~~ In an artesian aquifer, the coefficient of storage depends upon the compressibility of the aquifer and included water and is generally only a small fraction of the specific yield. As the coefficient of storage defines the amount of water released when the head in the aquifer is lowered by pumping, it is necessary to determine this property as accurately as possible in order to predict the effect of pumping on water levels.

The coefficient of storage of an aquifer may be obtained by observing the effect of a pumping well upon the water level in a nearby observation well. Several methods of analyzing such data have been developed. Brown (1953) described the abbreviated and approximate Cooper-Jacob solution of the Theis nonequilibrium formula (Theis, 1935).

Specific yield

The specific yield of a rock is the ratio of the volume of water that the rock will yield by gravity to its own number. The specific yield of a rock can be determined by laboratory tests, but if the rock is unconsolidated, the results of such tests commonly are uncertain. Only a small sample of an aquifer that may be extensive and heterogeneous can be tested at a time. Also, it is difficult to arrange samples in the laboratory as they are in nature. All the wells and test holes completed in the headquarters area during this study have been drilled by the hydraulic-rotary method, and the formation samples obtained probably were less representative than those that might be obtained from outcrops or from the cuttings of a cable-tool drill. For these reasons, no attempt was made to determine the specific yield of the bolson deposits by laboratory methods.

The specific yield of a nonartesian aquifer also may be determined by dividing the quantity of water pumped from the aquifer during a known period of time by the volume of that part of the aquifer that has been dewatered during that period. This volume can be computed if accurate records of water-level declines throughout the area have been obtained. This was one of the principal reasons for attempting to compile accurate records of water-level fluctuations in the headquarters area. Although fairly complete records have been obtained of water-level fluctuations in the test holes and wells drilled since this study began, it has been impossible to obtain such records for the older wells in the area. It has been impossible to measure the depth to water in those wells with other than an air-line gage, and pumping schedules have not permitted reliable measurements of nonpumping water levels, even by air-line gage.

Between the time when the first wells were completed in the vicinity of the cantonment area and the end of 1954, approximately 1 billion gallons of water had been pumped from the area. A calculation based upon this figure and estimated declines of water levels indicates that the specific yield of the bolson deposits in that area is approximately 15 percent. The water level in well 22.4.24.222 apparently has declined about 8 feet (p. ~~65~~ 77) since well 10 was completed. This apparent decline corresponds approximately to a decline computed on the basis of an average coefficient of transmissibility of 15,000 gpd per foot and a specific yield of 15 percent.

how about 6000 acre/ft recharge per year?

Pumping Tests

When representative undisturbed samples of the aquifer can be obtained, some hydrologic characteristics can be determined by laboratory tests, but generally data obtained in the field under natural conditions by controlled pumping tests are the most reliable. It has been difficult to make satisfactory pumping tests of the older wells at White Sands Proving Ground for several reasons, as mentioned previously. However, pumping tests were made of most of the older equipped wells and of wells 14-16 before they were equipped with permanent pumps. The problem of water supply may become less critical after the new wells are added to the system, and it may be possible to make additional tests to supplement the data presented in this section of the report.

Well 9

On April 23, 1953, well 9 (22.5.31.424) in the old well field was pumped for $6\frac{1}{2}$ hours at an estimated rate of 35 gpm. The depth to water was determined by means of an air-line gage during the pumping period and for several hours after pumping had stopped. The depth to water prior to pumping was 240.5 feet; and at the end of the pumping period the water level in the well had declined to 263 feet.

The drawdown and recovery are plotted against the logarithm of time (t and t'), and the recovery is plotted against the logarithm of t/t' in figure 18. By applying the equation $T = 264\ Q/\Delta s$ to the early

Figure 18.--Data from pumping test of well 9, April 23, 1953.

part of the recovery curve, as indicated in the figure, the aquifer near the well was shown to have a coefficient of transmissibility of 840 gpd ~~/ft.~~ per foot.

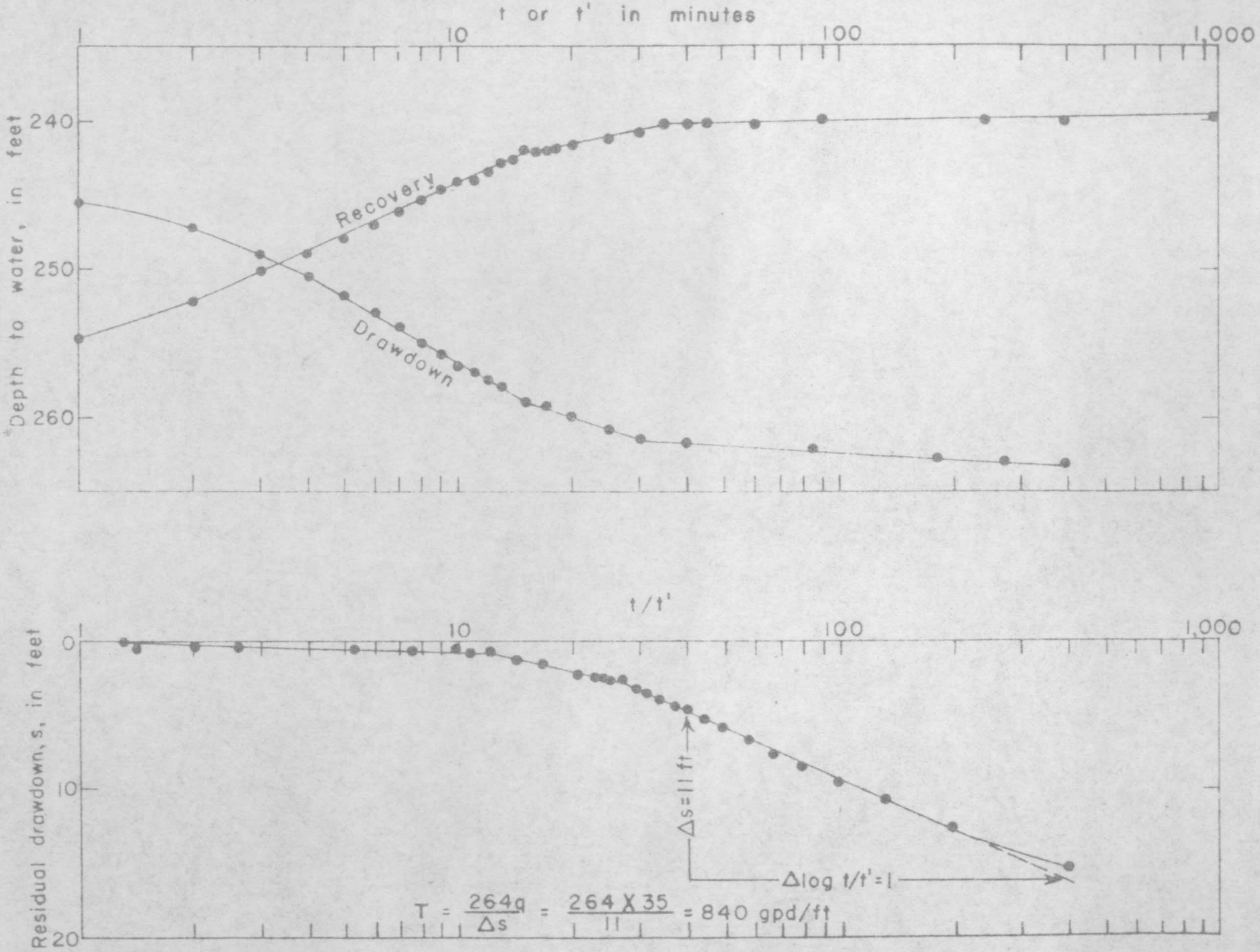

Figure 18 -- Data from pumping test of well 9, April 23, 1953

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Well 10

In August 1953, well 10 was pumped for 72 hours at an estimated average rate of 350 gpm. Prior to the pumping test, well 10 had not been pumped for 72 hours, and the nonpumping depth to water in the well was 357.75 feet. At the end of the 72-hour pumping period the drawdown in the well was about 17 feet, and the specific capacity of the well therefore was about 21 gpm ~~gallons per minute~~ per foot of drawdown. The drawdown and recovery curves are plotted in figure 19.

Figure 19.--Data from pumping test of well 10, August 1953.

The coefficient of transmissibility of the aquifer was determined by the Theis recovery method to be about 61,600 gpd per foot.

Well 11

In August 1953 well 11 was pumped for 29.5 hours at an average pumping rate of 366 gpm. Before pumping started, the depth to water in the well was 312.75 feet. After the well had been pumped for 29.5 hours the water level had declined 57 feet to a depth of 369.75 feet. As the bottom of the air line was at this depth, the pump was stopped.

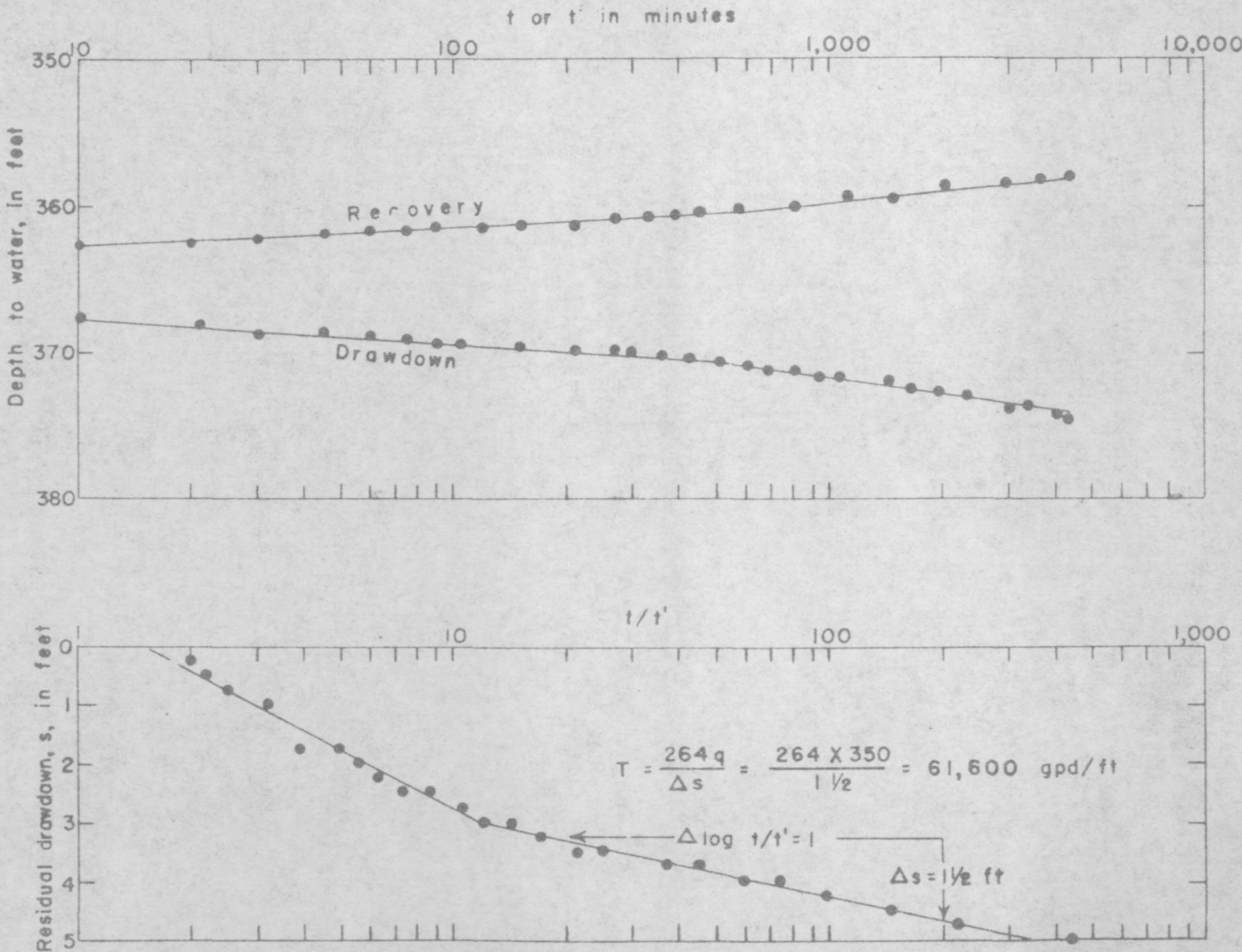

Figure 19 --Data from pumping test of well 10, August 1953

100a

The drawdown and recovery are plotted against the logarithm of time (t and t') in figure 20, and the recovery is plotted against the

Figure 20.--Data from pumping test of well 11, August 1953.

logarithm of t/t' in figure 21. Those curves do not define straight

Figure 21.--Recovery of water level in well 11, August 1953.

lines, as they theoretically should if the aquifer were homogeneous and of infinite extent (Theis, 1935). The semilogarithmic plots are curvilinear throughout with the exception of small segments near the end of the pumping and recovery periods. The aquifer does not conform to the basic assumptions of the Theis nonequilibrium formula; however, a value of about 2,500 gpd per foot was computed for the coefficient of transmissibility of the aquifer by applying the equation ($T = \frac{264\ Q}{\Delta s}$) to the linear segments near the end of the drawdown and recovery plots.

Well 13

In September 1953 well 13 was pumped for 50 hours at an average rate of 209 gpm. The nonpumping depth to water was 318.25 feet. During the pumping period the water level in the well declined 72 feet to a depth of 390.25 feet.

The drawdown and recovery are plotted against the logarithm of time (t and t') in figure 22, and the recovery is plotted against the

Figure 22.--Data from pumping test of well 13, September 1953.

logarithm of t/t' in figure 23.

Figure 23.--Recovery of water level in well 13, September 1953.

10/a

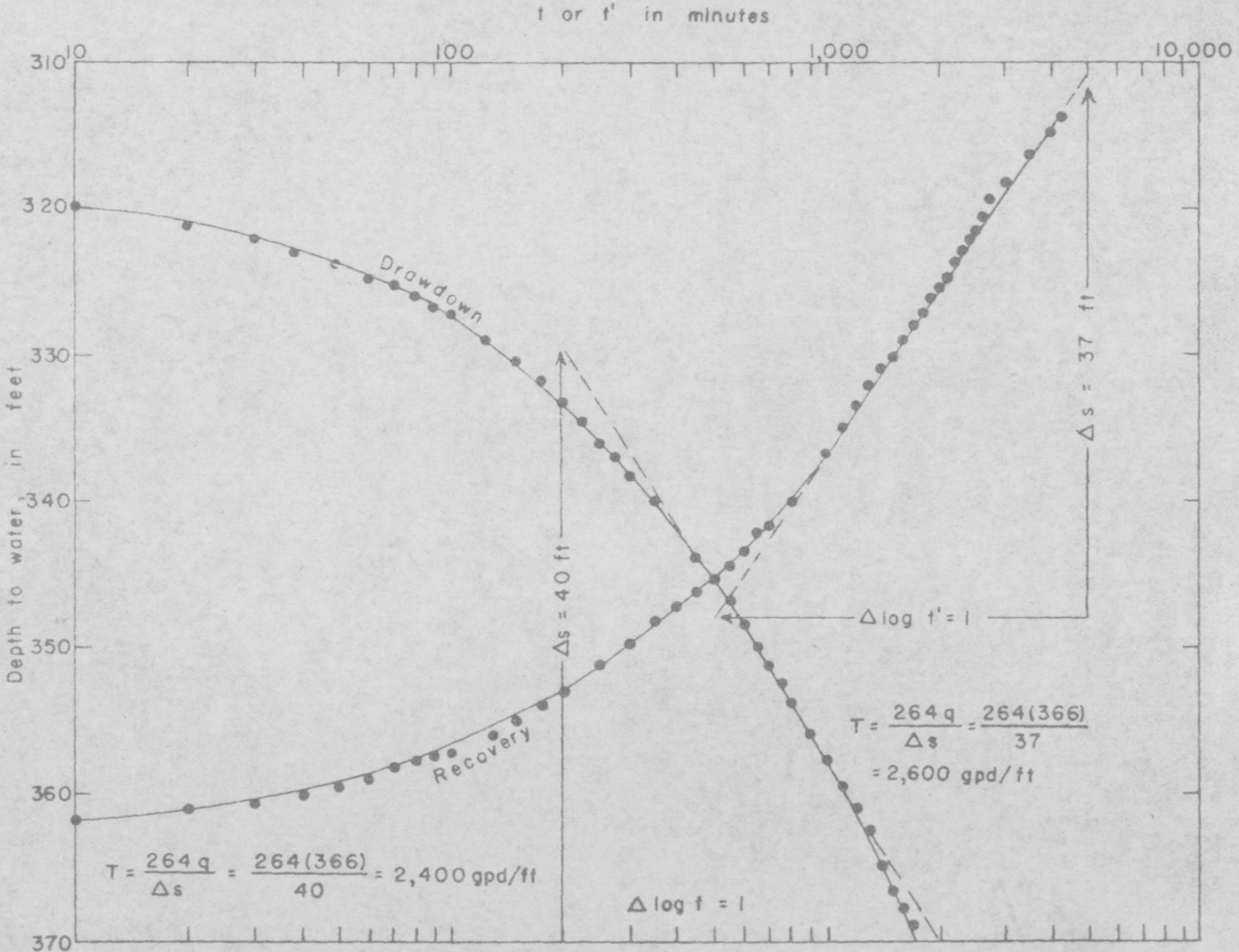

Figure 20 -- Data from pumping test of well 11, August 1953

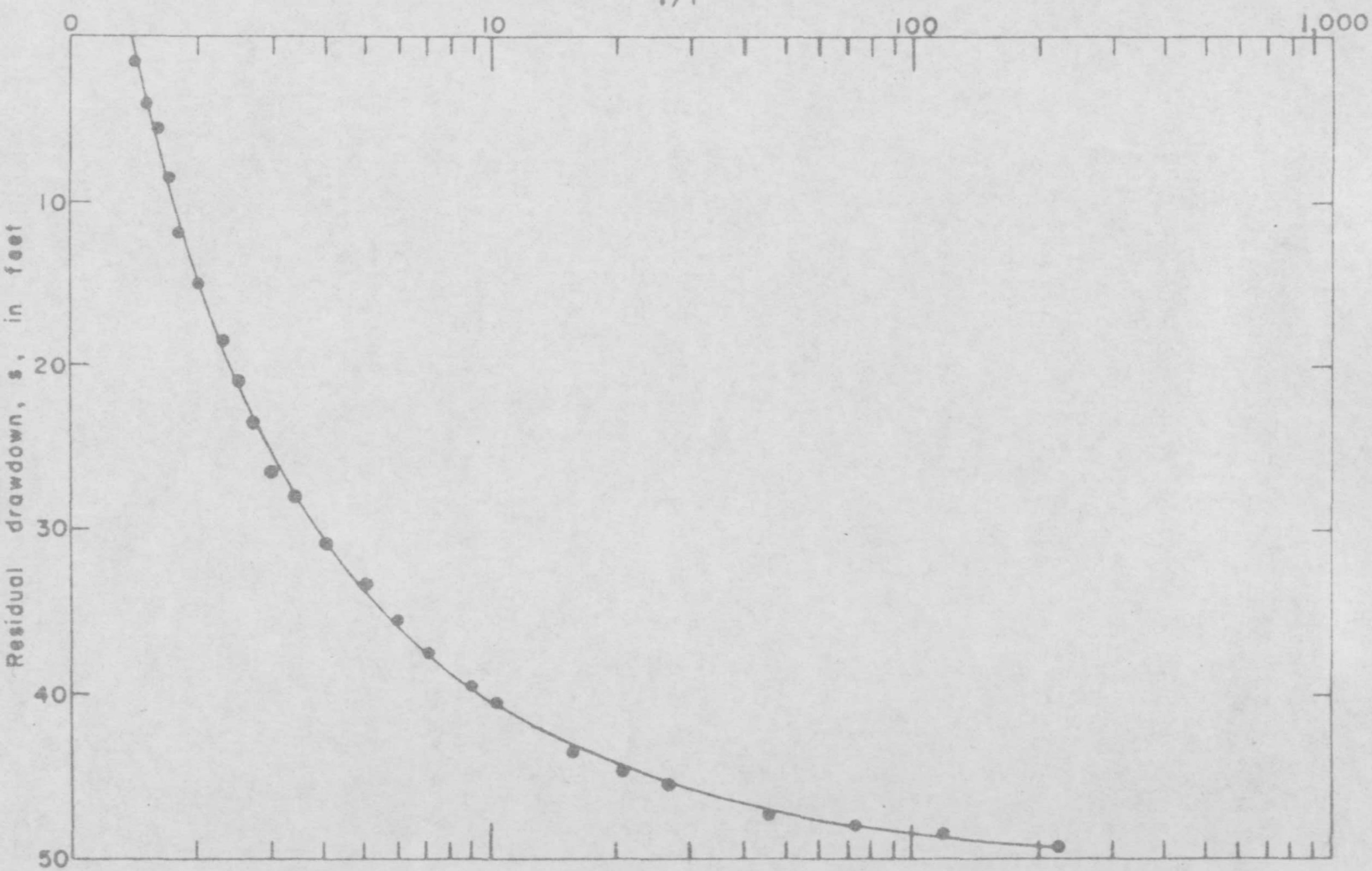

Figure 21--Recovery of water level in well 11, August 1953

9101

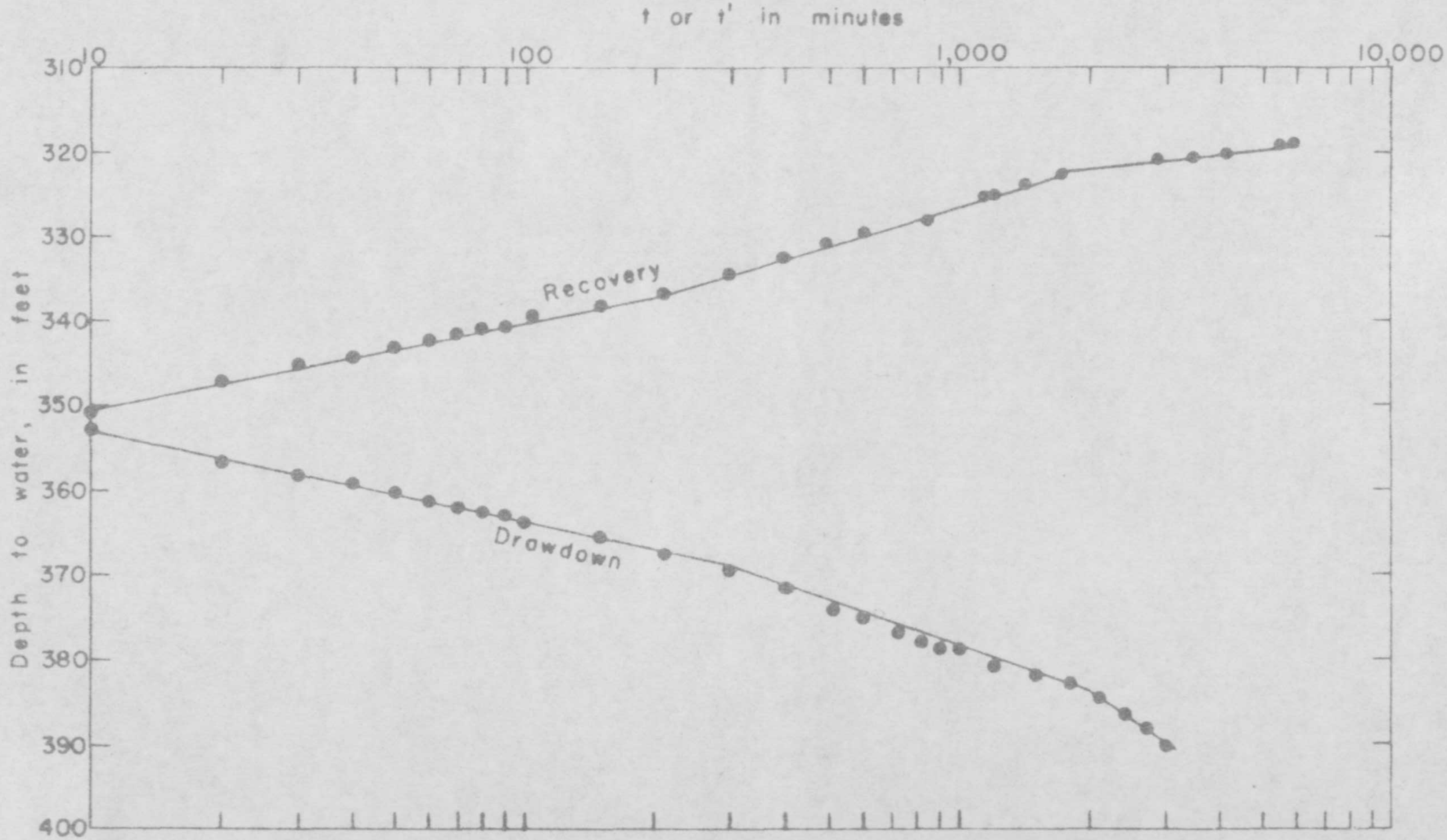

Figure 22-- Data from pumping test of well 13, September 1953

10/d

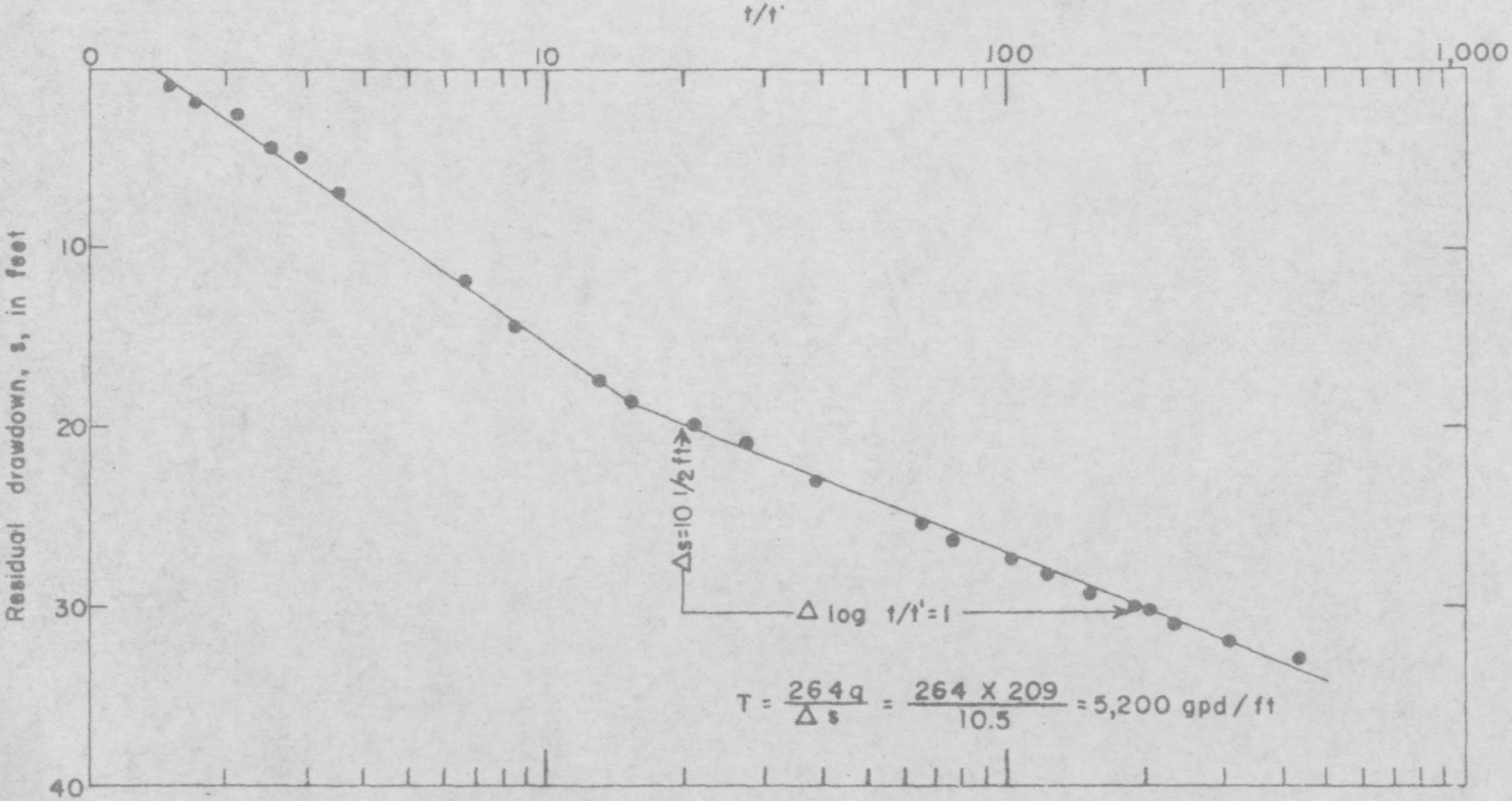

Figure 23--Recovery of water level in well 13, September 1953

A value for the coefficient of transmissibility of the aquifer was obtained by the Theis recovery method. The coefficient of transmissibility obtained by this method is 5,200 gpd per foot from the early part of the recovery curve and therefore may be applicable only to that part of the aquifer near the well.

Well 14

In December 1953, well 14 had been completed and was equipped with a turbine pump for the purpose of test pumping the well. On January 4 the depth to water in the well was 361 feet, and pumping was started at an average rate of 150 gpm. At the end of 6 hours the depth to water was 373 feet, and the pumping rate was increased to 250 gpm. At the end of the second 6-hour period the depth to water was 381.5 feet, and the pumping rate was increased to 350 gpm. After a period of 6 hours' pumping at a rate of 350 gpm (third 6-hour period), the depth to water was 394 feet, and the pumping rate was increased to 450 gpm. That pumping rate also was maintained for 6 hours, and the depth to water at the end of the period was 407.5 feet. The well was then pumped for 6 hours at a rate of 600 gpm, and the water level was drawn down to 429 feet. At that time the pumping rate was increased to the maximum rate of the equipment, about 720 gpm. The well was pumped at that rate for 18 hours; at the end of that period the depth to water was 455.5 feet, 95.5 feet below the static water level of 360 feet. Toward the end of the pumping period the water level remained at approximately 455 feet for a period of 7 hours before the pump was stopped.

Following the step-pumping period of 48 hours, the well was undisturbed for nearly 54 hours, during which period the depth to water was determined periodically with the air-line gage. At the end of 54 hours, the depth to water in the well was 360.5 feet.

On the basis of the data obtained during the step-pumping test, it was estimated that the maximum yield the well could produce probably was at least 800 gpm. Therefore, it was decided to pump the well at a rate of 600 gpm during the 48-hour aquifer test pumping period.

On January 13, the depth to water in the well was 363 feet when test pumping was started. The well was pumped for 48 hours at an average rate of 600 gpm. At the end of that period the depth to water was 436.5 feet, representing a drawdown of 76.5 feet below the static level of 360 feet. The pumping level had remained at approximately 436.5 feet for 6 hours prior to the conclusion of the test pumping. During the following recovery period the depth to water was measured periodically. On January 16, 31 hours after pumping had stopped, the depth to water was 363 feet, the water level at the time pumping was started. On January 18, 44 hours later, the depth to water was 360 feet.

At no time during either the step pumping or aquifer test did it appear that the well was yielding any appreciable amount of sand. The well previously had been pumped for a short period in order that personnel of the Office of the Project Engineer at White Sands Proving Ground could check the amount of sand in the water. The gravel pack remained at a constant level throughout the test-pumping period, also indicating that very little sand was being removed from the well.

The depth to water in well 14, determined at frequent intervals during the step-pumping test, is plotted against time in figure 24 A.

Figure 24 A and B.--Data from step-pumping test of well 14, January 1954.

Figure 24 B is a plot of the drawdown in the well at the end of each 6-hour step against the discharge of the pump. The figures appearing along the slope of the line drawn through these plots are the incremental specific capacities of the well computed at the end of each 6-hour step. For example, after well 14 had been pumped for 6 hours at a rate of 150 gpm the corrected drawdown in the well was 13 feet; the specific capacity of the well then was 150 ÷ 13, or 11.5. During the next ~~six~~ 6 hours the well was pumped at a rate of 250 gpm, an increase of 100 gpm over the rate during the first step. The additional increase in drawdown during this second step was 8.5 feet; thus the incremental specific capacity at the end of the second step was 100 ÷ 8.5, or 11.8. It will be observed that the slope of the line drawn through the plots has no sharp breaks; the incremental specific capacities decline more or less consistently. During the test the well obviously was not pumped at its maximum rate; otherwise, beyond that rate, the incremental specific capacity should have dropped off abruptly and there should have been a definite break in the slope of the line. This type of plot is useful for comparing the performance of the well at various rates of pumping and with that of other wells.

104a

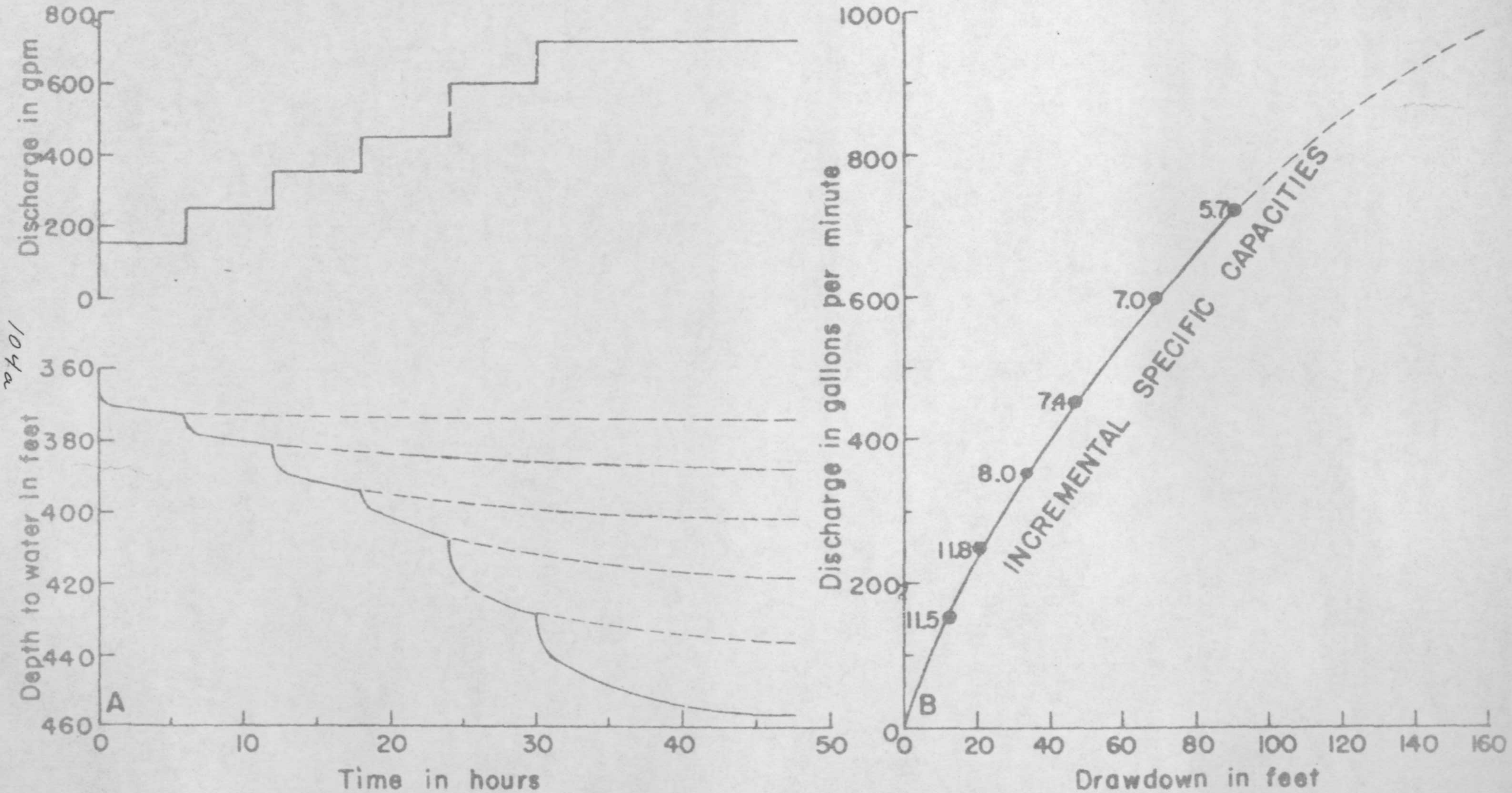

Figure 24.--Data from step-pumping test of well 14, January 1954

The coefficient of transmissibility of the aquifer in the vicinity of well 14 was computed by the recovery method from both the constant-discharge test and the step-pumping test. The recovering water levels in the well following the constant-discharge test are plotted against the logarithm of t/t' in figure 25B. As indicated in the figure, the

Figure 25 A and B.--Data from constant-discharge pumping test of well 14, January 1954.

coefficient of transmissibility computed by this method was 7,900 gpd per foot. The coefficient of transmissibility computed from the recovery following the step-pumping test was 7,800 gpd per foot (see fig. 26).

Figure 26.--Recovery data from step-pumping tests of wells 14, 15, and 16.

The results of a pumping test made of well 14 in November 1954 were analyzed by the method of determining the coefficient of storage discussed on p. 96. The well was pumped at an average rate of 670 gpm for 96 hours, and the water level in well 15, 2,250 feet distant, was measured frequently before, during, and after the pumping period. Although neither well had been pumped for several days, the water levels were still recovering at the start of the test, and a correction was applied to the observed drawdowns. The corrected drawdowns in well 15 are plotted against the logarithm of t/r^2 in figure 27.

Figure 27.--Plot of drawdown test data for well 15 (r = 2,250 ft).

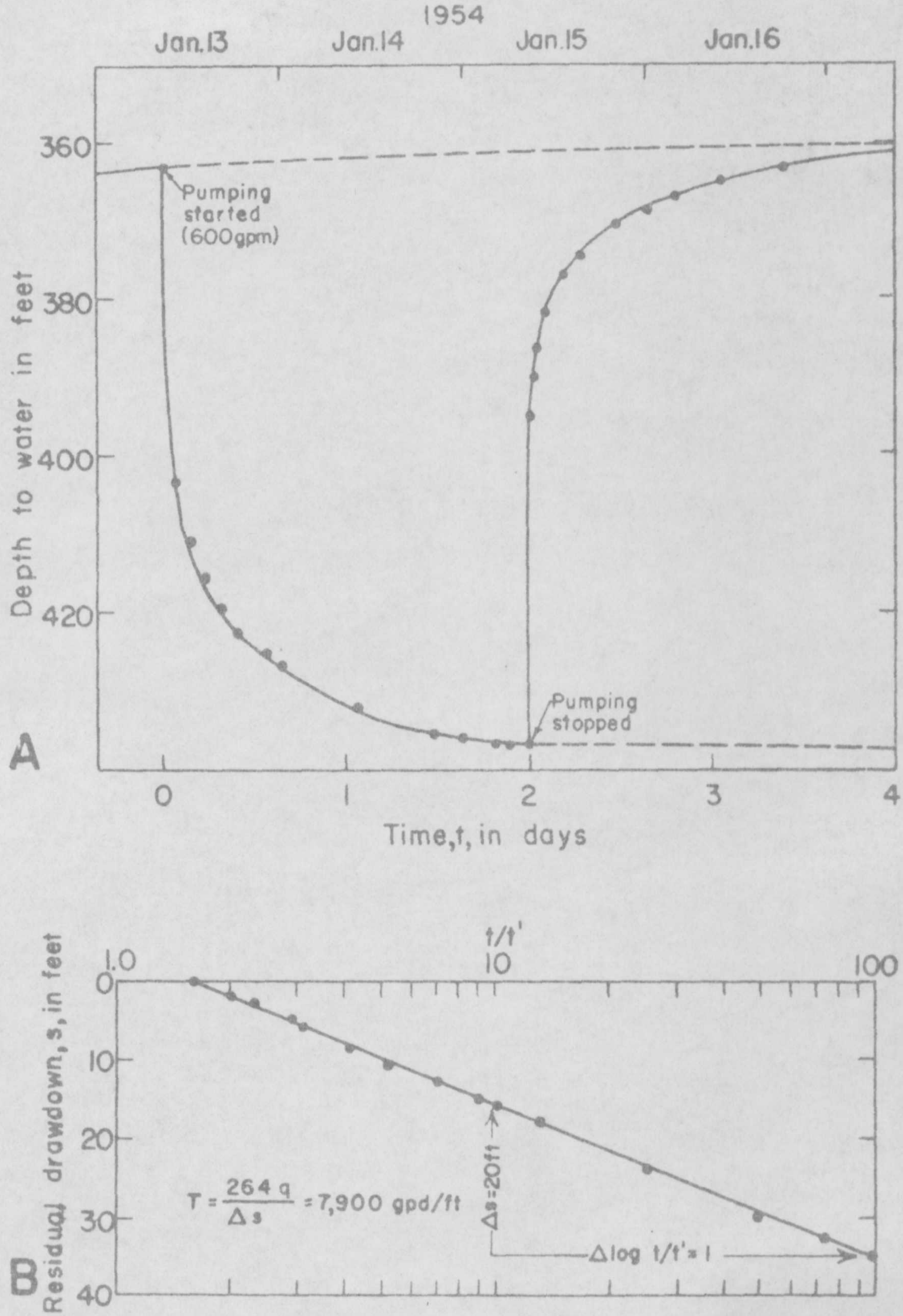

Figure 25--Data from constant discharge pumping test of well 14, January 1954

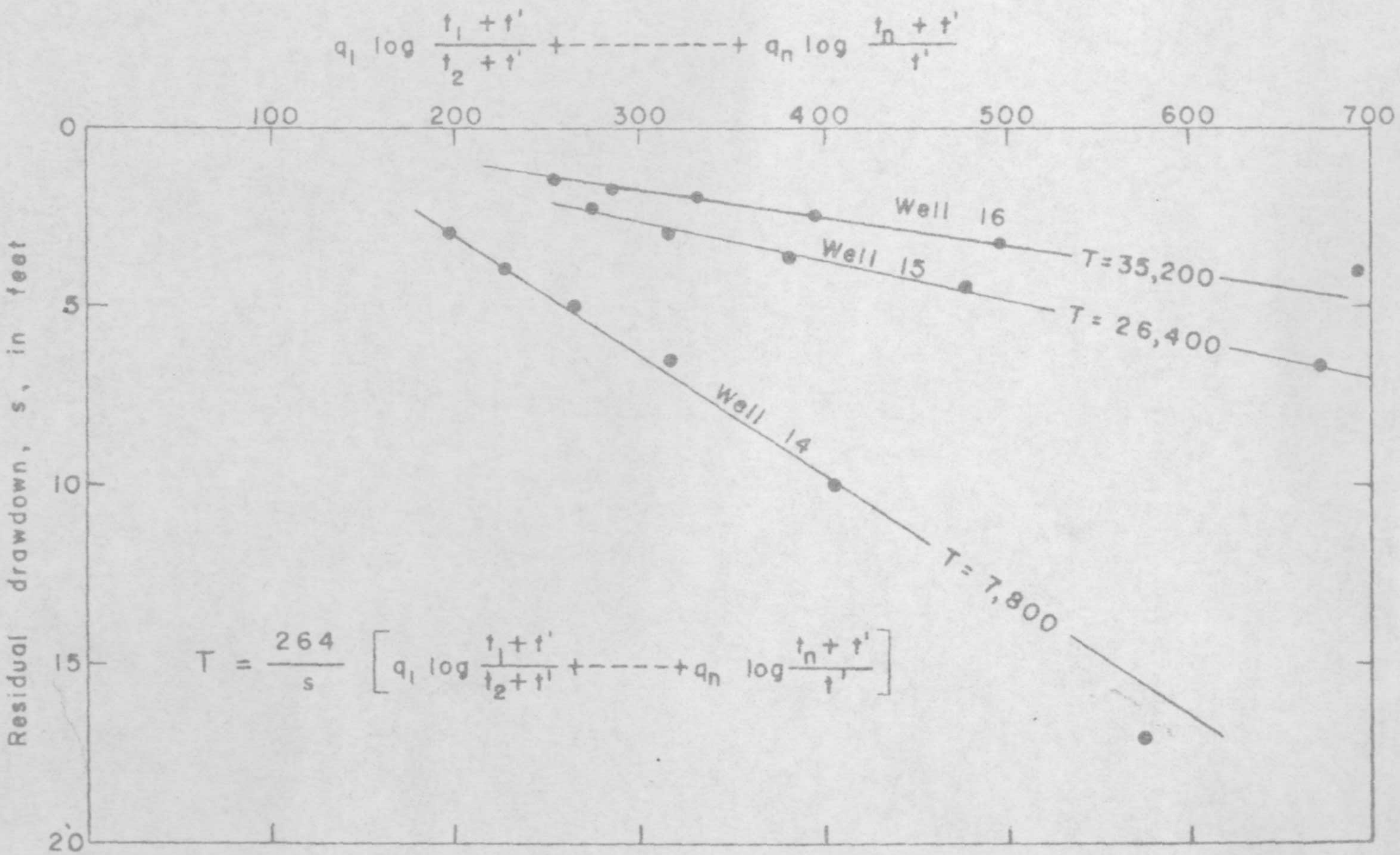

Figure 26--Recovery data from step-pumping tests of wells 14, 15, and 16

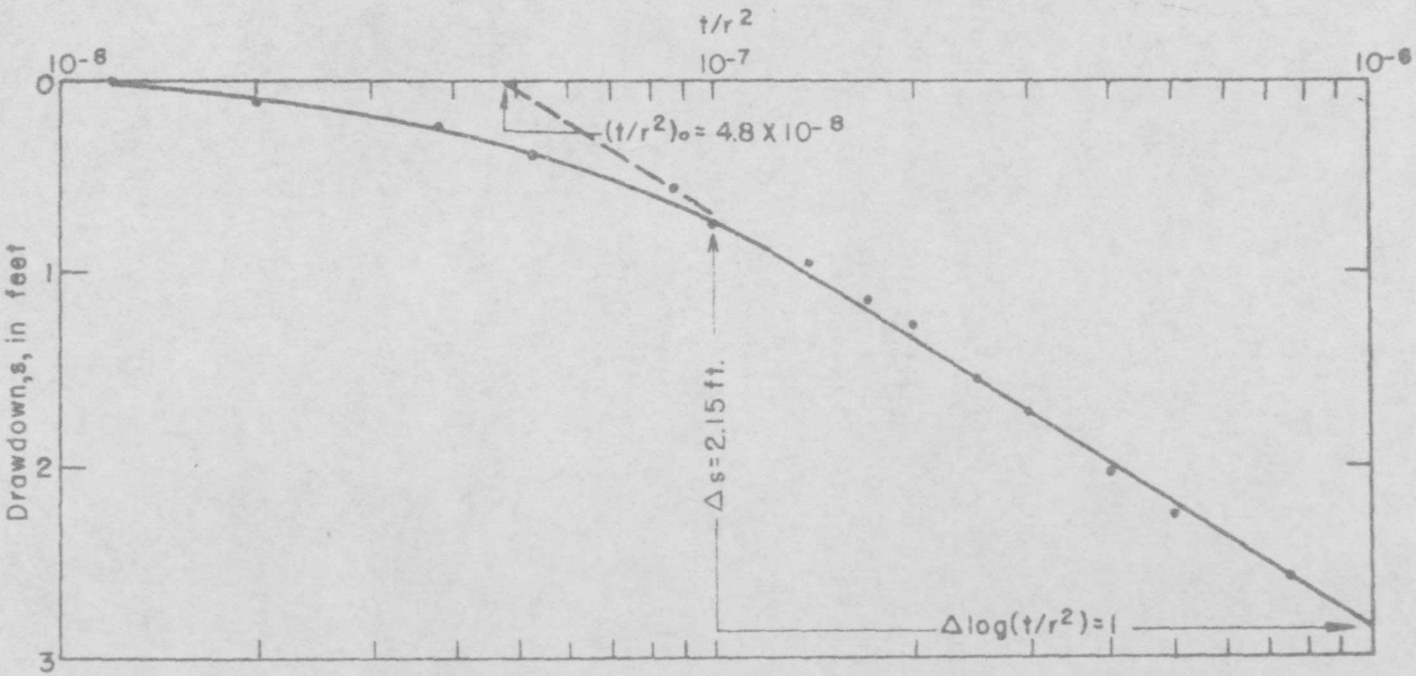

Figure 27--Plot of drawdown test data for well 15 (r = 2,250 ft.).

From figure 27, Δs is found to be 2.15, and when the straight part of the drawdown curve is extended, the zero intercept is 4.8×10^{-8}. By substitution of these values in the Cooper-Jacob solution of the Theis nonequilibrium formula: $T = \frac{264 Q}{\Delta s} = 82{,}300$ gpd per foot, and,

$S = 0.301\, T\, (t/r^2)_0 = 12 \times 10^{-4}$ or 0.0012.

Well 15

In February 1954, well 15 was finished to a depth of 820 feet. The well was developed by jetting with air and by surging with the pump later used for test pumping. During the development of the well, it was noted that the gravel pack maintained its original level, and very little sand was pumped.

On February 13 the well was pumped for 2 hours at an average rate of 830 gpm ~~gallons per minute~~ to determine the amount of sand being yielded by the well. When the pump was first started, the water was muddy but contained very little sand. The water was clear a half hour after the pump was started. Samples of water were obtained at half-hour intervals during the pumping; only negligible amounts of fine sand were found in the samples. During the 2-hour pumping period, the water level in the well declined 30.5 feet from a level of 338.5 feet before pumping started. Approximately 24 hours after pumping stopped the water level in the well had returned to 338.5 feet.

On February 14 the well was pumped for 6 hours at 250 gpm ~~gallons per minute~~. At the end of the period the drawdown was about 8.5 feet, and the pumping rate was increased to 350 gpm. ~~gallons per minute~~. After the well had been pumped for 6 hours at the latter rate, the drawdown in the well was 12.5 feet. The well was then pumped for 6 hours at a rate of 450 gpm ~~gallons per minute~~, resulting in a drawdown of 16.5 feet. The pumping rate was then increased to 600 gpm ~~gallons per minute~~ and after 6 hours, the drawdown was 23.5 feet. The pumping rate was then increased to 800 gpm ~~gallons per minute~~ for an additional 24 hours. At the end of the period, 48 hours after the step-pumping test was started, the depth to water in the well was 379 feet, about 40.5 feet below the level prior to the test-pumping.

Following the step-pumping, the recovering water levels were measured at regular intervals. On February 18, 57½ hours after the end of the step-pumping test, the depth to water in the well was about 339.5 feet. At that time the constant-discharge test was started.

During the constant-discharge test, the well was pumped continuously at an average rate of 750 gpm. ~~gallons per minute~~. After a pumping period of 40.5 hours, the engine failed and the test was concluded. At the end of the pumping period, the depth to water in the well was about 374.5 feet, representing a drawdown of 35 feet.

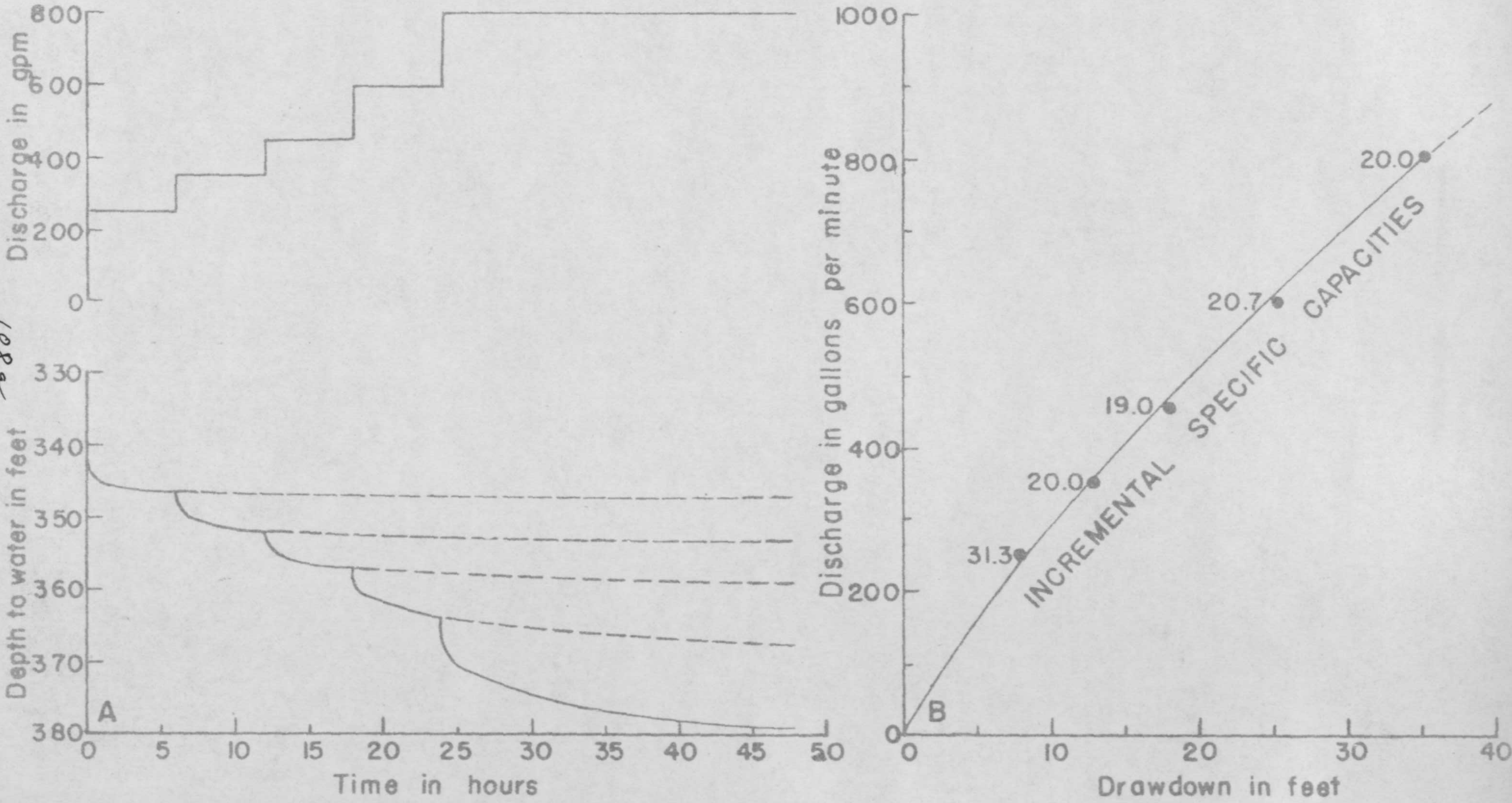

Figure 28.--Data from step-pumping test of well 15, February 1954

During the recovery period following the aquifer test, the water level in well 15 was measured periodically. About 72 hours after pumping stopped the water level in the well had recovered to approximately its pre-pumping level, 339.5 feet.

The well did not yield any noticeable amount of sand throughout the test-pumping periods. The gravel pack remained at a constant level, an additional evidence that very little sand was being pumped.

The depths to water in well 15 during the step-pumping test are plotted against time in figure 28A, and in figure 28B the residual

A and B

Figure 28.--Data from step-pumping test of well 15, February 1954.

drawdown at the end of each step is plotted against the pump discharge. The incremental specific capacities are computed as for well 14, (p.106). The slope of the line drawn through the plots in figure 28B indicates that well 15 was not pumped at maximum capacity; there is no pronounced break in the slope of the line. The incremental specific capacity at the end of 6 hours in step 5 (20.0) is equal to the incremental specific capacity of the well at the end of step 2. In other words, during a short pumping test the performance of the well at a rate of 800 gpm is about as good as the performance of the well at a rate of 350 gpm. The incremental specific capacities of well 15 are higher than those obtained for well 14, just as its overall performance is better.

The recovery of the water level in well 15 following the constant discharge test is plotted against the logarithm of t/t' in figure 29B. The value of the coefficient of transmissibility obtained by

Figure 29 A and B.--Data from constant discharge pumping test of well 15, February 1954.

the standard recovery method, as indicated in the figure, is 28,300 gpd per foot. The coefficient of transmissibility obtained from the recovery of the water level following the step-pumping test is 26,400 gpd per foot (see fig. 26).

Well 16

In September 1954 well 16 was completed. The well was developed by washing and bailing, swabbing and surging, and finally by pumping. During the development of the well, a considerable amount of clay, sand, and gravel was induced through the screens and removed from the well. At the end of the development and during the test pumping, the gravel pack did not lower appreciably, and very little sand was pumped.

On September 30 well 16 was pumped at an average rate of 800 ~~gallons per minute~~ gpm for ~~two~~ 2 hours to determine the sand content. Water samples were obtained from the dishcarge pipe at intervals of 30 minutes. At the end of the ~~two~~ 2-hour pumping period the sand content of the water was less than ~~one~~ 1 ounce per 100 gallons. Following the sand test the pump was idle for a period of 72 hours.

On October 3, at the end of the 72-hour rest period, the depth to water in the well was about 351 feet below the top of the casing. The pumping levels were determined by means of an air line gage.

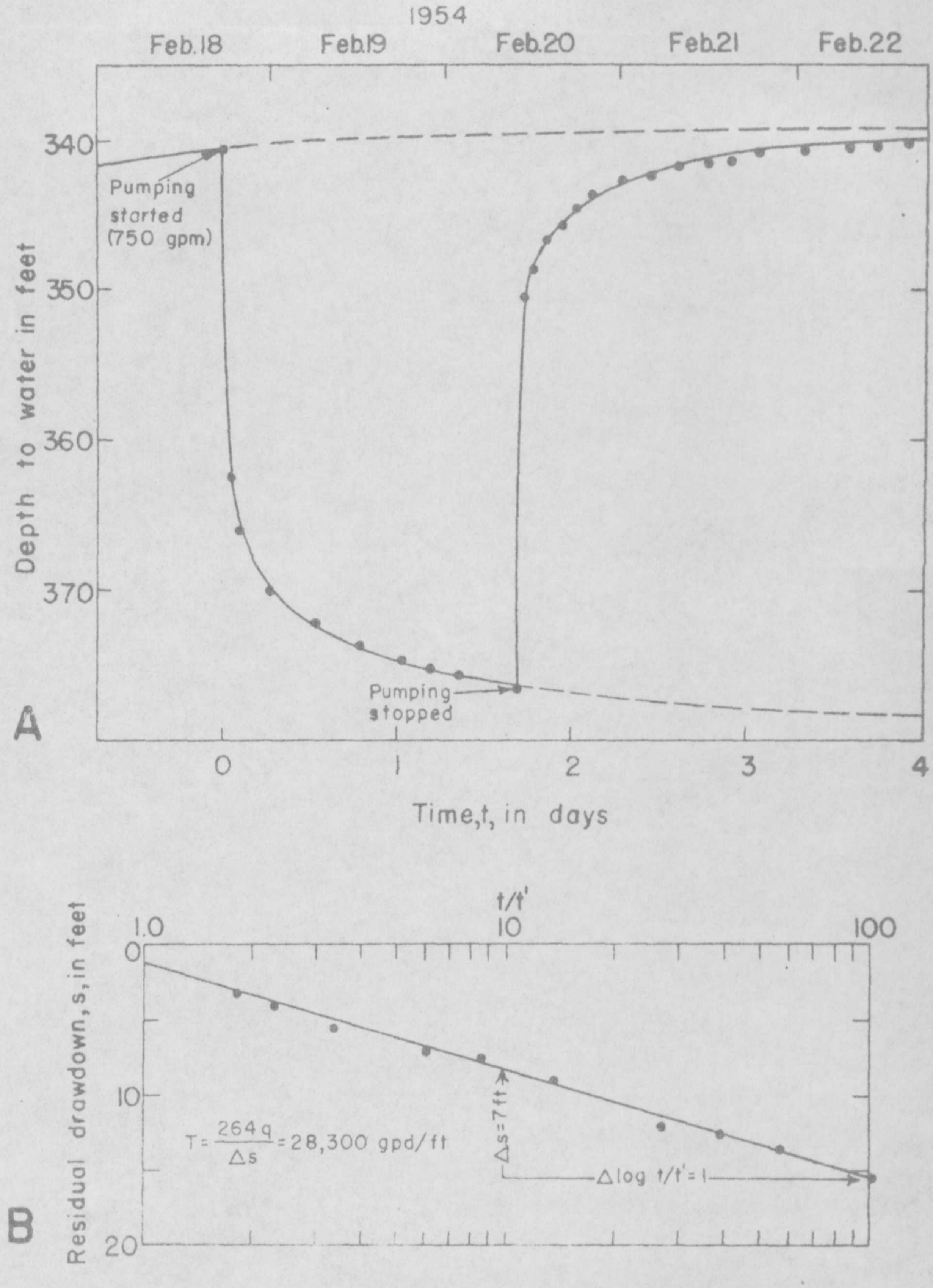

Figure 29--Data from constant discharge pumping test of well 15, February 1954

At the beginning of the step-pumping test the well was pumped at a rate of 350 gpm for 6 hours. At the end of the period the drawdown was about 13.5 feet. The pumping rate was then increased to 450 gpm, and the drawdown at the end of the 6 hours was about 17 feet. The pumping rate was then increased to 550 gpm, and the drawdown after 6 hours was 19 feet. An increased pumping rate to 650 gpm resulted in a drawdown of 23 feet after 6 hours. During the final 24 hours of the test the well was pumped at a rate of 800 gpm. At the end of the pumping period the total drawdown was about 30 feet.

Following the step-pumping test, the pump was idle for a period of 51 hours, during which time the recovering water level was measured regularly. At the end of the rest period the depth to water was approximately 352 feet.

On October 7, 8, and 9 the well was pumped at a rate of 600 gpm for 48 hours. At the end of the pumping period the depth to water, as indicated by the air-line gage, was 376 feet, representing a drawdown of about 25 feet. Toward the end of the pumping period an attempt was made to check the air-line gage reading against a measurement with a steel tape. The latter measurement may be somewhat unreliable, but it indicated that the drawdown probably was somewhat less than that indicated by the air-line gage.

Following the aquifer test, the recovering water level was measured regularly with a steel tape for a period of 48 hours. After 48 hours of recovery the depth to water was approximately 353 feet and fluctuating, probably owing to interference effects from wells 14 and 15, both of which were pumped throughout a large part of the testing period. Because the latter wells were pumped during the test, it was impossible to determine the effect that pumping of well 16 had upon the water level in well 15. Such data are necessary for computing future effects of pumping upon water levels in the well field.

The depths to water in well 16 during the step-pumping test are plotted against time in figure 30A. In figure 30B the residual

Figure 30 A and B.--Data from step-pumping test of well 16, October 1954.

drawdown at the end of each step is plotted against the pump discharge. The incremental specific capacities are computed in figure 30B as for wells 14 and 15. The incremental specific capacities of well 16 do not have a consistent decline with increased rates of pumping as those of wells 14 and 15, probably because some development of the well was occurring during the step-pumping test. However, there is no pronounced break in the slope of the line drawn through the specific capacity plots, indicating again that well 16 was not pumped at maximum capacity. The overall performance of well 16 is better than that of wells 14 and 15, as indicated by the higher incremental specific capacities of the latter well.

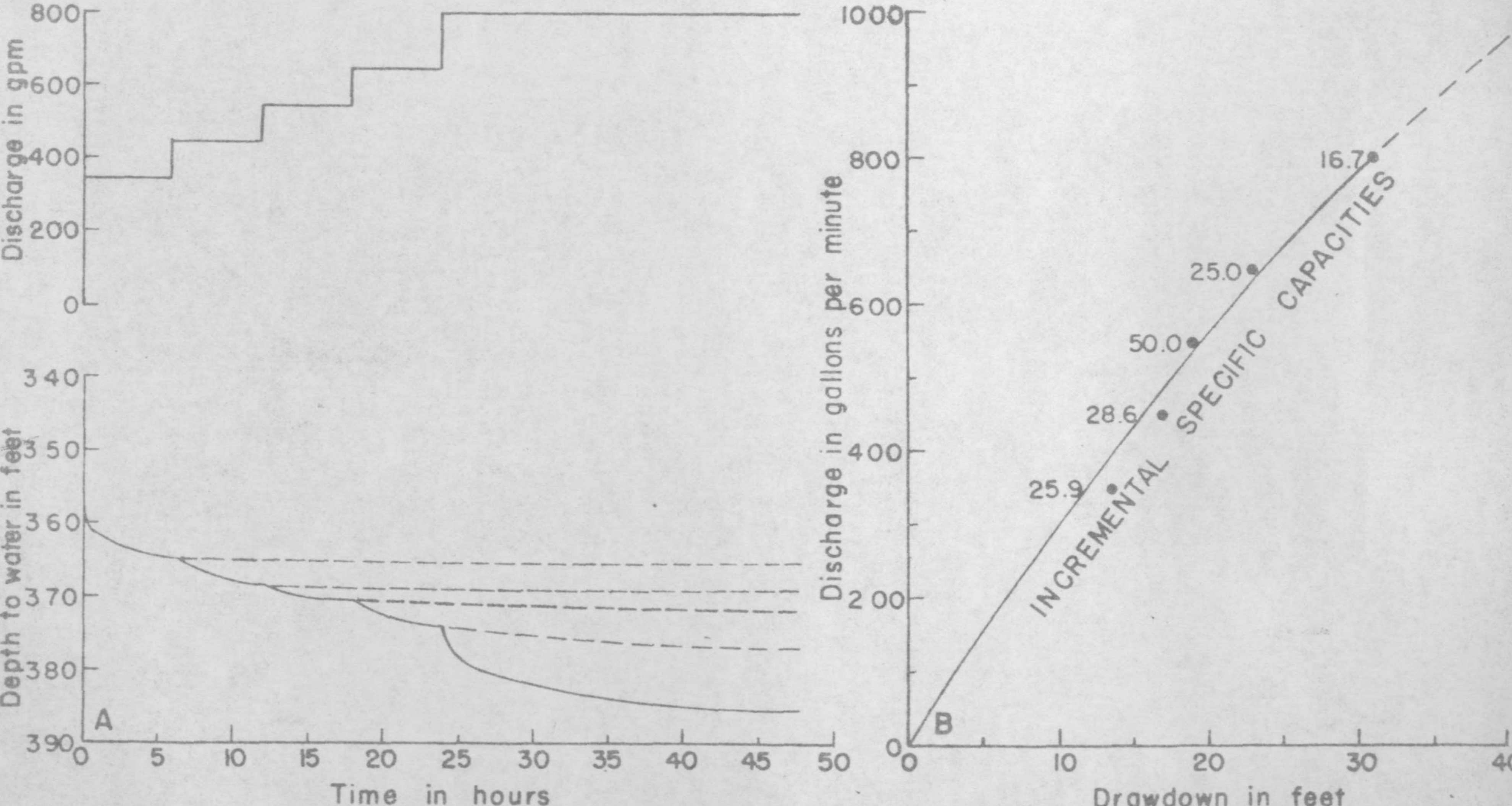

Figure 30.--Data from step-pumping test of well 16, October 1954

The recovery of the water level in well 16 following the constant discharge test is plotted against the logarithm of t/t' in figure 31 B.

A and

Figure 31 B.--Data from constant discharge pumping test of well 16, October 1954.

The coefficient of transmissibility, computed by the standard recovery method, is 33,000 gpd per foot. The coefficient of transmissibility obtained from the recovery of the water level following the step-pumping test of well 16 is 35,200 gpd per foot (see fig. 26).

Specific capacities of wells

The specific capacity of a well generally is defined as the number of gallons per minute of water produced per foot of drawdown:

Thus,
$$SC = \frac{Q}{s}$$

where: SC = specific capacity.

Q = yield of the well, in gallons per minute.

s = drawdown of the water level, in feet.

During the first few minutes of pumping the water level in a well drops rapidly, then at a constantly declining rate until the decline may be almost imperceptible. For this reason, the specific capacity of a well should be calculated only when the well has been pumped for such a time that the rate of decline of the water level is small. Comparison of specific capacities between wells are more meaningful when the lengths of the pumping periods are known.

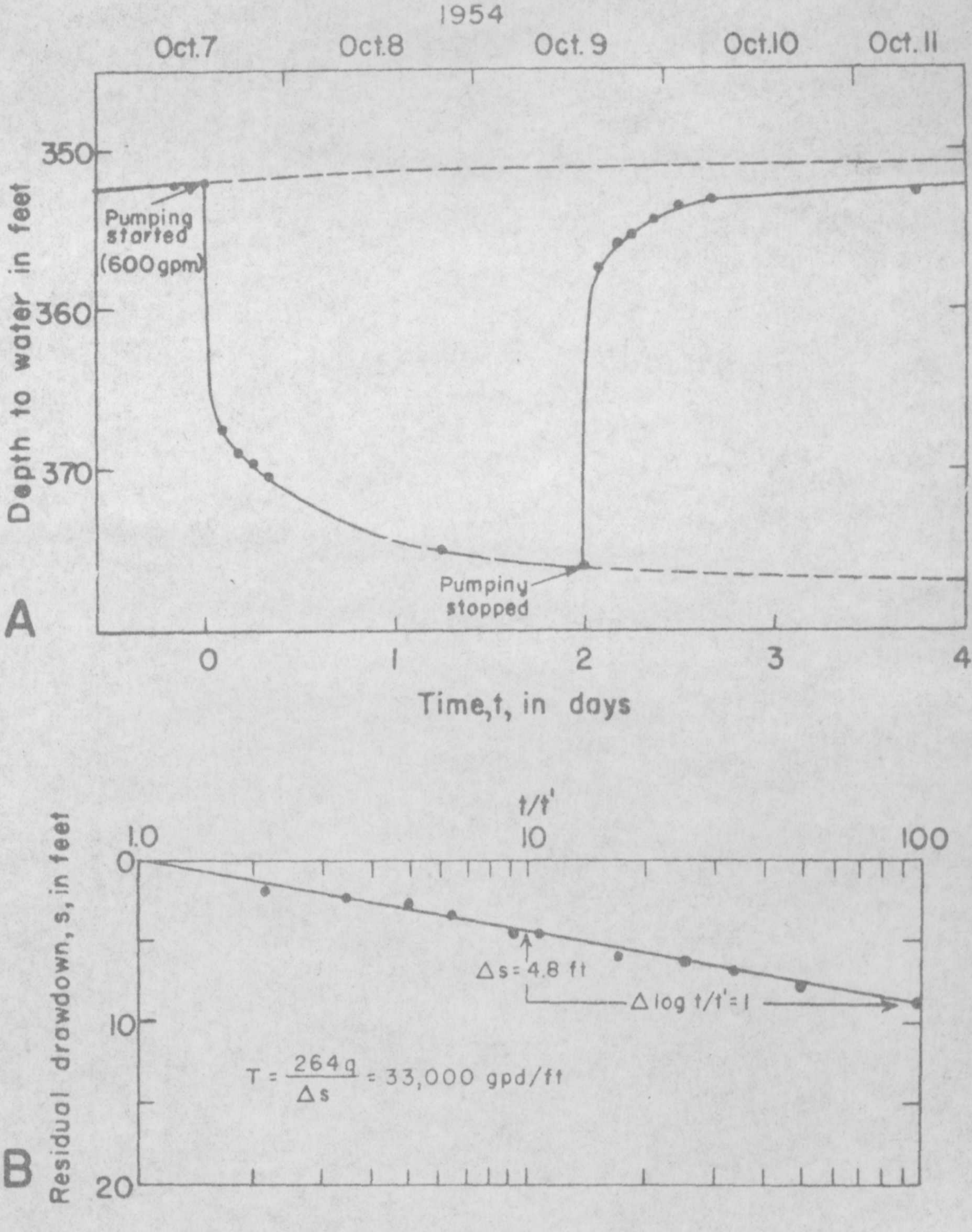

Figure 31--Data from constant discharge pumping test of well 16, October 1954

The specific capacity of a well generally declines with increased pumping rates because the water level continues to decline and well-entrance losses are greater at higher pumping rates. The incremental specific capacities of wells 14, 15, and 16, obtained from step-pumping tests of those wells have been discussed, and the incremental specific capacities are plotted in figures 24, 28, and 30.

The specific capacity of a well is a function also of the transmissibility of the aquifer and such factors as the diameter and depth of the well, the type and position of the perforations, the extent to which the well has been developed, and the length of the pumping period.

For these reasons, the specific capacity of a well should not be regarded as an exact value, but rather as an approximate indication of the performance of the well, and a useful index for comparing the performances of two or more wells.

It will be noted that the decrease in specific capacity with increased length of pumping time is not consistent among the wells. For example, at the end of a 6-hour pumping period, well 11 apparently had a higher specific capacity than well 14. But the water level in well 11 continued to decline at approximately a linear rate, and the performance of the well at the end of 24 hours was considerably poorer than well 14. Furthermore, the water level in well 11 at the end of $29\frac{1}{2}$ hours was below the top of the pump bowls and still declining at an appreciable rate, but the water level in well 14 declined only 5.5 feet during the final 24 hours of the test and was still more than 100 feet above the top of the pump bowls.

Well 16 had the highest specific capacity, but both wells 10 and 15 also have considerably higher specific capacities than other wells in the area. It is probable that well 10 can be safely pumped at a higher rate than it is at present, but it is also likely that the specific capacity of the well will decline appreciably if its yield is increased appreciably.

It is significant that the wells in the eastern part of the well field, that is, in the eastern part of secs. 13 and 24, T. 22 S., R. 4 E., have the highest specific capacities. This fact supports the evidence of well logs and other data that the bolson deposits in that part of the area are more permeable than in the area of wells 11, 12, and 13.

The specific capacities of most of the equipped wells at the Proving Ground have been determined and are given in table ~~2~~ 6.

The specific capacity of well 5 is not given because the length of the pumping period is not known, but for comparative purposes it is apparent from the data that the specific capacity of the well at the time of the test was approximately 5. At the present time it is impossible to measure the water level in the well, but there are various indications that the specific capacity of well 5 probably is considerably less than that indicated by the above test.

A specific capacity is not given for well 12, because it has been impossible to obtain even an approximate value for the drawdown in the well. It can be estimated from what is known of the performance and past history of the well that its specific capacity probably is approximately equal to that of well 13, about 3.5.

Summary of hydrologic properties

The coefficients of transmissibility obtained by observing the recovery of water levels in the pumped wells are given in table ~~2~~ 6. It is estimated that the average coefficient of transmissibility of the bolson deposits in the vicinity of the well field is on the order of 15,000 gpd per foot and this figure was used in estimating future effects of pumping (p. ~~108~~ 119). The coefficient of transmissibility obtained by observing the drawdown in well 15 when well 14 was pumped (p. ~~95~~ 105) is much higher than that obtained by the recovery method. This can be attributed, at least in part, to the somewhat linear but irregular distribution of the sediments. It is apparent that the permeability of the sediments varies widely within short distances, and pumping effects are transmitted much more rapidly in some directions than others. Also, it is probable that the wells produce some water from artesian parts of the aquifer, and during short periods of pumping, the observed effects are a result of artesian conditions. Over long periods of pumping, the artesian effects probably would become less apparent and eventually the effects of pumping would be those expected from a true water-table aquifer.

The coefficient of storage obtained from the analysis of the pumping test of well 14 is much lower than the estimated average specific yield of the area, and is additional evidence that the wells are semiartesian, at least for short periods of pumping. An estimate of the average specific yield of the aquifer, 15 percent, has been obtained from a comparison of water level declines in the area with the quantity of ground water removed by pumping (p. 97). This estimated specific yield has been used in computing future effects of pumping in the area. It has been noted in other areas that a true value of the specific yield is obtained only after the saturated material has been drained for a long time (Williams and Lohman, 1949, p. 220). Therefore, the calculated value of 15 percent for this area may be somewhat less than the true value.

Effects of Pumping

Estimated Future Declines of Water Levels

The effects of pumping on water levels and the quantity of ground water that will be removed from storage in an area within a certain period of time can be estimated if the hydrologic characteristics of the aquifer are known.

According to Theis (1935), in an ideal aquifer of infinite areal extent, the drawdown of the water level at any time and any place is given by the following equation:

$$s = 114.6 \; Q/T \int_{z}^{\infty} (e^{-u}/u) \, du$$

in which

s = drawdown at any point, in feet.

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

T = coefficient of transmissibility of the aquifer, in ~~gpd~~ gallons per day per foot.

$z = 1.87 \, r^2 \, S/Tt$.

r = distance from discharging well to the point where drawdown is to be determined, in feet.

S = coefficient of storage of the aquifer.

t = time the well has been discharging, in days.

The logarithmic integral has a definite value for any value of z, and this value can be found in prepared tables. Thus, the drawdown, s, can be found by (1) computing z, (2) finding the corresponding value of the integral, and (3) multiplying this value by 114.6 Q/T.

To reduce the labor involved in computing drawdowns in the vicinity of a discharging well, Theis has developed a graphical method of solution which has been used in estimating the following declines. As an example of how such an analysis can be made the declines in the water in the well field were computed from average yields arbitarily assigned to the various wells.

Well	Transmissibility (gpd per foot)	Assumed average yield (gpm)	Computed declines of water levels (feet)			
			20 years	30 years	40 years	50 years
10	60,000	100	14	16	18	19
11	2,500	50	65	70	74	77
12	5,000	50	37	42	45	48
13	5,000	50	40	45	48	51
14	8,000	100	41	45	48	49
15	30,000	175	23	26	28	29
16	35,000	175	20	22	24	26

Table ~~3~~ 7.--Computed declines of nonpumping water levels in wells at the headquarters area, White Sands Proving Ground, N. Mex.

These estimates, of course, are theoretical and are based upon certain necessary assumptions. To arrive at a more realistic estimate of decline the actual average yields of the wells in the field should be substituted for the arbitrarily assigned yields. In addition to the basic assumptions regarding the aquifer that are essential to the computations, a continuous pumping rate (Q) for each well, as given in the above table, has been used.

As the computed declines are based upon assumptions that are not satisfied in full, they should not be considered as exact values but rather as orders of magnitude of expected declines. It should be possible in the future to refine these estimates as additional data are obtained.

Possibilities of Encroachment of Saline Water

The bolson deposits in the vicinity of the wells consist of clay, silt, sand, and some gravel. Much of the clay is silty or sandy, and some of the sand contains clay, but, in general, the deposits in that part of the reentrant are fairly well stratified. The vertical movement of ground water within the zone of saturation is considerably more restricted than lateral movement. The fact that all the wells in the area show semiartesian characteristics, or partial confinement of the water, indicates that the clay lenses are fairly effective barriers to vertical movement of ground water, at least locally and over short periods. Also, the interface between fresh and highly mineralized ground water apparently is sharply defined in the places where data were obtained, indicating that vertical mixing is slight under natural conditions. This sharp ~~vertical~~ horizontal boundary probably is in part owing to the fact that ground water at that depth has not been subject to appreciable ~~fluctuations~~ movement.

It is not certain that highly mineralized ground water extends beneath the wells north of the cantonment area, as illustrated in figure 11. No highly mineralized water has been sampled from wells drilled west of the access highway, but samples of water from at least wells 15 and 16 should be analyzed chemically at about 6-month intervals as a precautionary measure. Even if saline water should eventually reach the wells, it would be in small quantities compared to the amount of fresh water with which it would be diluted during pumping. The mineral content of the water presently produced by the wells is so low that a considerable amount of saline contamination could occur before the water would become impotable.

Vertical migration of highly mineralized water should not be a serious threat in the near future, and nonpumping water levels probably could be lowered 50 feet, and perhaps more, before vertical contamination would occur.

A few miles east of the reentrant, where the shallow ground water is reported to be highly mineralized, the water table is more than 100 feet lower than the present lowest nonpumping water levels in wells in the eastern part of the well field (~~pl. 1~~ fig. 2A). Therefore, in order for the shallow saline water to move laterally to the area of the wells, the pumping levels in those wells must be reduced to a depth considerably more than 100 feet below the present nonpumping levels. Even then, many years would elapse before such pumping would cause the highly mineralized water to move laterally toward the wells, and then such movement would be slow, probably less than a few hundred feet per year.

Location and Spacing of Future Wells

Examination of the available data, including logs of test holes and wells, pumping tests, and electrical-resistivity measurements, indicate that the bolson deposits are probably most permeable in the eastern part of sec. 13; the northeastern part of sec. 24, T. 22 S., R. 4 E., as illustrated by the performance of wells 10, 15, and 16, and in secs. 11 and 12, T. 22 S., R. 4 E., north and northwest of the well field.

The depth to water in this area ranges from less than 350 feet in the eastern part of sec. 13 and the western and northern parts of sec. 11 to about 400 feet in parts of sec. 12 (fig. 9). Electrical-resistivity measurements indicate that the saturated deposits, as shown in figure 10, range in thickness from less than 500 feet in the southwestern part of sec. 11 to more than 1,000 feet in the north-central part of sec. 11, the central and eastern parts of sec. 12, the eastern part of sec. 13, and the northeast cor. of sec. 24.

The bolson deposits vary considerably in composition within short distances, and beds usually pinch out in a few hundred feet, as indicated by test drilling and the resistivity survey. For these reasons, the aquifer in some parts of the area outlined above would have a higher permeability and, therefore, would be more favorable for the development of wells than other parts of the area. Only exploratory drilling will indicate for certain if a particular well location is satisfactory. However wells comparable to well 14 probably could be developed in the vicinity of test hole T-2 and in most of the southern parts of secs. 11 and 12. As shown in figure 10, the saturated deposits apparently are relatively thin in the western half of sec. 11; therefore, the eastern half of that section and sec. 12 probably should be given perference in future test drilling in that area. The eastern part of sec. 13 probably is the most favorable location for an additional well.

Highly mineralized water probably would not be encountered at a depth of less than 1,000 feet anywhere within that part of the reentrant west of the access highway. However, as a precautionary measure and to provide additional useful data, a sample of water for chemical analysis should be obtained from the lowest producing zone in any deep well drilled within a mile west of the highway. It does not appear advisable to drill wells for potable water east of the access highway because of the possibility of tapping a body of highly mineralized water. Furthermore, the deposits become increasingly finer grained and clayey in that directinn.

Wells should be spaced so that a minimum of pipe and other material is required; but interference between wells should be kept to a minimum. Therefore, the spacing of wells is an economic as well as a hydrologic problem.

The relative effects of pumping on water levels at various distances from a pumped well may be computed roughly. Assume that the average coefficient of storage of a homogeneous aquifer of infinite areal extent that receives no recharge is 0.15 and that the average coefficient of transmissibility is 15,000 gpd per foot. If a well tapping such an aquifer is pumped at an average rate of 150 gpm (600 gpm 6 hours per day), the water level at a distance of a quarter of a mile from the pumped well would decline about $4\frac{1}{2}$ feet in 10 years and about 6 feet in 25 years. At a distance of half a mile, the water level would decline about 3 feet in 10 years and about $4\frac{1}{2}$ feet in 40 years. At a distance of 1.0 mile, the water level would decline about $1\frac{1}{2}$ feet in 10 years and about $4\frac{1}{2}$ feet in 160 years.

The aquifer within the reentrant does not measure up to this ideal aquifer in any major respect, and mutual interference caused by pumping several wells is neglected. Nevertheless, a general idea of proper well spacing in the well field may be obtained from the above computations. A spacing between wells of a quarter of to half a mile should be adequate. As noted before, the choice of spacing is somewhat arbitrary within certain limits because of economic considerations. With closer spacing, less pipe and other materials are required, but pumping effects are greater and occur more rapidly, and the costs of pumping are thus higher. With wider spacing, more pipe is required, but pumping effects of adjacent wells are less, pumping levels are more stable, and thus pumping costs are lower.

Well Construction

Methods of Drilling

The two methods of drilling water wells most commonly used in New Mexico are the cable-tool (percussion) and hydraulic-rotary methods. Although under certain conditions one method may be as satisfactory as the other, the cable-tool method generally is unsatisfactory in loose, caving sand, and the hydraulic-rotary method is unsatisfactory in cavernous formations where circulation cannot be maintained. In formations in which either method can be used, such as unconsolidated, or partly consolidated bolson deposits, the cable-tool method generally is used for small-diameter shallow wells and the hydraulic-rotary method for large-diameter deep wells.

With the cable-tool method of drilling, a heavy cutting tool, or bit, at the end of a steel cable is alternately raised and dropped to break and loosen the formation material. The drill cuttings are removed by means of a bailer. In unconsolidated material, casing must be lowered in the hole above the bit to prevent caving. Normally, drilling mud is not used with this method.

With the hydraulic rotary method, a bit attached to the lower end of a string of hollow drilling pipe is rotated while drilling fluid is pumped down through the drilling pipe, out through openings in the bit, and up to the surface through the annular space between the drilling pipe and the wall of the hole. The drilling mud carries the drill cuttings to the surface, where they are deposited in a settling pit. The fluid forms a cake or seal against the wall of the hole, preventing caving. With this method of drilling, it generally is unnecessary to case the hole, except near the surface, during drilling operations.

Generally speaking, the drill cuttings obtained from a cable-tool rig, though finer grained, are more representative of the formations than those obtained from a rotary drill. In order to obtain as much reliable data as possible from a rotary-drilled hole, it is necessary to keep the drilling procedures as uniform as possible. Even then, much clay and fine sand may be washed away or recirculate unnoticed in the drilling fluid.

Well perforations and screens

The choice of a suitable screen is one of the most important steps in the construction of a large-capacity well in unconsolidated deposits.

In general, a screen should pass about two-thirds of the formation material, except where homogeneous sand with a low uniformity coefficient is screened. By allowing from 60 to 70 percent of the finer materials near the screen to be passed through the screen during development, a natural gravel pack with particles increasing in size toward the screen is formed, which will result in more efficient well performance.

The size, shape, and distribution of screen openings are important factors in the selection of a screen. The ideal screen should contain as many openings as possible without undue loss of strength, and the shape of the openings should be such as to minimize bridging of particles at the screen face. A wide choice of manufactured screens is available; some are designed with the above considerations in mind, although others probably are no more efficient than slotted casing. The required characteristics of screens or perforated casing for gravel-packed wells are slightly different than those for wells that are not gravel packed and are discussed under gravel-packed wells.

Well development

The purpose of well development is to facilitate maximum yield with minimum drawdown and to prolong the life of a well. This important phase of well construction commonly is disregarded or ignored, but proper development can mean the difference between a successful well and a failure.

Many methods of developing wells are in common use. The most common method of developing wells in unconsolidated deposits is by surging, which is designed to remove the fine sand, silt, and clay from the water-bearing strata near the well to form a natural gravel pack. Within the gravel pack, the formation materials become more uniform and more permeable as the screen is approached. Thus, entrance losses are greatly reduced, and pumping of sand may be reduced greatly or eliminated.

A well may be surged by lowering and raising a plunger in the well, back washing by intermittently starting and stopping the pump, or agitating the water with compressed air or dry ice. Development by a plunger is selective and concentrates the action in the immediate vicinity of the plunger. Overpumping alone in unconsolidated ~~such~~ deposits may remove fine particles from the formation around the well but is likely to result in bridging of sand particles, thus preventing full development. Also, development by overpumping is not selective and cannot be depended upon to affect all parts of the screens. The fine materials brought into the well during the development are removed with a bailer. Development normally must be accomplished by more than one method and is complete only when no more fine particles can be moved into the well, the water is clear, and the well has a reasonable specific capacity as determined by an examination of the drill cuttings and logs and consideration of the transmissibility of the aquifer as determined from the pumping test.

Gravel-packed wells

In recent years, the gravel-envelope or artificially gravel-packed well has become fairly common. In constructing an artificial gravel pack, the hole is reamed to a diameter several inches greater than that of the casing and screen to be used. The annular space between the casing and the wall of the well, or between an inner and an outer casing, is filled with sorted gravel of a uniform size.

In a rotary-drilled hole, the drilling fluid may be gradually thinned during the placement of the gravel. Also, a plunger sometimes is surged inside the casing to help wash the plastered mud off the walls of the hole. It is possible that, unless some effective washing procedure is followed while the gravel is being placed in a rotary-drilled hole, drilling mud may remain which cannot be removed by subsequent development.

There is considerable disagreement over the relative advantages of artificial and natural gravel packs. Probably artificial gravel packs are most advantageous in formations of fine uniform sands which contain an insufficient amount of coarse material to build up a natural gravel pack about the screen. An artificial gravel pack will permit the use of screens having larger slots than would otherwise be possible in such a formation. The size of the screen opening in a gravel-packed well depends not only upon the size of gravel used but also to some extent upon the shape of the slot openings. The slot size and shape should be such that the smaller gravel sizes will pass into the well during well development, thus inducing a gradation in the gravel pack from the larger size at the screen to the smaller size at the well face.

Ideally, the size of the gravel to be used should be determined by a mechanical analysis of the sand in the formation; studies indicate that the size of the gravel should be from four to six times the size of the finest materials in the formation that are to be excluded. If too coarse a gravel is used, fine sand may move from the formation into the gravel and may fill the voids in the pack, resulting in a reduced permeability. For maximum permeability, the gravel should be well-rounded and of a uniform size. It must be carefully placed, of course, to avoid bridging and to insure uniform placement.

When a well is drilled by the cable-tool method, the gravel envelope is inserted between an outer and inner casing. Usually the outer casing is withdrawn as the gravel is emplaced. The inner casing is slotted at the water-bearing strata; both are slotted if the outer casing is to be left in the well.

Basically the ability of a well to produce water is a function of the permeability of the aquifer, and the main effect of gravel packing is to enlarge the well diameter and thus reduce well entrance losses. Such being the case, a screened well of equal diameter might be more effective, but such a well having a large-diameter fine-slot screen would be more expensive than a gravel-packed well. It is apparent also that the main function of the gravel pack is to support the walls of the hole rather than act as a filter. Wells that are constructed with large and ungraded gravel permit more sand to move into the gravel pack and thus function more like filters. It is to be expected that the deterioration of such wells in time will be greater than those wherein the proper size gravel was installed.

Well Construction at White Sands Proving Ground

The first wells drilled by the Army at White Sands Proving Ground were drilled in secs. 31 and 32, T. 22 S., R. 5 E., by the cable-tool method. None of the wells drilled in that area were large producers, and several were failures. Of the 10 wells completed in the old well field, only 5 and 9 were still in use in 1955. (See table 8.)

Well 5, drilled in 1946, is of the gravel-packed type. A 20-inch steel casing, with the lower 36½ feet perforated with ¼ by 4-inch slots, was set from the ground surface to a depth of 267 feet. A 7-inch casing, also with the lower 36½ feet slotted, was set from a depth of 183½ feet to a depth of 267 feet. Gravel of a relatively large but unknown size and gradation was placed between the two casings. The well originally yielded 70 gpm with a drawdown of 13 feet, according to reports. In 1953 the well was reported to yield about 40 gpm, but it was impossible to determine the drawdown, as the air-line was broken and a steel tape could not be inserted in the well.

Well 9, also completed in 1946, was drilled to a depth of 348 feet and cased with 18-inch casing slotted at the water-bearing strata. The original test data indicate that the well was pumped at a rate of 35 gpm and had a drawdown of 26 feet. In April 1953 the well was pumped at a reported rate of 35 gpm for 6 hours, and the resulting drawdown, determined by air-line gage, was about 23 feet.

Several wells in the old well field yielded a considerable amount of fine sand, according to reports, and were abandoned for that reason. Records are so meager that it is impossible to estimate to what extent the poor performance of the wells is due to their construction. Some improvement of the wells probably would have resulted from a more careful choice of screens and, in well 5 at least, of gravel. Some of the gravel remaining on the ground around well 5 contained particles more than an inch in diameter, and many of them angular.

The available data indicate that any well drilled in the immediate vicinity of the old well field probably would yield a relatively small amount of water, regardless of the methods used in drilling and finishing the well. The sediments in that area, as indicated by the drillers' logs, consist of poorly sorted clay, sand, and gravel with a predominance of clay and fine sand. A fully developed and properly constructed well drilled to a depth of at least 400 feet might yield as much as 100 gpm with a drawdown of 20 to 40 feet. The cable-tool method of drilling probably would be more successful than the hydraulic-rotary method, as there is some chance that drilling fluid used with the latter method might seal off thin water-bearing sands. A gravel pack may be of some value if the gravel is selected on the basis of a mechanical analysis of the drill cuttings. However, a careful selection and placement of screens based upon an analysis of the cuttings and an electric log of the hole, respectively, might result in fully as efficient a well.

Wells of greater capacity probably could be drilled at a greater distance from the mountains, east of the old well field where the sediments presumably are somewhat better sorted. Several fresh-water sands were penetrated in test hole T-21 (23.5.35.300)~~, in the SW$\frac{1}{4}$ sec. 34, T. 23 S., R. 5 E~~. Similar fresh-water sands also may underlie the area north and northeast of the old well field, in secs. 29 and 30, T. 22 S., R. 5 E. Drilling in that area should be done cautiously, with careful attention to the chemical quality of the water.

Wells 10, 11, 12, and 13 were drilled by the hydraulic-rotary method and were gravel packed. The gravel apparently was not well sorted, ranging from less than half an inch to more than an inch in diameter. Slotted casing, rather than manufactured screens, was used in the wells. The poor performance of wells 11, 12, and 13 may be partly due to the choice of perforations and gravel and lack of adequate development.

In wells 14, 15, and 16, also drilled by the hydraulic-rotary method, a manufactured screen having eliptical openings with a maximum width of $\frac{1}{4}$ inch was used. The gravel used in packing the wells was graded between 1/8 and 3/8 inch. Sieve analyses of representative samples of drill cuttings from well 16 are plotted in figure 32. As indicated in the

Figure 32.--Distribution of grain sizes in representative drill cuttings from well 16, White Sands Proving Ground, New Mexico.

figure, the gravel used in the pack should pass formation particles as large as $1\frac{1}{4}$ mm in diameter. According to Leatherwood and Peterson (1954), filter action occurs only if the ratio of the grain size of the filter to that of the particles in the filtered liquid is less than 5. Thus, theoretically, the gravel pack should be of a sufficient particle size to pass about 70 percent of the formation particles next to the gravel envelope in the screened sections illustrated in figure 32.

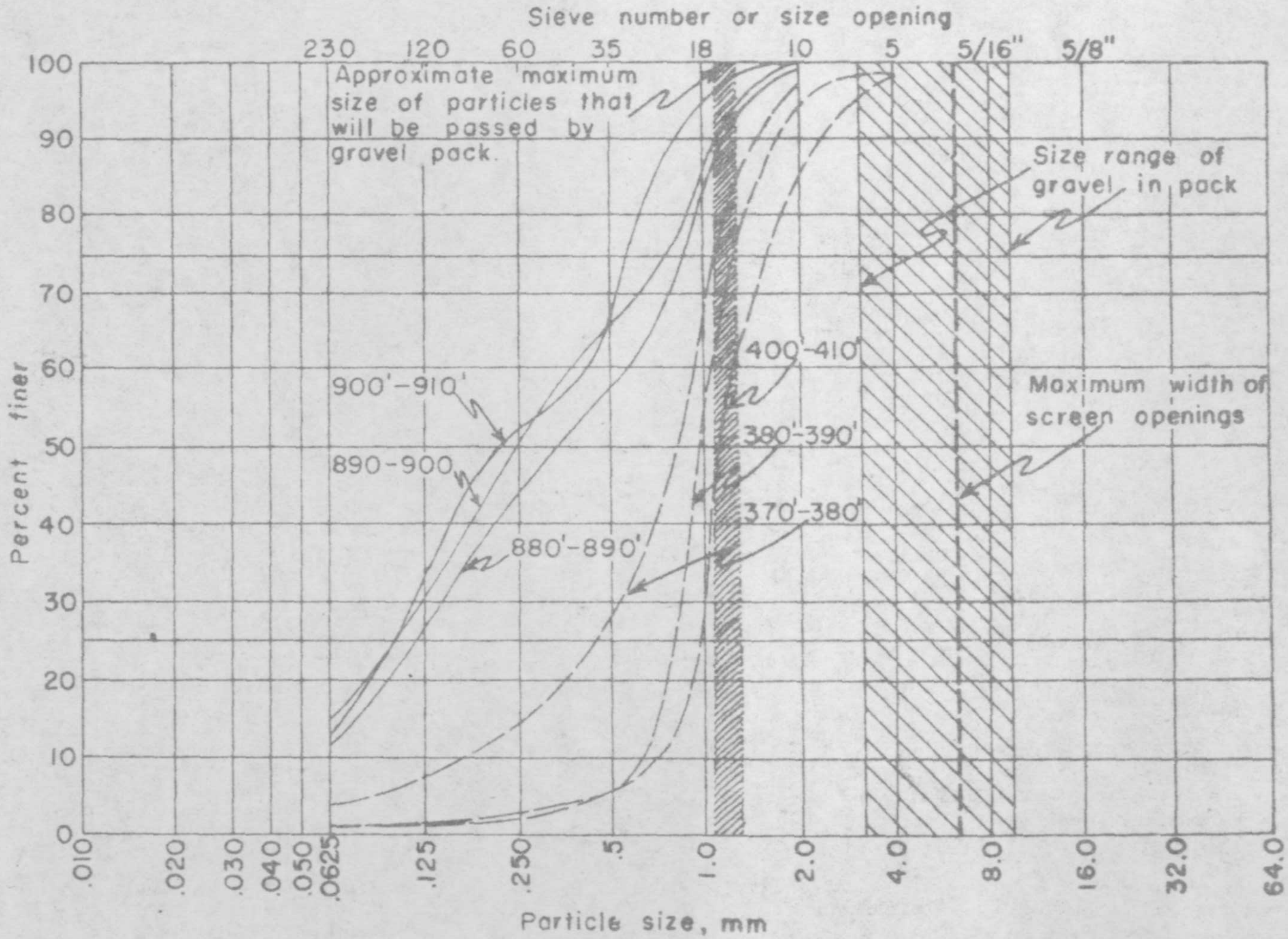

Figure 32 --Distribution of grain sizes in representative drill cuttings from well 16, White Sands Proving Ground, New Mexico. (Solid curves are cuttings from unscreened section of the hole, and dashed curves are of cuttings from screened section of the hole.)

Wells 14 and 15 were developed principally by agitation with compressed air within the casing, and well 16 was developed principally by surging with close-fitting blocks. During the development of wells 14 and 15, the gravel packs were not lowered appreciably, although a considerable amount of clay and fine sand was removed from the wells by bailing and later by pumping. The gravel pack in well 16 was lowered about 70 feet by surging with blocks, and a considerable amount of bailing was required to remove the gravel, as well as clay and sand, from the well. The gravel used in all three wells was from a common source and was similarly graded, and the screens are identical in all three wells. Therefore, it is apparent that surge blocks were much more effective in disturbing the gravel pack and bringing in sand from the formation than compressed air. The performance of well 16 is slightly better than that of well 15, and both wells have considerably higher specific capacities than well 14. Despite the somewhat greater specific capacity of well 16, there is no substantial proof that the use of surge blocks effected a more satisfactory development than the use of compressed air.

It is doubtful if a large-diameter deep well, such as wells 14, 15, and 16, could be drilled more economically by the cable-tool method than by the hydraulic-rotary method. The hydraulic-rotary method may be preferable for the construction of such wells in that particular area for several reasons. The hydraulic-rotary method permits the use of electric logs for a more complete interpretation of the formation log and a more efficient placement of screens. If a well is to be gravel packed, the gravel generally can be placed in a rotary-drilled hole without installing an outer casing. The only readily apparent disadvantage of this method of drilling is the uncertainty that all drilling fluid can be effectively removed from the formation and from the gravel pack. Some consideration should be given to the possible advantages of drilling a small pilot hole with the hydraulic-rotary method, principally in order to obtain an electric log, and then reaming the hole to the desired larger diameter below the water table with a cable-tool rig. This would require the temporary placement of an outer casing, if the well were to be gravel packed, and undoubtedly would be somewhat more expensive.

As all the wells near the housing and cantonment areas are gravel packed, it is impossible to evaluate the advantages of the gravel pack in those wells. The additional cost of the gravel undoubtedly is balanced by the shorter development time that is necessary in the gravel-packed well and by the saving that is accomplished by the use of less expensive screens in the gravel-packed well. The principal purpose of gravel packing the wells has been to prevent, or at least to minimize, the movement of fine sand into the wells. At least in well 11, this purpose has not been realized; that well in August 1954 was pumping a large amount of sand and was temporarily shut down to await rehabilitation. The gravel used in packing well 11 apparently was poorly sorted and much larger than is desirable.

Conservation of Water

The primary purpose of this study was to evaluate the ground-water resources of the headquarters area at White Sands Proving Ground and to consider methods by which those resources can be most effectively developed. However, some brief consideration of methods by which those resources may be conserved by careful utilization appears to be warranted.

The development of an adequate water supply at the Proving Ground has been difficult and expensive. It has been shown that the pumping of ground water in that area is, in effect, mining, because the ground water is being removed from storage. Being a defense installation, the permanency of the Proving Ground is somewhat uncertain; however, as long as the area is occupied and large quantities of ground water are pumped, water levels will gradually decline and, consequently, the cost of pumping will gradually increase.

Restricted Landscaping and Efficient Irrigation Practices

Possibly as much as 70 percent of the water pumped at White Sands Proving Ground is used for irrigation and cooling. This estimate is based mainly on comparisons of pumpage in wet periods with that in dry periods and pumpage during the winter with that during the summer growing season.

Landscaping at the Proving Ground is desirable and perhaps essential; however, in view of the limited supply of available water, the planting and irrigation of lawns and shrubbery should be minimized.

Consideration should be given to a more extensive use of plants requiring relatively small amounts of water. Many of the native plants can be planted very attractively, as attested by their extensive use on both private and public grounds in many parts of the Southwest.

A significant quantity of water could be saved if efficient and conservative irrigation practices were strictly enforced. On several occasions a large proportion of the lawn sprinklers in the housing area have been turned on during the warmest part of the day when evaporation is greatest, although an attempt is made to discourage this practice by regulating the watering hours; some lawn sprinklers are so located that fully as much of the street or driveway is watered as grass area; and sprinklers have been left on throughout the night. These practices are extremely wasteful of water and should be discouraged. Installation of individual house meters also should reduce unit-water usage.

Utilization of Sewage Effluent

Effluent from the sewage-treatment plant at White Sands Proving Ground is a potential source of water, which, if it were utilized, might significantly reduce the pumping of ground water in the summer when pumping is greatest.

The use of effluent from sewage-treatment plants for irrigation is an established practice in many cities, and in some areas the effluent is used to recharge the ground-water reservoir (Thomas, 1951, p. 67). At Los Alamos, New Mexico, about 200 acre-feet of sewage effluent presently is utilized for irrigation of grass on a golf course, baseball fields, and elsewhere. In addition, sewage effluent is used for cooling at one of the city's electric-power plants, although this use has been only moderately successful, mainly because of the rapid concentration through evaporation and the precipitation of dissolved solids in the cooling towers.[1]

[1] Weir, J. E., ~~Personal~~ Oral communication, December 1954.

The practicality of using reclaimed sewage effluent at White Sands Proving Ground was not studied. To be economically feasible, such use probably would have to be restricted to the irrigation of relatively large areas such as the athletic fields and the large lawn areas in the vicinity of the Administration Building.

If the population of the Proving Ground continues to increase, water consumption and discharge of sewage effluent will increase concomitantly. It appears that the possibility of reducing pumpage and thereby conserving water by utilization of the sewage effluent is worthy of consideration.

Suggestions for Compilation and Disposition of Records

The value of complete and accurate records of exploratory drilling, well data, pump operation, water levels, and pumping-test data commonly is underestimated. Although, in general, operation records at White Sands Proving Ground are reasonably complete and accurate, during the course of this investigation, attempts to find data relating to exploratory drilling, well construction, and water levels often were discouragingly unsuccessful. Many such data probably were not recorded because their value was not realized. Other data may have been recorded, but the records were lost or destroyed.

Not only are such records aids in planning, but they should contribute to a more efficient utilization of existing wells. Periodic analysis of accurately kept records will indicate variations in well performance and the need for changes in operation or modification of equipment to meet changing conditions.

The following suggestions are included in this report in the hope that they may aid in utilizing more efficiently, and therefore more economically, the ground-water supplies of the area.

Exploratory Drilling

Many holes reportedly have been drilled in the headquarters area of White Sands Proving Ground in efforts to obtain water for general use and construction.

It might appear that records of shallow holes drilled for temporary use in construction would be of little future value, particularly if little water was obtained or if the water was known to be chemically unsuited for general use. However, almost all data relating to the occurrence of ground water are of value in estimating the extent and nature of the occurrence. Accurate formation logs aid in an interpretation of general geologic conditions; accurately measured water levels aid in determining the direction of slope and the gradient of the water table; data relating to the performance of wells contribute to a knowledge of the hydrologic characteristics of the aquifer; and chemical analyses of the water permit a more accurate estimate of the amount of potable ground water available in the area and may aid considerably in determining the source and direction of movement of the ground water.

Information should be collected and recorded whenever a test hole or well is drilled for any purpose. Recording of well data should be a mandatory part of construction contract. Such data should be collected for test holes and wells drilled even in remote or what may at the time seem to be relatively unimportant areas. At a future time, such data may be of considerable help in locating new installations, planning expansions of installations, or in locating temporary water supplies for construction and other purposes.

Well Data

The well-data sheet described in U. S. War Department Army Technical Manual 5-660 (~~Nov.~~ 1952, p. 38-39) has been carefully planned to present much important well data in convenient form. Not all the information called for on this form is available for all wells. However, such information as can be obtained should be recorded, preferably at the time wells are drilled. The records should be retained in some accessible place even after the wells have been abandoned, as they may provide information that will be valuable in the development of future supplies or in rehabilitation of existing supplies.

Pump Operation

Daily operation logs and monthly operating reports which give the hours pumped and pumpage are compiled for all wells supplying water for general use in the housing and cantonment areas of the base. Operation records of wells outside the main system apparently are not as carefully compiled and are not readily accessible. If all such records could be filed together for ready and convenient reference, periodic general surveys of all the ground-water facilities would be considerably simplified.

Water Levels

Accurate records of changes in water levels, both pumping and nonpumping, are of great importance. Unfortunately, such records generally are the ones most often neglected or inaccurately kept. This is largely because it is physically impossible to obtain accurate measurements with existing equipment and pumping schedules.

Generally, when a well is first drilled, the depth to water is determined by means of an air-line gage and is recorded. Apparently some such determinations have been incorrect, because of inaccurate gages or other reasons. Therefore, whenever possible, before a new well is pumped, the depth to water should be accurately measured from a fixed measuring point by means of a steel tape. The measuring point used should be described and its altitude relative to a permanent reference point determined.

The depth to water in a well, both while the well is pumping and after the water level has recovered, should be accurately determined at intervals of not more than 2 or 3 months. Such measurements should be made under similar circumstances each time. For example, the pumping level should be determined after the well has been pumped steadily for a definite length of time. The nonpumping level should be determined after the well has been off for a definite length of time, sufficient to allow water levels to recover as much as possible from pumping effects.

Weekly recording gages should be installed on all production wells. These generally are air-line gages actuated by small automatically operated air compressors. They are relatively inexpensive, require a minimum of maintenance, and provide an excellent record of fluctuations of the water levels in the wells.

Periodic analysis of water-level fluctuations in relation to data on such factors as yields of the wells will aid in determining the cause of a decline in yield, whether due to a deterioration of the well, a decline in water levels, or a decrease in pump efficiency. Such analyses may indicate approaching problems before they become serious. An accurate record of water-level fluctuations will permit appraisals of pumping effects and will aid in evaluating the hydrologic characteristics of the aquifer.

Pumping-Test Data

Soon after a well is completed, it generally is test pumped, principally in order to determine if the well has been adequately developed and to determine the size of the pump to be installed. Such a test also may have considerable value in determining aquifer characteristics.

In order for such data to be of greatest value, it is necessary that, during both the pumping and recovery periods of such a test, the depth to water and the time of measurement be frequently and accurately recorded. During the pumping period, the yield of the pump should be frequently and accurately determined and should be recorded with other pertinent observations.

Often the specific capacity of a well is computed and recorded without an indication of how long the well had been pumped. Specific capacities usually are meaningful only when the yield of the pump, drawdown of the water level, and the duration of the test are known.

Disposition of Records

Good records are valuable, of course, only if they are available for reference and study. All records relating to wells and ground-water conditions should be filed together in an accessible place. Many of the records then could be summarized periodically and at the same time studied and analyzed. Thus, many duplicate records could be disposed of in order to conserve space.

SUMMARY OF AVAILABILITY OF GROUND WATER IN THE HEADQUARTERS AREA

General Consideration

One of the principal objectives of this study was to determine, insofar as possible, the amount of potable ground water that can be withdrawn by pumping from the aquifer underlying the headquarters area at White Sands Proving Ground. Closely related to this objective were such considerations as the probable future effects of pumping on ground-water levels, the possibility of highly mineralized ground water migrating to the area of the wells, and the most favorable locations and optimum spacing for future wells.

Pumping in the headquarters area, as in any area of new large-scale ground-water development, constitutes a new discharge imposed on a previously stable hydraulic system, and it must be balanced by an increase in recharge to the aquifer, a decrease in the natural discharge, a reduction in storage, or a combination of these factors. In order to estimate the amount of safe ground-water withdrawal in the area and the future effects of pumping, it is necessary to determine the source of the pumped water by considering the general occurrence of ground water in the area and the hydrologic characteristics of the aquifer.

The geology and altitude of the water table in the headquarters area are shown on ~~plate 1~~ figure 2A. The contours of the water table indicate that ground water moves eastward out of the reentrant to the lower part of the Tularosa Basin. The ground water apparently then moves southward and southeastward through the lower part of Tularosa Basin and the Hueco bolson to discharge into the Rio Grande southeast of El Paso, Texas.

The average annual recharge to the bolson deposits within the reentrant at the headquarters area probably is not more than 6,000 acre-feet and may be considerably less than that. Recharge is not rejected in the area, and pumping cannot move back the ground-water divide to increase the recharge area appreciably. The only apparent, though not necessarily feasible, method by which recharge in the headquarters area might be increased is by the construction of dams in the western part of the reentrant and near the mountains to spread floodwaters that normally flow east of the headquarters area, where the conditions for recharge are poor and the ground water saline. By restricting the floodwaters to the sides of the reentrant, where the recharge conditions are best, a greater proportion of the floodwaters would reach the ground-water body. Properly located and constructed dams also would greatly reduce the possibility of flood damage to roads and installations. Such dams are used in many areas of the Southwest. The effect of spreading upon recharge in the reentrant area cannot be estimated quantitatively, nor can its practicality be evaluated without further study. Probably the additional recharge thus furnished would be small, ~~and~~ as floodwaters have not caused appreciable damage at the headquarters area in the past. ~~Also, some of this increased recharge presumably would be lost in the form of increased natural discharge.~~

If it were possible to reduce the natural discharge of ground water from the area, some and perhaps all of the water pumped eventually could be balanced by the reduction in natural discharge. The principal natural discharge of ground water from the bolson deposits is many miles from the headquarters area and cannot be reduced in the foreseeable future by pumping of wells in the reentrant. As only a small amount of ground water is discharged in the headquarters area through transpiration by plants, destruction of the plants would not be a practical means of reducing discharge.

Nearly all the water pumped from wells originates as recharge within the reentrant, but, because recharge to the ground-water body cannot be appreciably increased nor natural discharge appreciably reduced, pumping in the headquarters area must continue, at least for a long time, to remove ground water from storage.

The volume of saturated bolson deposits underlying the reentrant west of the access highway is estimated to be approximately 4 million acre-feet. Most of the ground water in those deposits probably is potable with respect to chemical characteristics, as is the shallower ground water underlying part of the area east of the access highway. (See fig. 11.) The specific yield of the deposits probably is about 15 percent; therefore, about 600,000 acre-feet of water would be removed if the deposits west of the highway could be completely dewatered. Much of the water stored in the bolson deposits, however, is not available to wells. If water levels are lowered drastically, highly mineralized ground water may migrate to the wells, although this possibility is not of immediate concern at the present rate of pumping.

The coefficient of transmissibility of the bolson deposits has been computed from several pumping tests by the recovery method. Analysis of a pumping test of well 9 in the old well field indicated a coefficient of transmissibility of only 800 gpd per foot. This test was of short duration, and it was not possible to make other tests in that area. Examination of performance records and available drillers' logs of wells and abandoned wells in that area indicates that the average transmissibility of the bolson deposits is much lower in the old well field than it is in the present well field north of the cantonment area. Coefficients of transmissibility obtained from pumping tests made in the present well field ranged from 2,500 at well 11 to 60,000 gpd per foot at well 10. The computed average coefficient of transmissibility in the vicinity of wells in the present well field is about 15,000 gpd per foot, although the average throughout the reentrant may be less than that.

Effects of Pumping

Future declines of water levels in the supply wells at the Proving Ground are estimated on pages 118-120. An average pumping rate of 1,000,000 gpd or 1,100 acre-feet per year was used in estimating the declines shown in table ~~3~~ 7. Actual pumping rates may cause declines appreciably different than those given in table ~~3~~ 7.

Declines of water levels (table ~~3~~ 7) are estimated to range from 16 feet in well 10 to 70 feet in well 11 in 30 years. Recent data obtained for well 11 indicate that the decline estimated for that well probably is excessive. The greatest declines for equal rates of pumping will occur in the lower capacity wells (11-14) in the western part of the well field where contamination from saline water is least probable. However, if wells 10, 15, and 16 are pumped at higher average rates than have been assumed, the declines in the latter wells should be correspondingly greater than are given in the table. If pumping is distributed uniformly among the wells, declines of the water levels will be spread throughout the well field, and the danger of an excessive decline at any one well will be reduced to a minimum. An accurate record of water-level fluctuations in all the wells should be maintained; measurements should be made at least once every 2 months. This information is necessary to reevaluate the estimates from time to time. More accurate evaluation with more complete data will permit a more efficient use of the ground-water resources.

Within the reentrant west of the access highway, the ground water to a depth of at least 1,000 feet is potable. Highly mineralized water may extend beneath the wells, as indicated in figure 11, although this is speculative. Samples of water from the easternmost wells should be analyzed at about 6-month intervals in order to detect contamination by highly mineralized ground water. Migration of highly mineralized water to the wells, however, should not be a serious threat in the near future. Nonpumping water levels in those wells probably can be lowered more than 50 feet before contamination could occur. Contamination probably would become apparent first in the easternmost wells, 15 and 16, and a regular sampling and analyzing of water from those wells should disclose any threat of contamination before it becomes serious.

Location and Spacing of Wells

The available data indicate that the most permeable bolson deposits underlie the eastern part of sec. 13 and the northeastern part of sec. 24, T. 22 S., R. 4 E. Mainly on the basis of resistivity data, much of secs. 11 and 12, T. 22 S., R. 4 E., also is underlain by relatively permeable bolson deposits. The depth to water in these areas (fig. 9) ranges from less than 350 feet in the eastern part of sec. 13 and the northwestern part of sec. 11 to about 400 feet in the north-central part of sec. 12. The thickness of the saturated bolson deposits (fig. 10) ranges from less than 500 feet in the southwestern part of sec. 11 to more than 1,000 feet in the central and eastern parts of sec. 12, the eastern part of sec. 13, and the northeastern corner of sec. 24.

Drilling and resistivity measurements indicate that the bolson deposits vary considerably within short distances. Therefore, not all parts of the area outlined would be equally favorable for the development of wells. The eastern part of sec. 13 appears to be the most favorable location for an additional well, but the chemical quality of the ground water at depth should be carefully determined if additional wells are drilled in that area. The saturated deposits underlying the western half of sec. 11 are relatively thin (fig. 10); therefore, the eastern half of that section and sec. 12 probably should be given perference over the western half of sec. 11 in future test drilling.

The bolson deposits become increasingly finer grained and probably less permeable east from the access highway; also, the danger of encountering highly mineralized water is much greater in that direction. For these reasons, it does not appear advisable to attempt the development of large-capacity wells for potable water east of the access highway.

As noted previously ~~(p.   )~~, the spacing of wells is an economic as well as a hydrologic problem. With short~~h~~er spacings between wells, less pipe and other materials are required, but interference between wells may cause pumping costs to be greater. With longer spacings, more materials are required, but the possibility of interference becomes less. It is believed that a spacing between wells of a quarter of ~~0.25~~ to half a ~~0.5~~ mile is adequate for the conditions existing in the headquarters area.

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Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.

Well 1 - 22.5.32.131 - Driller's log

	Thickness (feet)	Depth (feet)
Soil	4	4
Sand and rock	5	9
Gravel, sand, and dirt	227	236
Gravel, carrying water	21	257

Well 2 - 22.5.31.244 - Driller's log

	Thickness (feet)	Depth (feet)
Soil	3	3
Sand and rock	5	8
Sand, gravel, and dirt	232	240
Gravel, carrying water	50	290
Red shale	4	294

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 4 - 22.5.32.311 - Driller's log

	Thickness (feet)	Depth (feet
Loose gravel	7	7
Shell	5	12
Gravel and clay	215	227
Water sand	44	271
Red shale	11	282
Gravel	5	287
Gray shale	18	305
Red shale	21	326
Gray shale	4	330
Red shale	6	336
Gravel, sand, clay, and boulders	81	417
Red shale	23	430
Sandy shale	17	447
Red shale	5	452

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 5 - 22.5.32.313 - Driller's log

	Thickness (feet)	Depth (feet)
Red gravel wash --	25	25
Gravel and brown clay --------------------------------	210	235
Water sand and gravel --------------------------------	12	247
Red shale --	20	267

Well 6 - 22.5.32.321 - Driller's log

	Thickness (feet)	Depth (feet)
Red clay and gravel ----------------------------------	158	158
Gray shale ---	22	180
Brown shale --	45	225
Gravel and clay (water yielding) --------------------	8	233
Red shale --	7	240
Sand ---	5	245
Red shale --	18	263
Blue shale ---	25	288
Brown shale --	11	299
Brown sandy shale ------------------------------------	5	304
Red sandy shale (water yielding) --------------------	20	324
Red shale --	8	332
Red sandy shale --------------------------------------	6	338

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 7 - 22.5.32.323 - Driller's log

	Thickness (feet)	Depth (feet)
Gravel and red clay	54	54
Gravel, clay, and boulders	21	75
Gravel and red clay	84	159
Gray shale	29	188
Gravel and red clay	7	195
Gray shale	5	200
Red shale	21	221
Blue shale	4	225
Gravel and red clay (water-bearing)	3	228
Red shale	23	251
Gray sand (water-bearing)	14	265
Sandy shale	25	290
Brown shale	14	304

Table ~~7~~ 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 8 - 22.5.32.332 - Driller's log

	Thickness (feet)	Depth (feet)
Sand and clay	31	31
Sand and brown clay	19	50
Gravel and brown clay	60	110
Gravel and sand	20	130
Gravel and brown sand	40	170
Red shale	20	190
White shale	10	200
Brown gravel	8	208
Red rock and shale	17	225
Red sand	5	230
Gravel and water	8	238
Blue shale	18	256

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 9 - 22.5.31.424 - Driller's log

	Thickness (feet)	Depth (feet)
Gravel	78	78
Clay and red gravel	181	259
Gravel (water-yielding)	14	273
Gravel and clay	19	292
Gravel	3	295
Gravel and clay	11	306
Gravel (water-yielding)	5	311
Shale	4	315
Gravel and clay	13	328
Gray shale	7	335
Blue shale	13	348

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 11 - 22.4.13.333 - Driller's log

	Thickness (feet)	Depth (feet)
Top soil and caliche	17	17
Caliche, sand, gravel, and boulders	23	40
Gravel, sand, and layers of clay	140	180
Clay, gravel, and fine sand	83	263
Sand, clay, and gravel - lots of sand	25	288
Coarse sand and gravel (water)	20	308
Boulder	1	309
Sand and coarse gravel	111	420
Boulder	1	421
Sand and gravel	25	446
Boulder	2	448
Sand and gravel	32	480
Hard rock	4	484
Sand and gravel	39	523

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 12 - 22.4.23.214 - Driller's log

	Thickness (feet)	Depth (feet)
Surface formation - gravel and adobe clays -----------	17	17
Boulder bed in sand and adobe -----------------------	3	20
Adobe clay and dry gravel conglomerate --------------	29	49
Heavy boulders --------------------------------------	5	54
Beds of sand, gravel, and some conglomerate, not very hard - some soft places ------------------	136	190
Sand, gravel and clay cemented into a hard conglomerate -------------------------------	88	278
Hard packed sandy formation - slow drilling ---------	52	330
Loose fine sand (water-bearing) --------------------	12	342
Loose coarse water sand (some clay streaks) ---------	18	360
Hard dense sand (very slow drilling) ----------------	67	427

Table 7.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 13 - 22.4.13.311 - Driller's log

	Thickness (feet)	Depth (feet)
Top soil and sand	23	23
Coarse sand with some clay	24	47
Rocks and boulders	4	51
Coarse sand and gravel with some layers of clay	105	156
Cemented sand and boulders	13	168
Coarse sand and gravel	68	236
Coarse sand - hard drilling	19	255
Medium coarse sand	119	374
Coarse sand - water	15	389
Hard sand, boulders	21	410
Hard sandy clay	62	472
Coarse sand - water	55	527
Hard cemented sand	7	534

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 14 - 22.4.13.411 - Sample log

	Thickness (feet)	Depth (feet)
Sand, very fine to fine, silt, and clay --------------	40	40
Gravel and medium sand --------------------------------	50	90
Gravel, medium sand, and boulders ---------------------	30	120
Gravel, medium --	20	140
Gravel, coarse --	20	160
Gravel, medium to coarse, and fine to medium sand ----	30	190
Sand, fine to medium, and gravel ----------------------	20	210
Sand, fine to medium, silt, and clay ------------------	10	220
Sand, medium, fine gravel, silt, and clay -------------	10	230
Sand and fine gravel ----------------------------------	10	240
Clay, some fine to medium sand ------------------------	40	280
Sand, coarse --	10	290
Clay, some fine sand ----------------------------------	100	390
Sand, fine to medium, silt, and clay ------------------	30	420
Sand, fine to medium, gravel, silt, and clay ---------	50	470
Sand, medium to coarse, gravel, silt, and clay -------	20	490

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 14 - 22.4.13.411 - Sample log - Continued

	Thickness (feet)	Depth (feet)
Sand, medium to coarse, and fine gravel	10	500
Sand, fine to medium, silt, and clay	10	510
Sand, medium to coarse	40	550
Clay, some medium to coarse sand	10	560
Sand, medium to coarse	60	620
Sand and gravel	10	630
Sand, medium to coarse	20	650
Sand, fine, silt, and clay	20	670
Clay and little sand	20	690
Sand, coarse gravel, silt, and clay	30	720
Clay, some sand and gravel	100	820
Clay and fine sand	20	840
Sand, fine to medium, silt, and some clay streaks	70	910
Sand, fine to medium, little gravel	20	930
Sand, fine to medium, silt, and clay	75	1,005

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 15 - 22.4.13.424 - Sample log

	Thickness (feet)	Depth (feet)
Clay and very fine to fine sand	10	10
Sand, fine to medium, and some gravel	10	20
Gravel, medium to coarse, and some sand	10	30
Coarse gravel	10	40
Sand, medium to coarse, and fine gravel	20	60
Gravel, medium to coarse, silt, and clay	20	80
Sand, medium to coarse, and fine gravel	84	164
Boulder	1	165
Gravel, medium to coarse	25	190
Sand, medium to coarse, and gravel	10	200
Coarse gravel; some sand and clay	10	210
Sand, fine to medium, silt, and clay	30	240
Sand, medium to coarse, clay, some gravel	10	250
Clay, silt, and fine sand	70	320
Sand, fine to medium, and clay	60	380
Sand, fine to medium, clay and some gravel	10	390
Gravel, medium to coarse, fine sand, and little clay	20	410

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 15 - 22.4.13.424 - Sample log - Continued

	Thickness (feet)	Depth (feet)
Clay and fine to medium sand	80	490
Sand, medium to coarse, gravel, and clay	10	500
Clay and fine to medium sand	10	510
Sand, medium to coarse, gravel and clay	20	530
Sand, medium, silt, and clay	10	540
Sand, medium, gravel and clay	30	570
Sand, fine to medium, silt and clay	20	590
Sand, medium to coarse, and gravel	10	600
Sand, fine to medium, silt, and clay	20	620
Sand, medium to coarse, and gravel	10	630
Sand, medium, and some gravel	10	640
Clay and fine to medium sand	30	670
Sand, medium to coarse, and some gravel	10	680
Sand, fine, silt, and clay	20	700
Clay	10	710
Clay and fine to medium sand	10	720
Clay	10	730
Clay and fine to medium sand	60	790

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 15 - 22.4.13.424 - Sample log - Continued

	Thickness (feet)	Depth (feet)
Clay	10	800
Gravel, fine to medium, and sand	20	820
Clay and gravel	20	840
Clay, sand, and some gravel	30	870
Sand, fine to medium, and some gravel	10	880
Clay and sand	10	890
Sand, fine to medium, clay, and some gravel	30	920
Sand, medium, and clay	40	960
Clay and sand, medium	10	970
Sand, medium, and clay	10	980
Sand, medium, clay, and some gravel	10	990
Sand, fine to medium, and clay	20	1,010

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 16 - 22.4.13.432 - Sample log

	Thickness (feet)	Depth (feet)
Sand, fine to medium	20	20
Sand, fine to coarse	10	30
Sand, medium to very coarse	10	40
Sand, very coarse	10	50
Sand, coarse to very coarse	20	70
Sand, very coarse, and very fine gravel	10	80
Gravel, very fine, and coarse to very coarse sand	10	90
Gravel, very fine to fine, and coarse to very coarse sand	10	100
Sand, coarse to very coarse, and very fine gravel	10	110
Sand, coarse to very coarse	60	170
Sand, coarse to very coarse, and very fine gravel	10	180
Sand, medium to very coarse	10	210
Sand, coarse to very coarse, and very fine gravel	40	250
Sand, coarse to very coarse	10	260

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 16 - 22.4.13.432 - Sample log - Continued

	Thickness (feet)	Depth (feet)
Sand, coarse to very coarse, and very fine gravel ----	10	270
Sand, medium to very coarse ------------------------	30	300
Sand, coarse to very coarse -------------------------	10	310
Sand, medium to very coarse -------------------------	70	380
Sand, coarse to very coarse -------------------------	10	390
Sand, coarse to very coarse, and very fine gravel ----	60	450
Sand, medium to very coarse, and very fine gravel ----	30	480
Sand, medium to very coarse -------------------------	10	490
Sand, medium to very coarse, silt and clay ----------	10	500
Sand, medium to very coarse, and very fine gravel ----	20	520
Sand, medium to very coarse ------------------------	80	600
Sand, fine to very coarse ---------------------------	40	640
Sand, coarse and very coarse ------------------------	10	650
Sand, fine to coarse --------------------------------	10	660
Sand, fine to very coarse ---------------------------	10	670
Sand, very fine to coarse, silt and clay ------------	10	680

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 16 - 22.4.13.432 - Sample log - Continued

	Thickness (feet)	Depth (feet)
Sand, fine to very coarse	20	700
Sand, fine to coarse	10	710
Sand, very fine to coarse	10	720
Sand, very fine to coarse, silt and clay	10	730
Sand, very fine to medium, silt and clay	20	750
Sand, very fine to coarse, silt and clay	20	770
Sand, very fine to very coarse, silt and clay	40	810
Sand, medium to very coarse, and very fine gravel	10	820
Sand, very fine to very coarse	10	830
Sand, very fine to very coarse, silt and clay	20	850
Silt, clay, and very fine to fine sand	10	860
Silt, clay, very fine and coarse sand	10	870
Sand, very fine to coarse, silt and clay	10	880

Table 2.--Logs of wells at White Sands Proving Ground, N. Mex.--Continued

Well 16 - 22.4.13.432 - Sample log - Continued

	Thickness (feet)	Depth (feet)
Sand, very fine to very coarse, silt and clay --------	20	900
Sand, very fine to coarse, silt and clay -------------	10	910
Sand, very fine to very coarse, silt and clay --------	20	930
Sand, medium to very coarse --------------------------	10	940
Sand, very fine to very coarse -----------------------	10	950
Sand, fine to very coarse ----------------------------	10	960
Sand, fine to coarse ---------------------------------	20	980
Sand, fine to coarse, silt and clay ------------------	10	990
Sand, fine to coarse ---------------------------------	10	1,000
Sand, silt and clay ----------------------------------	10	1,010
Sand ---	10	1,020

Table 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex.

Test hole T-1

Depth of sample (feet)	Percentages of sample by volume			
	Gravel	Very coarse and coarse sand	Medium and fine sand	Very fine sand, silt, and clay
	>2.0 mm.	2.0 - 0.5 mm.	0.5 - 0.125 mm.	<0.125 mm.
0- 10	-	-	-	-
10- 20	71	20	7	2
20- 30	40	37	18	5
30- 40	31	40	23	6
40- 50	44	28	23	5
50- 60	90	5	3	2
60- 70	85	5	5	5
70- 80	79	14	5	2
80- 90	27	45	21	7
90-100	29	45	23	3
100-110	30	42	24	4
110-120	73	14	10	3
120-130	86	9	3	2
130-170	65	17	14	4
170-180	65	15	13	7
180-190	65	19	10	6
190-200	48	38	11	3
200-210	73	19	7	1
210-220	67	26	6	1
220-230	62	30	7	1

Table 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-1 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel	Very coarse and coarse sand	Medium and fine sand	Very fine sand, silt, and clay
	>2.0 mm.	2.0 - 0.5 mm.	0.5 - 0.125 mm.	<0.125 mm.
230-240	63	28	8	1
240-250	39	34	19	8
250-260	32	45	20	3
260-270	29	42	22	7
270-280	12	59	26	3
280-290	12	52	33	3
290-300	36	42	18	4
300-310	31	41	24	4
310-320	59	28	12	1
320-330	45	37	13	5
330-340	57	27	12	4
340-350	44	36	16	4
350-360	61	28	10	1
360-370	82	15	2	1
370-380	46	31	18	5
380-390	48	34	15	3
390-400	32	42	22	4
400-410	23	40	32	5
410-418	-	-	-	-
418-430	19	42	32	7

Table ~~8~~ 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-1 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
430-440	20	45	31	4
440-450	32	41	20	7
450-460	35	38	22	5
460-470	24	43	28	5
470-480	22	39	31	8
480-490	35	38	21	6
490-500	29	43	25	3
500-510	19	42	35	4
510-520	19	48	30	3
520-530	18	42	31	9
530-540	20	41	32	7
540-550	22	40	30	8
550-560	14	34	39	13
560-570	18	36	37	9
570-580	21	37	34	8
580-590	16	35	41	8
590-600	22	29	36	13
600-610	20	29	34	17
610-620	23	32	31	14
620-630	23	30	34	13

Table 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-1 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel > 2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay < 0.125 mm.
630-640	38	25	24	13
640-650	35	29	27	9
650-660	42	25	24	9
660-670	58	25	12	5
670-680	65	20	11	4
680-690	37	39	19	5
690-700	25	25	38	12
700-710	20	45	27	8
710-720	30	41	24	5
720-730	20	49	25	6
730-740	19	49	26	6
740-750	41	39	16	4
750-760	39	38	18	5
760-770	37	35	21	7
770-780	33	35	23	9
780-790	30	45	20	5
790-800	24	45	24	7
800-810	18	55	24	3
810-820	24	31	25	20
820-830	21	34	27	18

Table ~~8~~ 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-1 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
830- 840	8	44	36	12
840- 850	13	44	33	10
850- 860	19	44	28	9
860- 870	14	43	33	10
870- 880	11	37	40	12
880- 890	11	34	37	18
890- 900	13	36	36	15
900- 910	12	32	33	23
910- 920	18	32	30	20
920- 930	13	29	36	22
930- 940	23	25	21	31
940- 950	25	26	27	22
950- 960	24	27	24	25
960- 970	41	25	17	17
970- 980	22	27	30	21
980- 990	33	26	22	19
990-1,000	28	28	26	18

Table ~~8~~3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-2

Depth of sample (feet)	Percentages of sample by volume			
	Gravel >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
0- 23	50	30	15	5
23- 33	65	20	10	5
33- 43	55	30	10	5
43- 53	45	30	20	5
53- 63	65	20	10	5
63- 73	65	20	10	5
73- 83	60	20	20	10
83- 93	60	20	20	10
93-103	65	20	10	5
103-113	65	20	10	5+
113-123	65	15	15	5+
123-133	60	15	15	10
133-143	70	20	10-	5-
143-153	62	13	16	9
153-163	42	13	25	20
163-173	66	16	11	6
173-183	57	14	17	12
183-193	62	25	11	2
193-203	62	21	11	6

Table 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-2 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
203-213	64	22	10	4
213-223	50	23	19	8
223-233	39	36	19	6
233-243	47	32	18	3
243-253	57	13	23	7
253-263	34	38	22	6
263-268	13	13	55	19
268-273	15	29	39	17
273-278	32	29	28	11
278-283	37	40	18	5
283-293	37	33	22	8
293-303	36	39	21	4
303-313	32	38	24	6
313-318	43	30	20	7
318-323	34	24	30	12
323-328	31	31	32	6
328-338	28	26	34	12
338-343	36	34	23	7
343-348	46	34	16	4

Table ~~8~~ 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-2 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel	Very coarse and coarse sand	Medium and fine sand	Very fine sand, silt, and clay
	> 2.0 mm.	2.0 - 0.5 mm.	0.5 - 0.125 mm.	< 0.125 mm.
348-356	48	30	18	4
356-361	53	32	11	4
361-366	31	34	28	7
366-375	26	36	30	8
375-385	46	18	20	16
385-395	52	15	18	15
395-405	48	27	20	5
405-415	76	13	7	4
415-425	41	30	23	6
425-435	61	25	11	3
435-445	56	21	18	5
445-455	26	28	35	11
455-465	52	29	15	4
465-475	25	34	35	6
475-485	64	15	16	5
485-495	68	19	9	4
495-505	50	24	21	5
505-510	52	25	17	6
510-515	60	19	15	6
515-525	49	21	20	10

Table 3.--Mechanical analyses of drill cuttings from test holes at White Sands Proving Ground, N. Mex. - Continued

Test hole T-2 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel	Very coarse and coarse sand	Medium and fine sand	Very fine sand, silt, and clay
	>2.0 mm.	2.0 - 0.5 mm.	0.5 - 0.125 mm.	<0.125 mm.
525-535	52	22	17	9
535-545	60	22	12	6
545-550	68	14	12	6
550-560	47	23	20	10
560-570	51	21	20	9
570-580	63	17	14	6
580-590	57	25	14	4
590-600	23	22	41	14
600-610	49	28	17	6
610-620	34	32	25	9
620-630	31	28	27	14
630-640	27	22	33	18
640-650	16	24	42	18
650-660	26	40	27	7
660-670	37	35	23	5
670-680	36	33	22	9
680-690	34	36	22	8
690-700	21	35	33	11
700-710	29	40	26	5
710-720	23	35	34	8

Table 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-2 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
720-730	29	42	24	5
730-740	22	34	33	11
740-750	23	37	30	10
750-760	35	32	26	7
760-770	47	37	14	2
770-780	42	29	23	6
780-790	46	34	18	2
790-800	42	33	21	4
800-810	11	41	41	7
810-820	7	40	47	6
820-830	21	35	36	8
830-840	20	35	36	9
840-850	23	43	29	5
850-860	6	27	54	13
860-870	-	-	-	-
870-880	51	23	19	7
880-890	30	36	27	7
890-900	47	32	17	4
900-910	48	34	14	4
910-920	48	28	16	8

Table 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-2 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel	Very coarse and coarse sand	Medium and fine sand	Very fine sand, silt, and clay
	>2.0 mm.	2.0 - 0.5 mm.	0.5 - 0.125 mm.	<0.125 mm.
920- 930	42	35	18	5
930- 940	48	31	17	4
940- 950	49	33	14	4
950- 960	41	25	26	8
960- 970	50	33	12	5
970- 980	56	24	18	2
980-1,000	65	13	14	8

Table ~~8~~ 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-3

Depth of sample (feet)	Percentages of sample by volume			
	Gravel	Very coarse and coarse sand	Medium and fine sand	Very fine sand, silt, and clay
	>2.0 mm.	2.0 - 0.5 mm.	0.5 - 0.125 mm.	<0.125 mm.
0- 10	32	37	29	2
10- 20	27	53	18	2
20- 30	14	45	34	7
30- 40	92	2	4	2
40- 50	89	5	4	2
50- 60	93	2	3	2
60- 70	90	3	5	2
70- 80	82	9	6	3
80- 90	87	7	4	2
90-100	90	3	4	3
100-110	91	4	3	2
110-120	81	9	7	3
120-130	82	10	5	3
130-140	95	3	1	1
140-150	81	11	5	3
150-160	88	6	4	2
160-170	57	17	19	7
170-180	49	29	19	3
180-190	48	3	16	5
190-200	50	30	17	3

Table ~~8~~ 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-3 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
200-210	34	39	22	5
210-220	28	43	22	7
220-230	33	41	21	5
230-240	46	36	14	4
240-250	48	31	17	4
250-260	47	29	19	5
260-270	29	38	26	7
270-280	43	32	20	5
280-290	34	35	27	4
290-300	26	38	28	8
300-310	37	34	22	7
310-320	41	39	15	5
320-330	36	29	25	10
330-340	38	36	18	6
340-350	39	39	19	3
350-360	75	15	6	4
360-370	62	19	12	7
370-380	61	17	13	9
380-390	56	20	15	9
390-400	53	21	18	8

Table ~~8~~ 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-3 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel	Very coarse and coarse sand	Medium and fine sand	Very fine sand, silt, and clay
	>2.0 mm.	2.0 - 0.5 mm.	0.5 - 0.125 mm.	<0.125 mm.
400-410	58	23	13	6
410-420	43	26	21	10
420-430	48	30	15	7
430-440	47	24	19	10
440-450	59	19	15	7
450-460	53	21	19	7
460-470	52	27	16	5
470-480	49	29	16	6
480-490	27	34	29	10
490-500	35	43	18	4
500-510	36	36	22	6
510-520	41	37	17	5
520-530	41	35	17	7
530-540	43	31	21	5
540-550	41	35	17	7
550-560	35	29	27	9
560-570	48	28	18	6
570-580	41	35	19	5
580-590	26	34	32	8
590-600	36	36	24	4

Table 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-3 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
600-610	36	37	23	4
610-620	39	36	21	4
620-630	27	35	32	6
630-640	8	34	49	9
640-650	19	43	32	6
650-660	17	42	33	8
660-670	12	48	35	5
670-680	13	48	32	7
680-690	14	56	25	5
690-700	26	42	24	8
700-710	16	34	41	9
710-720	18	46	27	9
720-730	29	36	30	5
730-740	17	46	31	6
740-750	16	45	32	7
750-760	8	31	51	10
760-770	5	46	41	8
770-775	7	40	44	9

Table ~~8~~ 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-4

Depth of sample (feet)	Percentages of sample by volume			
	Gravel <2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
0-10	-	-	-	-
10-20	70	11	12	7
20-30	88	6	4	2
30-40	34	14	34	18
40-50	67	14	13	6
50-60	71	8	13	8
60-70	70	9	16	5
70-80	42	17	24	17
80-90	29	19	34	18
90-100	34	18	34	14
100-110	34	18	29	19
110-120	10	-	-	-
120-130	10	-	-	-
130-140	10	-	-	-
140-150	10	-	-	-
150-160	5	-	-	-
160-170	5	-	-	-
170-180	5	-	-	-
180-190	5	-	-	-
190-200	5	-	-	-

Table ~~8~~ 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-4 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel	Very coarse and coarse sand	Medium and fine sand	Very fine sand, silt, and clay
	>2.0 mm.	2.0 - 0.5 mm.	0.5 - 0.125 mm.	<0.125 mm.
200-210	15	-	-	-
210-220	15	-	-	-
220-230	10	-	-	-
230-240	5	-	-	-
240-250	2	-	-	-
250-260	2	-	-	-
260-270	2	-	-	-
270-280	2	-	-	-
280-290	2	-	-	-
290-300	2	-	-	-
300-310	2	-	-	-
310-320	5	-	-	-
320-330	7	-	-	-
330-350	5	-	-	-
350-360	5	-	-	-
360-370	5	-	-	-
370-380	27	27	40	6
380-390	50	25	19	6
390-400	7	-	-	-
400-410	5	-	-	-

Table 3.--Mechanical analyses of drill cuttings from test holes at White Sands Proving Ground, N. Mex. - Continued

Test hole T-4 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel ≥ >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
410-420	5	-	-	-
420-430	5	-	-	-
430-440	7	-	-	-
440-450	5	-	-	-
450-460	5	-	-	-
460-470	5	-	-	-
470-480	5	-	-	-
480-490	7	-	-	-
490-500	7	-	-	-
500-510	3	-	-	-
510-520	5	-	-	-
520-530	5	-	-	-
530-540	5	-	-	-
540-550	7	-	-	-
550-555	10	25	57	8
555-560	11	33	52	4
560-565	22	31	41	6
565-570	20	28	45	7
570-575	26	29	40	5
575-580	5	-	-	-

Table ~~8~~ 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-4 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel	Very coarse and coarse sand	Medium and fine sand	Very fine sand, silt, and clay
	>2.0 mm.	2.0 - 0.5 mm.	0.5 - 0.125 mm.	<0.125 mm.
580-590	5	-	-	-
590-600	3	-	-	-
600-610	12	21	65	2
610-620	7	13	75	5
620-630	3	-	-	-
630-640	3	-	-	-
640-650	3	-	-	-
650-660	28	19	45	8
660-680	5	-	-	-
680-690	5	-	-	-
690-700	5	-	-	-
700-710	5	-	-	-
710-720	5	-	-	-
720-740	5	-	-	-
740-750	5	-	-	-
750-760	5	-	-	-
760-770	3	-	-	-
770-780	5	-	-	-
780-790	5	-	-	-
790-800	19	25	48	8

Table ~~8~~ 3.--Mechanical analyses of drill cuttings from test holes at White Sands Proving Ground, N. Mex. - Continued

Test hole T-4 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
800-810	13	16	64	7
810-820	16	26	47	11
820-830	16	27	49	8
830-840	16	16	57	11
840-850	11	8	70	11
850-860	17	17	54	12
860-870	32	18	41	9
870-880	34	17	37	12
880-890	25	20	45	10
890-900	27	20	43	10
900-910	16	11	59	14
910-920	9	9	68	14
920-930	16	14	56	14
930-940	20	13	59	8
940-950	22	14	50	14
950-960	23	16	46	15
960-970	16	12	56	16
970-980	10	7	69	14
980-990	6	5	73	16
990-1,000	11	11	67	11

Note: Predominantly calcareous clay from 110 to 370, 390 to 550, 575 to 600, 620 to 650, and 660 to 790 feet.

Table 3.--Mechanical analyses of drill cuttings from test holes at White Sands Proving Ground, N. Mex. - Continued

Test hole T-5

Depth of sample (feet)	Percentages of sample by volume			
	Gravel	Very coarse and coarse sand	Medium and fine sand	Very fine sand, silt, and clay
	> 2.0 mm.	2.0 - 0.5 mm.	0.5 - 0.125 mm.	<0.125 mm.
0-20	93	3	2	2
20-30	89	8	2	1
30-40	67	15	12	6
40-50	70	18	7	5
50-60	77	13	7	3
60-70	75	10	9	6
70-80	67	13	14	6
80-90	80	7	9	4
90-100	75	11	11	3
100-110	78	10	8	4
110-120	80	10	6	4
120-130	79	11	6	4
130-140	62	16	18	4
140-150	56	18	20	6
150-160	65	14	13	8
160-170	61	17	17	5
170-180	51	21	20	8
180-190	57	16	20	6
190-200	60	21	14	5
200-210	64	17	12	7

Table 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-5 - Continued

Depth of sample (feet)	Percentage of sample by volume			
	Gravel >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
210-220	55	20	18	7
220-230	50	21	22	7
230-240	41	26	27	6
240-250	56	28	13	3
250-260	42	27	25	6
260-270	47	22	22	9
270-280	34	21	30	15
280-290	15	29	45	11
290-300	23	27	37	13
300-310	32	29	30	9
310-320	26	23	32	19
320-330	12	17	55	16
330-340	14	18	43	25
340-350	21	18	37	24
350-360	28	19	32	21
360-370	33	20	28	19
370-380	24	32	31	13
380-390	23	34	30	13
390-400	26	29	30	15
400-410	28	31	28	13

Table 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-5 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay <0.125 mm.
410-420	23	30	32	15
420-430	28	22	32	18
430-440	35	31	25	9
440-450	16	10	32	42
450-460	21	23	31	25
460-470	30	24	30	16
470-480	24	22	40	14
480-490	29	25	33	13
490-500	24	17	36	23
500-510	22	25	38	15
510-520	25	25	35	15
520-530	14	33	37	16
530-540	16	35	35	14
540-550	20	35	31	14
550-560	10	34	43	13
560-570	29	19	20	15
570-580	32	23	27	18
580-590	38	24	25	13
590-600	22	26	33	19
600-610	12	21	38	29

Table $\overset{3}{8}$.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-5 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel >2.0 mm.	Very coarse and coarse sand 2.0 - 0.5 mm.	Medium and fine sand 0.5 - 0.125 mm.	Very fine sand, silt, and clay < 0.125 mm.
610-620	23	26	33	18
620-630	22	26	39	13
630-640	32	27	27	14
640-650	28	25	22	25
650-660	29	24	21	26
660-670	10	-	-	-
670-680	7	-	-	-
680-690	7	-	-	-
690-700	7	-	-	-
700-710	10	-	-	-
710-720	10	-	-	-
720-730	7	-	-	-
730-740	7	-	-	-
740-750	5	-	-	-
750-760	10	-	-	-
760-770	6	-	-	-
770-780	7	-	-	-
780-790	25	26	33	16
790-800	18	21	46	15
800-810	14	21	54	11

Table 3.--Mechanical analyses of drill cuttings from test holes

at White Sands Proving Ground, N. Mex. - Continued

Test hole T-5 - Continued

Depth of sample (feet)	Percentages of sample by volume			
	Gravel	Very coarse and coarse sand	Medium and fine sand	Very fine sand, silt, and clay
	>2.0mm.	2.0 - 0.5 mm.	0.5 - 0.125 mm.	<0.125 mm.
810-820	19	31	38	12
820-830	20	31	36	13
830-840	29	32	27	12
840-850	17	26	43	14
850-860	14	27	45	14
860-870	16	30	44	10
870-880	17	27	44	12
880-890	21	32	36	11
890-900	14	28	43	15
900-910	8	13	68	11
910-920	3	9	76	12
920-930	9	18	58	15
930-940	10	18	57	15
940-950	20	25	42	14
950-960	15	25	45	15
960-970	10	17	53	20
970-980	16	28	42	14
980-1,000	16	19	36	29

Note: Predominantly red clay from 660 to 780 feet.

Table 4.--Record of wells and test holes in the Headquarters Area, White Sands Proving Ground, ~~Dona Ana County,~~ N. Mex.

Table number	Field number	Location number 1/	Altitude of land surface (feet above msl) 2/	Height of measuring point above land surface (feet)	Depth to water below measuring point (feet) 3/ 4/	Altitude of water level (feet above msl)	Date measured	Driller
1	-	20.5.36.444	3,950	1.30	131.71	3,820	3/20/53	-
2	-	21.4.11.311	5,550	1.50	112.50	5,439	2/12/53	-
3	-	14.223	5,150	1.50	117.90	5,034	2/12/53	-
4	-	21.231	5,630	.60	96.91	5,534	2/12/53	-
5	-	25.232	4,625	.70	32.34	4,593	2/12/53	-
6	-	27.121	5,280	1.00	43.70	5,237	2/12/53	-
7	-	33.431	5,155	1.00	105.74	5,050	2/16/53	-
8	-	35.134	4,855	1.50	22.00	4,835	2/17/53	-
9	-	21.5.12.334	3,950	1.48	112.15	3,839	3/18/53	-
10	-	15.411	3,970	1.00	132.08	3,839	3/29/53	Bob Boyd
11	-	32.334	4,135	2.00	253.18	3,884	2/18/53	-
12	T-1	22.4.1.444	4,320	1.98	401.21	3,921	7/31/53	Layne-Texas Co.
13	-	2.131	4,730	.60	126.15	4,604	2/23/53	-
14	T-2	13.223	4,262.6	2.02	340.00	3,924.6	5/29/53	Layne-Texas Co.
15	13	13.311	4,330.3	-	310A 300R	4,020 4,030	9/ 8/53	-
16	11	13.333	4,333.5	-	313A 305A 296R	4,021 4,029 4,038	8/26/53 3/13/53	Layne-Texas Co.
17	14	22.4.13.411	4,290.3	2.09	359.17	3,933.2	5/ 3/54	B + W Drilling Co.
18	15	13.424	4,261.3	1.60	339.49	3,923.4	4/30/54	Do.
19	16	13.432	4,270	2.00	351.63	3,921	9/22/54	Harold P. Doty
20	T-3	14.211	4,442.4	1.95	383.20	4,061.2	6/ 6/53	Layne-Texas Co.
21	-	16.112	4,820	1.00	50.60	4,770	2/25/54	-
22	-	22.141	4,600	2.64	25.70	4,577	8/19/53	-
23	-	22.232	4,545	-	65R	4,480	-	-

Table 4.--Record of wells and test holes in the Headquarters Area,

White Sands Proving Ground, ~~Dona Ana County,~~ N. Mex.--Continued

Table number	Depth (feet) 4/	Diameter (inches)	Test Performance				Date completed	Type of pump 5/	Use of water 6/	Chemical analysis 7/
			Date 4/	Yield (gpm)	Drawdown (feet)	Duration of test (hours)				
1	148	7	-	-	-	-	-	N	N	-
2	-	7	-	-	-	-	-	WP	S	-
3	156	7	-	-	-	-	-	N	N	-
4	110	7	-	-	-	-	-	WP	S	X
5	-	-	-	-	-	-	-	WP	D,S	X
6	47	-	-	-	-	-	-	WP	D,S	-
7	147	8	-	-	-	-	-	WP	S	-
8	133	-	-	-	-	-	-	N	N	-
9	-	5	-	-	-	-	-	EP	PS	X
10	160R	12x6	12/2/52R	15	30	4-1/2	Nov. 1952	ET	PS	X
11	265	7	-	-	-	-	-	N	N	-
12	1,004	6	-	-	-	-	June 1953	N	N	X
13	190	8	-	-	-	-	-	WP	S	-
14	1,000	6	-	-	-	-	May 1953	N	N	X
15	534	24x12	9/8/53	209	72	50	Aug. 1951	ET	PS	X
16	500	24x12	8/26/53	366	57	29-1/2	May 1950	ET	PS	X
17	810	26x12	1/13/54	600	76-1/2	48	Dec. 1953	ET	PS	X
18	820	26x12	2/18/54	750	35	40-1/2	Feb. 1954	ET	PS	X
19	890	26x12	10/9/54	600	25	48	Sept. 1954	ET	PS	X
20	875	6	-	-	-	-	May 1953	N	N	X
21	-	8	-	-	-	-	-	WP	S	X
22	-	7	-	-	-	-	-	WP	S	-
23	120R	-	-	-	-	-	-	WP	D,S	-

Table 4.--Record of wells and test holes in the Headquarters Area,

White Sands Proving Ground, ~~Dona Ana County,~~ N. Mex.--Continued

Table number	Field number	Location number 1/	Altitude of land surface (feet above msl) 2/	Height of measuring point above land surface (feet)	Depth to water below measuring point (feet) 3/ 4/	Altitude of water level (feet above msl)	Date measured	Driller
24	12	22.4.23.214	4,369.3	-	332A	4,037	9/ 8/53	-
					300E	4,069	4/19/53	-
					291R	4,078		
25	-	24.222	4,255	1.50	343.68	3,913	8/18/53	-
26	10	24.212	4,271.3	-	358A	3,913	8/12/53	P. S. Judy
					345R	3,926		Air Made Well Co.
27	T-4	22.5.16.111	4,051.3	1.97	225.29	3,828.0	6/21/53	Layne-Texas Co.
28	T-5	20.111	4,149.8	1.98	272.25	3,879.5	7/31/53	Do.
29	2	31.244	4,130	-	235D	-	1/31/53	-
30	9	31.424	4,128.0	-	240A	3,888	4/23/53	Russel-Russel
					234R	3,894	4/10/47R	and Moore
31	1	32.131	4,130	-	205D	-	1/31/53	-
32	3	32.134	4,115	-	225D	-	1/31/53	-
33	4	32.311	4,110	1.00	223.31	3,888	5/ 4/53	-
34	4a	32.311a	4,115	-	-	-	-	-
35	5	32.313	4,112.0	-	225R	3,887	4/ 9/47	Russel-Russel and Moore
36	6	32.321	4,104.0	1.00	236.58	3,868.4	1/31/53	Do.
					231R	3,873		
37	7	32.323	4,083.5	.53	237.59	3,846.4	1/31/53	Do.
					216R	3,868		
38	8	32.332	4,084.0	1.70	211.75	3,874.0	1/31/53	-
39	-	23.5.5.311	4,110	6.60	137.55	3,979	2/17/53	-
40	T-21	35.300	3,937.4	-	165.1	3,772.3	4/ 4/53	B + W Drilling Co.

Table 4.--Record of wells and test holes in the Headquarters Area,

White Sands Proving Ground, ~~Dona Ana County,~~ N. Mex.--Continued

Table No.	Depth (feet) 4/	Diameter (inches)	Test Performance				Date completed	Type of pump 5/	Use of water	Chemical analysis 7/
			Date	Yield	Drawdown (feet)	Duration of test (hours)				
24	570	24x12	9/8/53 4/19/53	212	40 28	71-1/2 6	Jan. 1952	ET	PS	X
25	352	6	-	-	-	-	-	N	N	-
26	505	21x14	8/12/53	400R	17	72	Aug. 1948	ET	PS	X
27	1,000	6	-	-	-	-	June 1953	N	N	X
28	1,000	6	-	-	-	-	July 1953	N	N	X
29	293R	-	-	15R	-	-	-	N	N	-
30	348R	-	4/23/53 4/10/47R	35R 35	23 26	6-1/2 4	July 1946	ET	PS	X
31	-	10-1/4	-	-	-	-	-	N	N	-
32	381R	8	-	30R	-	-	-	N	N	-
33	390 452R	10	-	33R	-	-	-	N	N	-
34	-	-	-	-	-	-	-	N	N	X
35	267R	20x7	4/9/47R	39.5	21+	8	Apr. 1946	ET	PS	X
36	338R	-	4/9/47R	55	32	7	June 1946	N	N	X
37	304R	-	4/9/47R	26	20	6	May 1946	N	N	X
38	-	-	-	-	-	-	-	N	N	-
39	163	5	-	-	-	-	-	WP	S	X
40	1,200	6	-	-	-	-	May 1953	N	N	X

1/ See page for explanation of well-location number.
2/ Altitudes determined by instrument leveling are carried to tenths of a foot; others are estimated from topographic maps.
3/ A = measured with airline, others measured with steel tape; E = estimated; D = dry at depth given.
4/ R = reported.
5/ EP = electrically-driven plunger; ET = electric turbine; N = none; WP = wind-driven plunger.
6/ D = domestic; N = none; PS = public supply; S = stock.
7/ X = chemical analysis of water sample in table 6.

Table ~~6~~ 5.--Chemical Analyses of Water from Wells and Test Holes in the Headquarters area,

White Sands Proving Ground, ~~Dona Ana County,~~ N. Mex.

(By U.S. Geological Survey, in parts per million)

Table No.	Name or field No.	Location No. 1/	Date of collection	Silica (SiO_2)	Iron (Fe) 2/	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Carbonate (CO_3)
1	Lena Cox Ranch	21.4.21.231	2/12/53	32	-	82	16	51	0
2	Hal Cox Ranch	25.232	3/ 4/53	33	-	86	14	56	0
3	Navy Test Station	21.5.12.334	3/ 5/53	62	-	46	45	100	0
4	Small Missile Range	15.411	3/12/53	24	-	59	45	29	0
5	T-1 3/	22.4.1.444	7/14/53	24	0.03	44	9.5	32	0
6	T-2 3/	13.223	6/18/53	36	-	60	8.4	39	31
7	13	13.311	3/11/52	40	.07	34	9.1	21	0
8	13	13.311	5/20/53	42	.01	32	9.3	23	0
9	11	13.333	6/22/50	42	.01	36	8.9	18	0
10	11	13.333	5/30/53	44	.01	33	9.5	23	0
11	14 4/	13.411	1/ 4/54	-	-	-	-	-	0
12	14 5/	13.411	10/9/53	-	-	11	.0	-	0
13	15 4/	13.424	2/13/54	-	-	-	-	-	10
14	15 6/	13.424	9/24/53	-	-	-	-	-	0
15	15 7/	13.424	9/26/53	-	-	-	-	-	0
16	16 4/	13.432	10/5/54	37	-	35	7.2	26	0
17	T-3 3/	14.211	6/ 1/53	33	-	60	12	56	0
18		16.112	4/16/53	40	-	67	15	33	0
19	12	23.214	5/ 1/52	39	.04	34	9.0	25	0
20	12		5/20/53	45	.01	37	11	24	0
21	10	24.212	5/16/49	46	.03	36	8.3	21	0
22	10		5/20/53	44	.01	35	9.7	25	0
23	T-4 3/	22.5.16.111	6/12/53	16	.03	59	8.6	53	0
24	T-4 8/		6/10/53	13	-	499	85	2,210	0
25	T-5 3/	20.111	7/10/53	18	.02	24	3.5	51	0
26	T-5 9/		7/ 7/53	-	-	-	-	-	-

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Table ~~6~~5.--Chemical Analyses of Water from Wells and Test Holes in the Headquarters Area, White Sands Proving Ground, ~~Dona Ana County,~~ N. Mex. - Continued

(By U.S. Geological Survey, in parts per million)

Table No.	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$ Total	Hardness as $CaCO_3$ Noncarbonate	Specific conductance (micromhos at 25°C)	Percent sodium	pH
1	271	101	28	4.0	6.2	453	270	48	700	29	-
2	225	134	29	4.0	22	489	272	88	744	31	-
3	250	242	38	.7	6.4	663	300	95	950	42	-
4	195	170	36	1.6	3.1	464	332	172	725	16	-
5	188	41	14	.4	.5	257	149	0	409	31	7.4
6	138	64	26	.5	.1	333	184	18	505	32	8.7
7	128	46	8.5	.5	2.9	225	122	18	331	10	7.3
8	129	44	9.0	.4	3.3	226	118	12	318	27	7.3
9	123	45	9.0	.5	5.2	226	126	26	327	24	7.2
10	128	47	10	.4	3.0	233	122	16	325	27	7.2
11	140	38	9	-	-	-	-	-	321	-	-
12	151	-	15	-	-	-	28	0	477	-	-
13	95	-	1.0	-	-	-	-	-	340	-	-
14	128	-	14	-	-	-	43	-	437	-	-
15	104	-	16	-	-	-	31	0	380	-	-
16	138	39	11	.3	3.2	227	117	4	337	32	-
17	300	50	15	.5	.1	375	199	0	610	38	7.6
18	170	112	16	1.2	24	392	228	89	574	24	-
19	135	47	10	.4	2.3	234	122	12	340	31	7.7
20	134	61	10	.3	1.7	256	138	28	360	25	7.2
21	130	45	10	.4	2.3	233	124	18	337	27	7.7
22	140	48	10	.3	2.6	244	128	13	340	18	7.2
23	284	21	31	.2	.3	329	182	0	573	39	7.4
24	101	568	4,050	1.0	-	7,480	1,590	1,510	12,600	75	7.0
25	99	68	17	.3	9.8	241	74	0	379	60	7.4
26	-	68	-	-	-	-	-	-	672	-	-

Table ~~8~~5.--Chemical Analyses of Water from Wells and Test Holes in the Headquarters Area,
White Sands Proving Ground, ~~Dona Ana County,~~ N. Mex. - Continued
(By U.S. Geological Survey, in parts per million)

Table No.	Name or field No.	Location No. 1/	Date of collection	Silica (SiO_2)	Iron (Fe) 2/	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Carbonate (CO_3)
27	9	22.5.31.424	4/ 6/48	53	0.03	24	6.2	17	0
28	9	31.424	5/20/53	43	.02	23	6.0	18	0
29	4	32.311	4/ 6/48	57	.03	29	7.6	21	0
30	4		5/11/51	47	.01	27	7.2	20	0
31	5	32.313	4/ 6/48	49	.03	29	7.5	19	0
32	5		5/20/53	41	.01	27	7.9	19	0
33	6	32.321	4/ 6/48	59	.02	26	7.3	22	0
34	6		5/11/51	48	.01	27	7.2	20	0
35	7	32.323	4/ 6/48	56	.07	26	6.6	19	0
36	7		5/16/49	55	.02	28	6.6	19	0
37		23.5.5.310	3/20/53	37	-	65	10	66	0

Table No.	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	Percent sodium	pH
							Total	Noncarbonate			
27	96	30	8.5	0.5	1.2	188	86	7	248	-	7.2
28	99	25	9.5	.6	1.1	176	82	1	235	31	7.0
29	109	42	10	.3	3.1	224	104	14	297	-	7.2
30	107	36	10	.4	.8	201	97	10	284	31	7.1
31	94	44	14	.5	3.2	213	104	26	293	-	7.1
32	103	34	11	.5	3.1	194	100	16	264	27	7.0
33	104	38	11	.3	2.3	217	95	10	281	-	7.1
34	105	36	11	.3	.9	202	97	11	287	-	7.2
35	105	32	9.2	.4	2.0	203	92	6	268	-	7.1
36	106	35	8.5	.3	1.8	206	97	10	271	30	7.7
37	198	123	33	.3	2.9	437	203	41	671	41	-

Table ~~6~~ 5.--Chemical analysis of water from wells and test holes in the ~~H~~eadquarters ~~A~~rea,

White Sands Proving Ground, ~~Dona Ana County,~~ N. Mex.--Continued

(By U.S. Geological Survey, in parts per million)

Chemical analyses of water from test-hole T-21,

SW$\frac{1}{4}$ sec. 35, T. 23 S., R. 5 E.

Table No.	Date of collection	Depth (feet)	Silica (SiO_2)	Iron (Fe) 2/	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)
38 a	4/4/53	404' to 452'	58	0.00	36	3.9	19	5.6	0	104	35
38 b	4/5/53	470' to 510'	58	.08	35	4.2	22	6.3	0	104	42
38 c	4/9/53	630' to 660'	34	.00	31	6.4	25	4.2	0	102	37
38 d	4/10/53	715' to 744'	32	.02	28	4.9	31	3.9	0	106	38
38 e	4/12/53	827' to 865'	32	.01	29	3.5	45	3.7	0	107	59
38 f	5/3/53	962' to 1,012'	34	.00	42	3.8	44	4.0	0	94	59
38 g	5/6/53	1,162' to 1,216'	32	.00	630	57	421	14	0	54	541

Table No.	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$ Total	Hardness as $CaCO_3$ Noncarbonate	Specific conductance (micromhos at 25°C)	Percent sodium	pH
38 a	17	0.6	5.0	0.02	238	106	21	308	27	7.7
38 b	19	.6	4.2	.08	246	105	19	324	30	7.6
38 c	24	.5	4.2	.21	217	104	20	334	33	7.9
38 d	23	.5	4.3	.06	218	90	3	326	41	7.7
38 e	26	.5	4.2	.10	256	87	0	288	52	7.8
38 f	54	.5	4.0	.04	299	120	43	471	43	7.4
38 g	1,550	.1	1.5	.40	3,280	1,830	1,790	5,440	33	7.0

Table ~~6~~ 5.--Chemical analyses of water from wells and test holes in the ~~H~~headquarters ~~A~~area, White Sands Proving Ground, ~~Dona Ana County,~~ N. Mex.--Continued

(By U.S. Geological Survey, in parts per million~~s~~)

Explanation of footnotes

1/ See page 12 for explanation of location number.

2/ In solution at time of analysis.

3/ Sample of shallow water obtained by bailing.

4/ Sample obtained by pumping after well was completed.

5/ Sample obtained from zone between depths of 953 and 1,000 feet by jetting with air.

6/ Sample obtained from zone between depths of 755 and 800 feet by jetting with air.

7/ Sample obtained from zone between depths of 955 and 1,000 feet by jetting with air.

8/ Sample obtained from zone between depths of 956 and 1,003 feet by drill-stem method.

9/ Sample (mostly drilling fluid) obtained from zone between depths of 908 and 1,000 feet by drill-stem method.

Table ~~2~~ 6.--Test data of wells at White Sands Proving Ground, N. Mex.

Well	Date	Average yield ~~(gpm)~~ (gallons per minute)	Drawdown during test (feet)	Pumping time (hours)	Specific capacity			Transmissibility of formation indicated by test (gpd/~~ft~~ per foot)
					6 hours,	12 hours,	24 hours,	
5	Apr. 1946	70 R/	13 R/	-	-	-	-	-
9	Apr. 1953	35 R/	23	6.5	1.5	-	-	800
10	Aug. 1953	350 E/	17	72	28.0	25.9	24.1	61,600
11	Aug. 1953	366	57	29.5	13.1	9.4	6.9	2,500
12	Sept. 1953	212	-	-	-	-	-	-
13	Sept. 1953	209	72	50	3.9	3.5	3.3	5,000
14	Jan. 1954	600	76.5	48	10.6	9.2	8.5	7,900
15	Feb. 1954	750	35	40.5	24.2	23.4	21.4	28,300
16	Oct. 1954	600	25	48	33.3	30.3	30.0	33,000

R/ Reported

E/ Estimated

Table 8.--Construction Data for Water-Supply Wells at White Sands Proving Ground, N. Mex.

Well	Date completed	Depth (feet)	Diameter (inches)	Casing and screen			Air cleanout pipes	
				Depth of setting (feet)	Length (feet)	Description	Depth of setting (feet)	Description
10	Aug. 1948	505	21 to 456 feet 14 from 456 to 505 feet	10	10	30-inch diameter	348	2-inch diameter pipe, lower 4 feet perforated
				267	267	12-inch diameter blank steel casing	458	Do.
				497	230	12-inch diameter slotted steel casing		
11	May 1950	500	24 x 12	40	40	26-inch diameter steel welded surface casing	400	$2\frac{1}{2}$-inch diameter pipe
				380	380	12-inch diameter blank steel casing	490	Do.
				498	8	do.		
				490	110	12-inch diameter slotted steel casing		
				500	2	Set nipple with back-wash valve		

Table 8.--Construction Data for Water-Supply Wells at White Sands Proving Ground, N. Mex.--Continued

Well	Date completed	Depth (feet)	Diameter (inches)	Casing and screen: Depth of setting (feet)	Casing and screen: Length (feet)	Casing and screen: Description	Air cleanout pipe: Depth of setting (feet)	Air cleanout pipe: Description
12	Jan. 1952	570	24 x 12	50	50	24-inch diameter corrugated metal surface pipe	360	2½-inch diameter pipe
				330	330	12-inch diameter blank steel casing	480	Do.
				425	65	do.	560	Do.
				500	20	do.		
				360	30	12-inch diameter slotted steel casing		
				480	55	do.		
				560	60	do.		
13	Aug. 1951	534	24 x 12	50	50	24-inch diameter corrugated metal surface pipe	390	2½-inch diameter meter pipe
				373	373	12-inch diameter blank steel casing	531 3/4	
				470	77	do.		
				393	20	12-inch diameter slotted steel casing		
				534	64	do.		

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Table ~~5~~ 8.--Construction Data for Water-Supply Wells at White Sands Proving Ground, N. Mex.--Continued

Well	Date completed	Depth (feet)	Diameter (inches)	Casing and screen: Depth of setting (feet)	Casing and screen: Length (feet)	Casing and screen: Description	Air cleanout pipes: Depth of setting (feet)	Air cleanout pipes: Description
14	Dec. 1953	810	26 x 12	50	50	26-inch diameter steel surface casing	760	2½-inch diameter meter pipe perforated at each screen section
				370	370	12-inch diameter blank steel casing		
				398	8	do.	760	Do.
				454	36	do.		
				480	16	do.		
				510	10	do.		
				538	8	do.		
				554	6	do.		
				584	10	do.		
				632	38	do.		
				650	8	do.		
				680	10	do.		
				700	10	do.		
				728	18	do.		
				760	12	do.		
				390	20	12-inch diameter louvered steel screen		
				418	20	do.		
				464	10	do.		
				500	20	do.		
				530	20	do.		
				548	10	do.		
				574	20	do.		

Table 8.--Construction Data for Water-Supply Wells at White Sands Proving Ground, N. Mex.--Continued

Well	Date completed	Depth (feet)	Diameter (inches)	Casing and screen			Air cleanout pipes	
				Depth of setting (feet)	Length (feet)	Description	Depth of setting (feet)	Description
14 Cont.	Dec. 1953	810	26 x 12	594	10	12-inch diameter louvered steel screen		
				642	10	do.		
				670	20	do.		
				690	10	do.		
				710	10	do.		
				748	20	do.		
				810	50	do.		
15	Feb. 1954	820	26 x 12	50	50	26-inch diameter steel surface casing	770	$2\frac{1}{2}$-inch diameter meter pipe, perforated at each screen section
				350	350	12-inch diameter blank steel casing		
				486	46	do.	770	Do.
				508	12	do.		
				525	7	do.		
				598	33	do.		
				670	32	do.		
				690	10	do.		
				710	10	do.		
				800	50	do.		
				440	90	12-inch diameter louvered steel screen		

Table 8.--Construction Data for Water-Supply Wells at White Sands Proving Ground, N. Mex.--Continued

Well	Date completed	Depth (feet)	Diameter (inches	Casing and screen			Air cleanout pipes	
				Depth of setting (feet)	Length (feet)	Description	Depth of setting (feet)	Description
15 Cont.	Feb. 1954	820	26 x 12	496	10	12-inch diameter louvered steel screen		
				518	10	do.		
				565	40	do.		
				638	40	do.		
				680	10	do.		
				700	10	do.		
				750	40	do.		
				820	20	do.		
16	Sept. 1954	890	26 x 12	50	50	26-inch diameter steel surface casing	420	$2\frac{1}{2}$-inch diameter meter pipe, lower 6 feet perforated
				370	370	12-inch diameter blank steel casing		
				415	5	do.	840	
				443	8	do.		
				459	6	do.		
				486	7	do.		
				508	12	do.		
				542	14	do.		
				588	6	do.		
				606	8	do.		
				642	6	do.		
				657	5	do.		
				678	11	do.		

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Table 8.--Construction Data for Water-Supply Wells at White Sands Proving Ground, N. Mex.--Continued

Well	Date completed	Depth (feet)	Diameter (inches)	Casing and screen			Air cleanout pipes	
				Depth of setting (feet)	Length (feet)	Description	Depth of setting (feet)	Description
16 Cont.	Sept. 1954	890	26 x 12	708	20	12-inch diameter louvered steel screen		
				724	6	do.		
				742	8	do.		
				784	12	do.		
				804	10	do.		
				866	32	do.		
				890	4	do.		
				410	40	do.		
				435	20	do.		
				453	10	do.		
				479	20	do.		
				496	10	do.		
				528	20	do.		
				582	40	do.		
				598	10	do.		
				636	30	do.		
				652	10	do.		
				667	10	do.		
				688	10	do.		
				718	10	do.		
				734	10	do.		
				772	30	do.		
				794	10	do.		
				834	30	do.		
				886	20	do.		