UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Albuquerque, New Mexico

Ground-water exploration in the Bosque del Apache Grant, Socorro County, New Mexico

By

James B. Cooper

Open-file report

Prepared in cooperation with the U.S. Army Post Engineer
White Sands Missile Range

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Abstract

Test drilling along the Rio Grande in the Bosque del Apache Grant in Socorro County, New Mexico has shown that the area is hydrologically complex and that the quality of the ground water varies from saline to fresh within short distances both laterally and vertically.

Nearly all of the riverside land in the Grant is occupied by the migratory waterfowl refuge of the Bosque del Apache National Wildlife Refuge. Potable and near-potable water is obtained from 12 wells in this area that tap sand and gravel, and the wells are capable of yielding 1,000 gallons per minute or more.

Stallion Range Center, a military installation on the White Sands Missile Range, about 15 miles east of the waterfowl refuge, needs about 100,000 gallons per day of potable water. Potable water in large quantities is not known to be available at a location closer to the Center than the refuge area.

The Fish and Wildlife Service, which operates the waterfowl refuge, gave permission to White Sands Missile Range to test drill and to develop a supply well in certain areas along the Rio Grande outside the managed lands of the refuge. The U.S. Geolocical Survey was then asked by White Sands Missile Range to choose locations for test drilling and to monitor drilling and testing of the wells.

Between 1963 and 1967 test wells were drilled and a suitable location for a supply well was found. The well would be about 250 feet deep and would tap a body of potable water that is about 100 feet in thickness and is thought to underlie an area of at least 5 square miles.

This report contains diagrammatic sections that show the lateral and vertical relation of waters of different quality along the Rio Grande in a part of the Bosque del Apache Grant. Basic data are given in tables; they include records of 7 test wells and 12 high-yield supply wells, and 32 chemical analyses of ground water from the wells.

Introduction

The Bosque del Apache Grant, in Socorro County, New Mexico, contains several water wells that yield 1,000 gpm (gallons per minute) or more of potable water from sands and gravels in the valley of the Rio Grande. These wells are in the migratory waterfowl refuge areas of the Bosque del Apache National Wildlife Refuge and are from 11 to 15 miles directly west of Stallion Range Center, a permanent military installation on the White Sands Missile Range. (fig.1).

Stallion Range Center, and the area for many miles around, is underlain by saline water. It is supplied with potable water, for drinking and culinary use only, by tank trucks which obtain water from one of the wells in the Bosque del Apache Grant. Nonpotable water for all other uses is supplied by a well at the Center.

A phase of the Water Master Plan of White Sands Missile Range is to provide an ample supply of potable water to Stallion Range Center. This would result in the elimination of truck hauling, which is not only costly in time, fuel, and equipment, but in the past has resulted in injuries to Army personnel through road accidents.

The availability of unrestricted amounts of potable water for hygienic irrigation, and recreational use would also benefit the morale of the personnel at this relatively isolated installation.

The existing high-yield wells in the Bosque del Apache Grant are owned by the Fish and Wildlife Service. They are used for irrigation in connection with the operation of the migratory waterfowl refuge, which occupies nearly all of the riverside land in the Grant (fig. 2). Known locations of large volumes of potable water within the Grant are also restricted to areas occupied by the refuge.

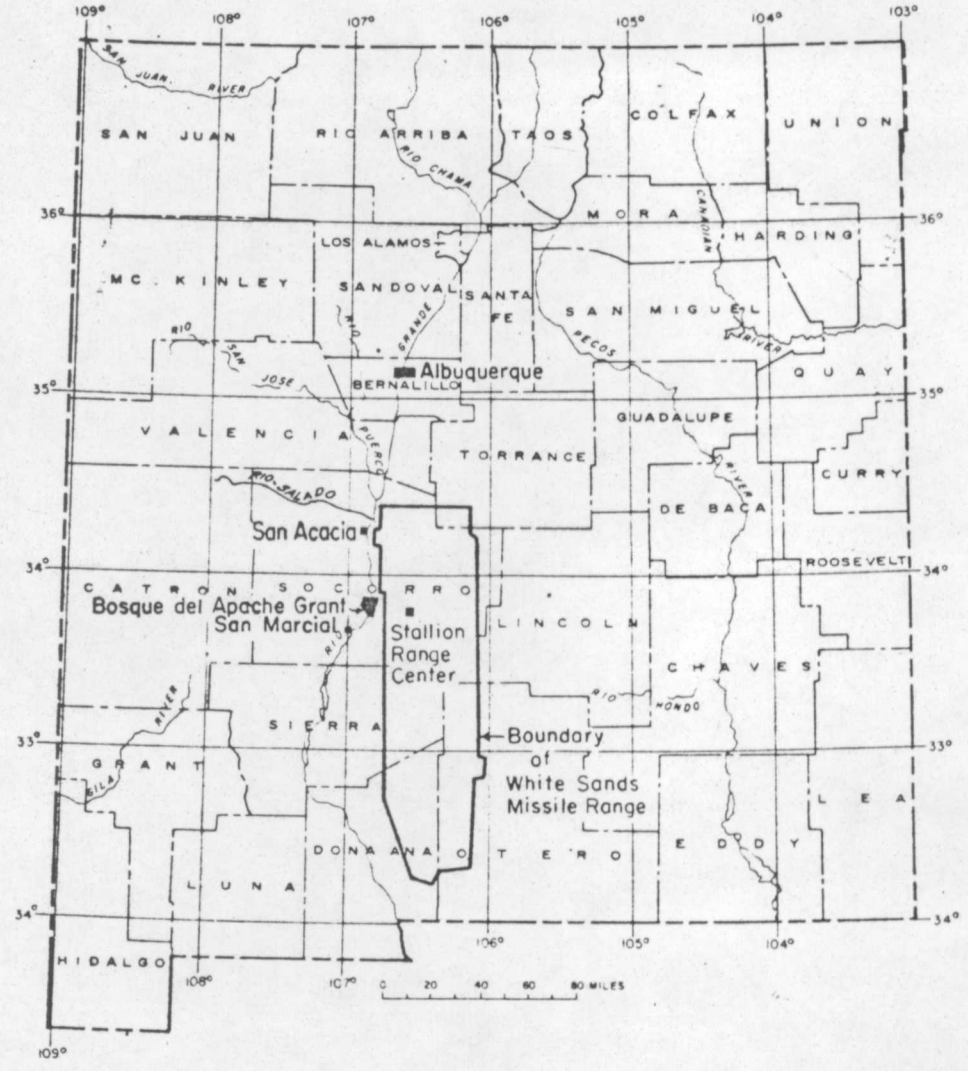

Figure 1.-- Bosque del Apache Grant, Socorro County, N. Mex., and White Sands Missile Range.

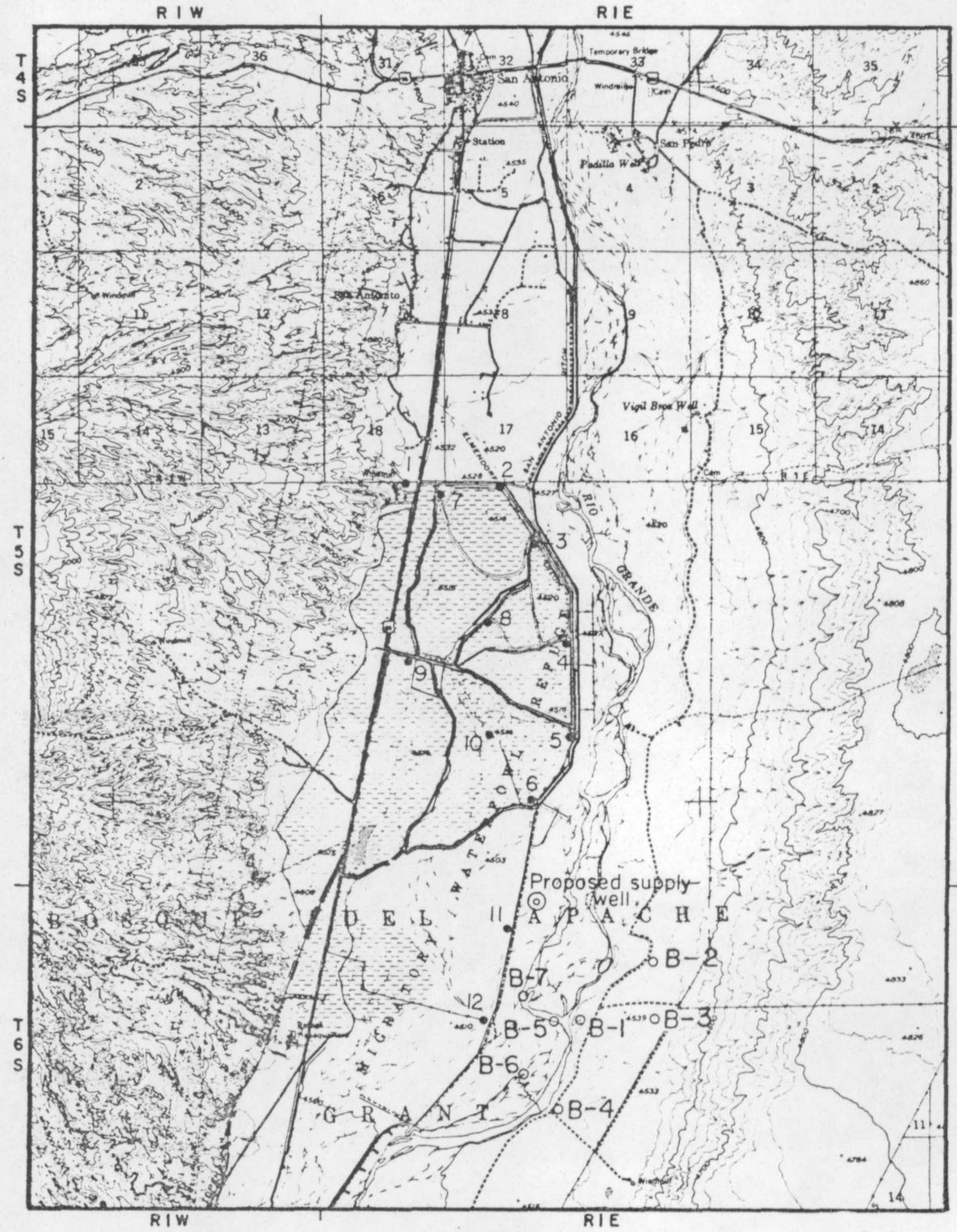

Figure 2.--Location of test wells and high-yield wells, Bosque del Apache Grant, Socorro County, N.Mex.

The waterfowl refuge is the nearest location to Stallion Range Center of known large supplies of potable water. Because of this, White Sands Missile Range personnel thought that it would be the most economical source of water for the Center; and that, if a suitable location for a supply well could be found, a pipeline could then be constructed from the well to the Center. A well capable of yielding 200 gpm for 8 hours per day of water in which neither sulfate nor chloride is in excess of 250 ppm (parts per million) was desired.

The Fish and Wildlife Service gave permission to White Sands Missile Range for test drilling and well development at any location east of the Rio Grande, and at agreed-upon locations at specified distances (at least 1,500 feet) from existing wells west of the Rio Grande.

The U. S. Geological Survey was asked by White Sands Missile Range to choose locations for test drilling in these restricted areas and to monitor drilling and testing of the wells. Test-drilling locations were further limited by construction considerations of pipeline length, access roads, and topography.

Seven test wells (fig. 2) were drilled before a suitable site was located where a supply well could be constructed to provide water to Stallion Range Center. Drilling was done under three separate contracts, which were completed in 1963, 1966, and 1967. This report summarizes the results obtained from the drilling and testing of these seven test wells; in particular it discusses the test drilling done in 1967 and states conclusions on the hydrology of the area as derived from all data available.

Previous Investigations

In 1955 and 1956, J. E. Weir, Jr., made a study of the geology and availability of ground water in the northern part of the White Sands Missile Range and vicinity. From this study he concluded that only small amounts of water of good to fair quality are present in the northern part of the Missile Range, and that large quantities of water of good chemical quality are present west of the river in the Rio Grande Valley (Weir, 1965, p. 50).

One test well (B-1 on fig. 2) was drilled in 1963 (Doty, 1968, p. 28) east of the Rio Grande. Potable water was found in this well to a depth of about 200 feet.

Three test wells (B-2, B-3, and B-4 on fig. 2) were drilled in 1966 (Cooper and Doty, 1966) to determine the extent of the potable water found in test well B-1. All of the test wells drilled in 1966 found saline water at depths of 100 and 250 feet. This indicated that further test drilling was needed to obtain a better understanding of the hydrology of the area.

Hydrology

The Rio Grande traverses an irregular course of about 10 miles from north to south through the eastern half of the Bosque del Apache Grant. In places it has been diverted from its original course by channel cut-offs and by dikes as part of a flood-control project of the Bureau of Reclamation. Throughout the length of the Grant a conveyance channel of 2,000 cubic feet per second capacity parallels the west side of the river and is separated from it by a dike. West of the conveyance channel, drains and surface-water diversions in canals criss-cross the waterfowl refuge over an area of 6 to 8 square miles.

The Rio Grande Valley is underlain by alluvial and flood-plain deposits that, in this area, are 50 feet or more thick. These deposits overlie sediments of the Santa Fe Group that are several thousands of feet thick. All these formations consist of clastic materials that range from coarse conglomerate and gravel to sand, silt, and clay. The formations commonly vary abruptly in composition, both laterally and vertically. Most of these sediments are permeable; however, the range of grain size causes a great variation in vertical and horizontal permeability. The availability of ground water is not a problem because of the permeable character of the material beneath the valley and the inflow of surface water into the area through the Rio Grande, the conveyance channel and the canals. Depth to water in wells is at, or within, a few feet of the surface over most of the area of the waterfowl refuge.

The chemical quality of the water in the waterfowl refuge, and throughout the Bosque del Apache Grant, is a major problem. Ground water that discharges into the Rio Grande Valley from the east is highly mineralized from contact with gypsiferous rocks of Permian age and carbonaceous rocks of Cretaceous age which crop out over a large area northeast of the Grant boundaries. Water that enters the valley from the west is of fair quality, as most of the rocks to the west, for many miles upstream from the refuge, are of volcanic origin; and few rocks with which the ground water comes into contact contain soluble minerals that impart salinity to the water.

The surface water that enters the area via the Rio Grande and the channels and canals is generally of fair chemical quality when its source is snowmelt or precipitation from drainage areas generally north of the latitude of Albuquerque. However, major tributaries on the west side of the Rio Grande south of the latitude of Albuquerque, such as the Rio Puerco and Rio Salado, can occasionally contribute large flows of water that have been in contact with rocks of Permian and Cretaceous age, and that water is saline.

Shallow water in the irrigated areas of the refuge generally is of poor chemical quality. The quality of the shallow ground water is believed to be mainly the result of continued irrigation and of the maintenance of ponded areas for wildfowl. These conditions, imposed upon the naturally shallow water table, cause some degree of waterlogging so that in topographically low areas water discharges at the surface where it evaporates and leaves deposits of mineral salts. During subsequent flooding of these low areas the salt residue is dissolved and can be re-circulated to the water table. Other factors that may contribute to the chemical deterioration of shallow ground water in the area are chemical fertilizers applied to agricultural lands and excrement from the many thousand of migratory wildfowl that winter in the area.

Existing high-yield wells

The Fish and Wildlife Service operates 12 high-yield wells for irrigation at the waterfowl refuge. (Fig. 2). The wells range in depth from 114 to 170 feet and are pumped at rates ranging from 660 to 2,170 gpm. All wells are believed to be artificially gravel packed. The chemical quality of the water from these wells ranges in specific conductance from 475 to 1,360 micromhos at 25°C; in sulfate from 74 to 314 ppm, and in chloride from 29 to 121 ppm.

Records of these wells are summarized in table 1. Table 2 lists partial chemical analyses of water from each well. Drillers' logs of some of the wells are given in table 3.

Test wells

The location of test well B-1 (fig. 2) was chosen with the dual objective of finding a source of potable water as near Stallion Range Center as possible and avoiding a costly pipeline crossing of the Rio Grande. Test wells B-2, B-3, and B-4 (fig. 2) were drilled to determine the areal and vertical extent of the potable water obtained from test well B-1; these wells penetrated saline water at a shallow depth within a distance of three quarters of a mile, or less, northeast, east, and south of test well B-1. The reservoir of potable water tapped by test well B-1 is small and therefore unlikely to provide a continuous supply of potable water to Stallion Range Center for a period of many years.

The record of test well B-1 is summarized in table 4 and chemical analyses of water samples from the well are given in table 5. Records of test wells B-2, B-3, and B-4 are given in tables 6, 7, and 8, respectively, and chemical analyses of water samples from the wells are given in table 12. Detailed data on testing procedures and geophysical logs for these test wells can be found in the report by Doty (1968) and the report by Cooper and Doty (1966).

Information from the first four test wells (B-1, B-4) and from the existing high-yield wells west of the Rio Grande, and from data on scattered stock wells in the area (Weir, 1965) suggested that continuous bodies of saline water extended westward to the edge of the channel of the Rio Grande and that fingers or wedges of saline water were present beneath at least a part of the river channel.

As the potable water aquifers in the area are apparently recharged by the Rio Grande, it was thought that a test well located on a topographically high area in the old channel of the Rio Grande should penetrate a considerable thickness of material saturated with potable water. A site for test well B-5 was chosen about a quarter mile due west of test well B-1, and slightly more than half a mile east of well number 12 of the Fish and Wildlife Service (fig. 2).

It was decided that if potable water in sufficient volume were found in test well B-5, test well B-6 about half a mile to the south would be drilled. If an adequate supply of potable water were obtained from test well B-6, a supply well would be constructed mid-way between the two test wells. Also it was decided that if either of these two test wells penetrated saline water at a shallow depth, a third test well would be drilled west of the Rio Grande.

Test well B-5

Test well B-5 was drilled to a depth of 512 feet and water samples were collected at approximate depths of 100, 250, and 500 feet. The hole penetrated sand and coarse gravel from depths of 50 to 95 feet, 120 to 140 feet, and 155 to 190 feet (table 9). Chemical analyses of water samples collected at 100 and at 250 feet indicated that the water was potable and that sulfate and chloride concentrations were well within the limits set by White Sands Missile Range. A water sample collected at a depth of 500 feet was saline and contained 955 ppm sulfate and 1,300 ppm chloride (table 10).

A dual-induction-laterolog (fig. 3) made in the hole indicated water of good chemical quality to a depth of 150 feet. From 150 to 190 feet the water was of good quality with thin zones of water of poorer quality at about 150 to 160 feet, at 164 feet, and near 190 feet. Between 240 and 330 feet the water was indicated to be of good to fair quality. Water of poor quality was indicated from 190 to 240 feet and from 330 to 512 feet.

A microlog (fig. 4) made in the hole indicated excellent formation porosity the full depth of the hole, except in thin zones where the clay content of the material increased. The intervals containing clay are better defined in the drillers' log than in the sample description log of the well (table 9).

Figure 3.--Dual induction-laterolog of test well B-5. (In pocket)

4.--Microlog of test well B-5. (In pocket)

Test hole B-5 was completed by casing with 8-inch pipe to a depth of 185 feet. The pipe was perforated with 1/8 x 2-inch mill-cut slots from 55 to 95 feet, 125 to 150 feet, and 160 to 170 feet. It was then bailed and surged for 26 hours with a bailer, jetted with compressed air for 10 hours, and surged and pumped with a turbine pump for 13 hours. At the end of this period the water was clear and no sand could be detected in water being discharged.

Following well development the water level in the well was allowed to recover to static level which was 13.65 feet below land surface. On May 26 the well was test pumped for 8 hours at an average rate of 300 gpm. The pumping level at the end of 8 hours was 32.96 feet. Thus, the drawdown in the well was 19.31 feet and the specific capacity of the well was 15.5 gallons per minute per foot of drawdown. When the pump was stopped the water level recovered rapidly and in 10 minutes was within 0.34 foot of the original static level. Recovery measurements were made periodically for 16 hours, at which time the water level was 0.05 foot above the original static level. Because of the well characteristics, rapid drawdown and recovery, and limitations of pump yield, the transmissibility of the formation could not be calculated with accuracy. Figure 5 is a graph of water level and pumping rate for test well B-5. The results of chemical analysis of a water sample collected near the end of test pumping is given in table 10. The summary record of the well is given in table 9.

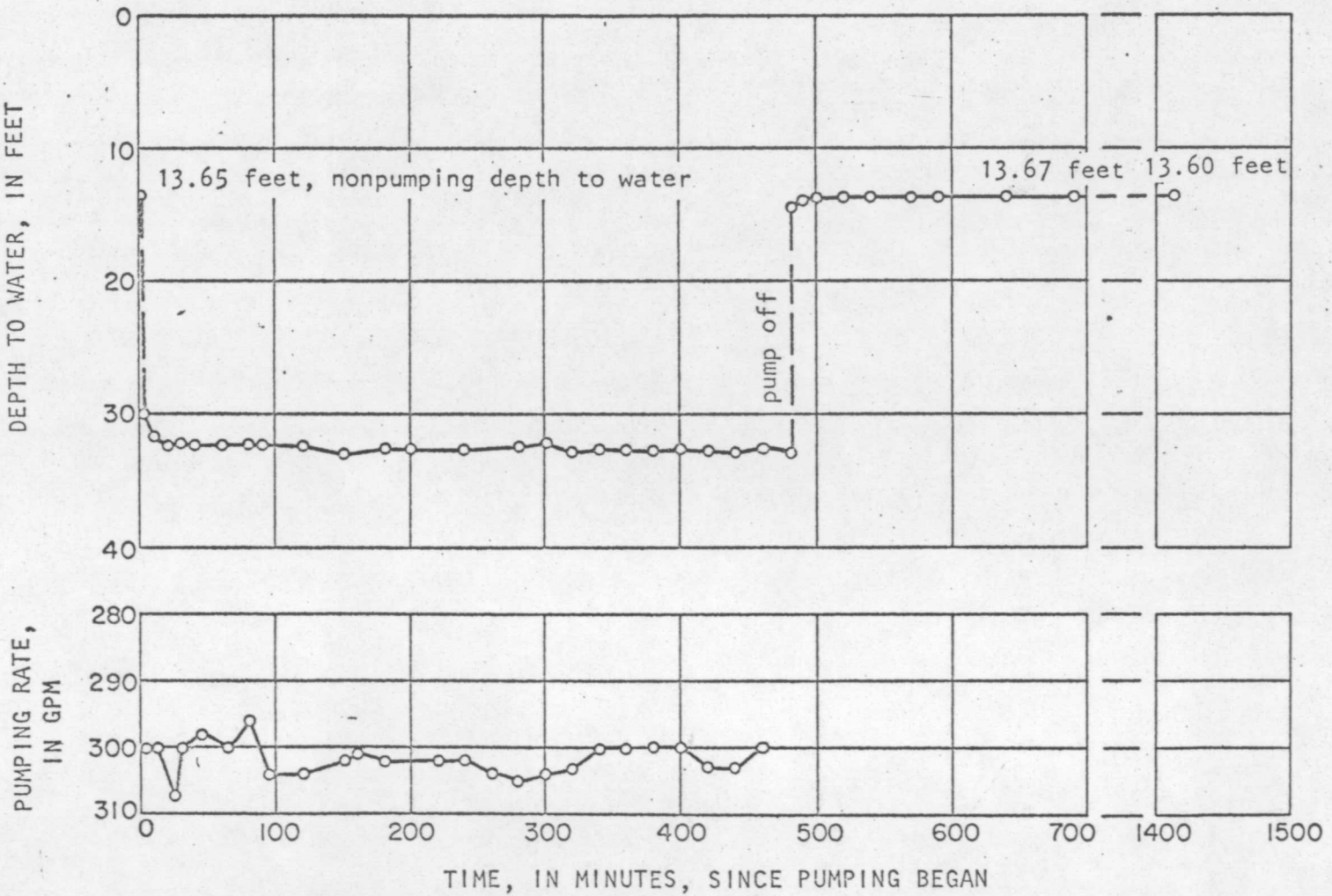

Figure 5.--Depth to water and pumping rate for test well B-5, May 26-27, 1967.

Test well B-6

Following successful completion of test well B-5 as a potable water well, an attempt to further define the limits of the potable water aquifer was made by drilling test well B-6 about half a mile to the south. It was drilled to a depth of 115 feet and a water sample was collected. The analysis (table 12) of the water sample indicated that the water contained a sulfate concentration of 960 ppm and a chloride concentration of 995 ppm. The well was plugged and abandoned. The summary record of test well B-6 is given in table 11.

Test well B-7

When the drilling and testing of test well B-6 indicated the presence of saline water at a relatively shallow depth it was decided to drill a test well west of the Rio Grande in, or near, the lands of the waterfowl refuge. The Fish and Wildlife Service gave approval for the well to be drilled at a site 1,800 feet northeast of well 12 and 2,900 feet southeast of well 11 (fig. 2) adjacent to the roadway along the conveyance channel. The site is 180 feet west of the center line of the conveyance channel and about 1,500 feet northwest of test well B-5.

Test well B-7 was drilled to a depth of 515 feet and water samples were collected at approximate depths of 100, 250, and 500 feet. The hole penetrated sand coarse gravel from depths of 48 to 102 feet and intermittent layers of gravel to a depth of 276 feet. (table 13). Chemical analyses of water samples collected at 100 feet contained 299 ppm sulfate and 137 ppm chloride, slightly above the maximum limit desired. The sample collected at 250 feet contained 127 ppm sulfate and 130 ppm chloride, well within the maximum limits. The sample collected at a depth of 500 feet was saline and contained 1,064 ppm sulfate and 1,410 ppm chloride (table 14).

A dual-induction-laterolog (fig. 6) made in the hole indicated water of good chemical quality to a depth of 80 feet, fair to poor quality from 80 to 165 feet, good quality 165 to 220 feet, poor quality 220 to 230 feet, good quality 230 to 255 feet, and water of poor quality from 255 to 515 feet.

Figure 6.--Dual induction-laterolog of test well B-7. (In pocket)

A microlog (fig. 7) made in the hole indicated excellent formation porosity to about 100 feet. From 100 to 515 feet the most permeable zones range from 2 to 20 feet in thickness and are separated by clay and sandy clay layers. See logs in table 3.

Test well B-7 was completed by casing with 8-inch pipe to a depth of 255 feet. The pipe was perforated with 1/8 x 2-inch mill-cut slots from 175 to 215 feet and from 235 to 250 feet. It was then bailed and surged for 12 hours with a bailer, jetted with compressed air for 8 hours, and surged and pumped with a turbine pump for 8 hours. At the end of this period the water was clear and no sand could be detected in water being discharged.

Following well development the water level in the well was allowed to recover to a static level which was 8.20 feet below land surface. On September 22 the well was test pumped for 8 hours at an average rate of 320 gpm. The pumping level at the end of 8 hours was 38.76 feet. Thus, the drawdown in the well was 30.56 feet and the specific capacity of the well was about 10.5 gallons per minute per foot of drawdown. When the pump was stopped the water level recovered rapidly and in 10 minutes was within 3.20 feet of the original static level. Recovery measurements were made periodically for 16 hours, at which time the water level was at 8.20 feet, the original static level. Because of the well characteristics, rapid drawdown and recovery, and limitations of pump yield, the transmissibility of the formation could not be calculated with accuracy.

Figure 7.--Microlog of test well B-7. (In pocket)

Figure 8 is a graph of water level and pumping rate for test well B-7. The chemical analysis of a water sample collected near the end of test pumping is given in table 14. The summary record of the well is given in table 13.

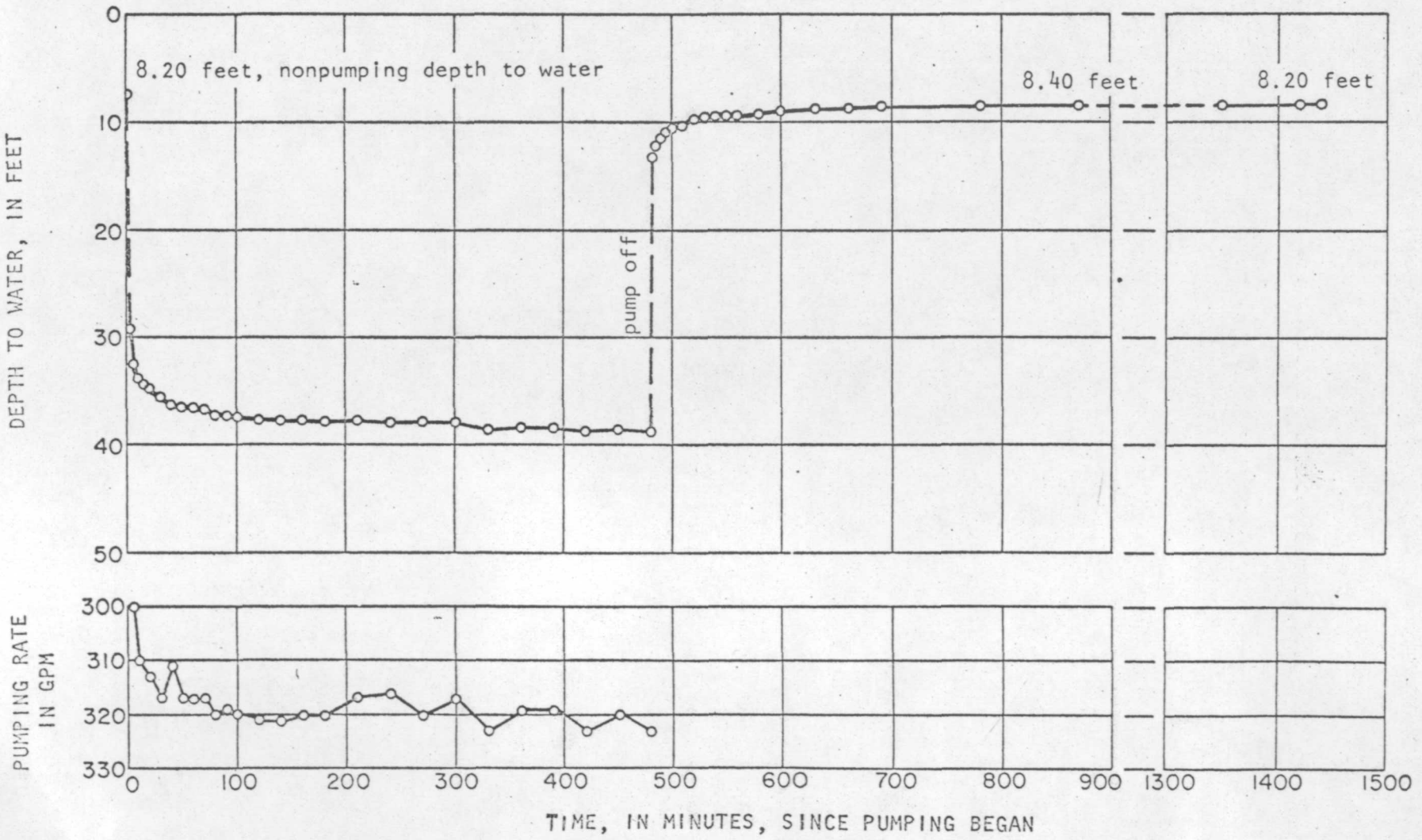

Figure 8.--Depth to water and pumping rate for test well B-7, September 22-23, 1967.

Water-level fluctuation

During the pumping and water-level recovery test made in test well B-7 on September 21-23, 1967, depth-to-water observations were made by recording gage in test well B-5 and by tape measurements at irregular intervals in well 12 of the Fish and Wildlife Service. The water level in test well B-5 showed no response to the drawdown of water level in the aquifer tapped by test well B-7. The water level in well 12 responded immediately, and shortly before the end of the pump test had lowered a total of 0.51 foot. The water level then responded to the cessation of pumping and by early morning of September 23 had recovered to its original static level.

Measurements made in the test well B-7 and well 12 are plotted on figure 9 and show the trend of the water level in the wells during the pumping test. Test well B-5 is 1,550 feet southeast of the pumped well and well 12 is 1,800 feet to the southwest.

Depth-to-water measurements have been made periodically in test well B-7 since shortly after its completion. The water level has risen gradually since the initial measurements, and in January 1968 was about one foot higher than in October 1967. During this same period daily mean gage-height records collected at two stations showed that the water level in the Rio Grande conveyance channel had risen about one and a half or two feet.

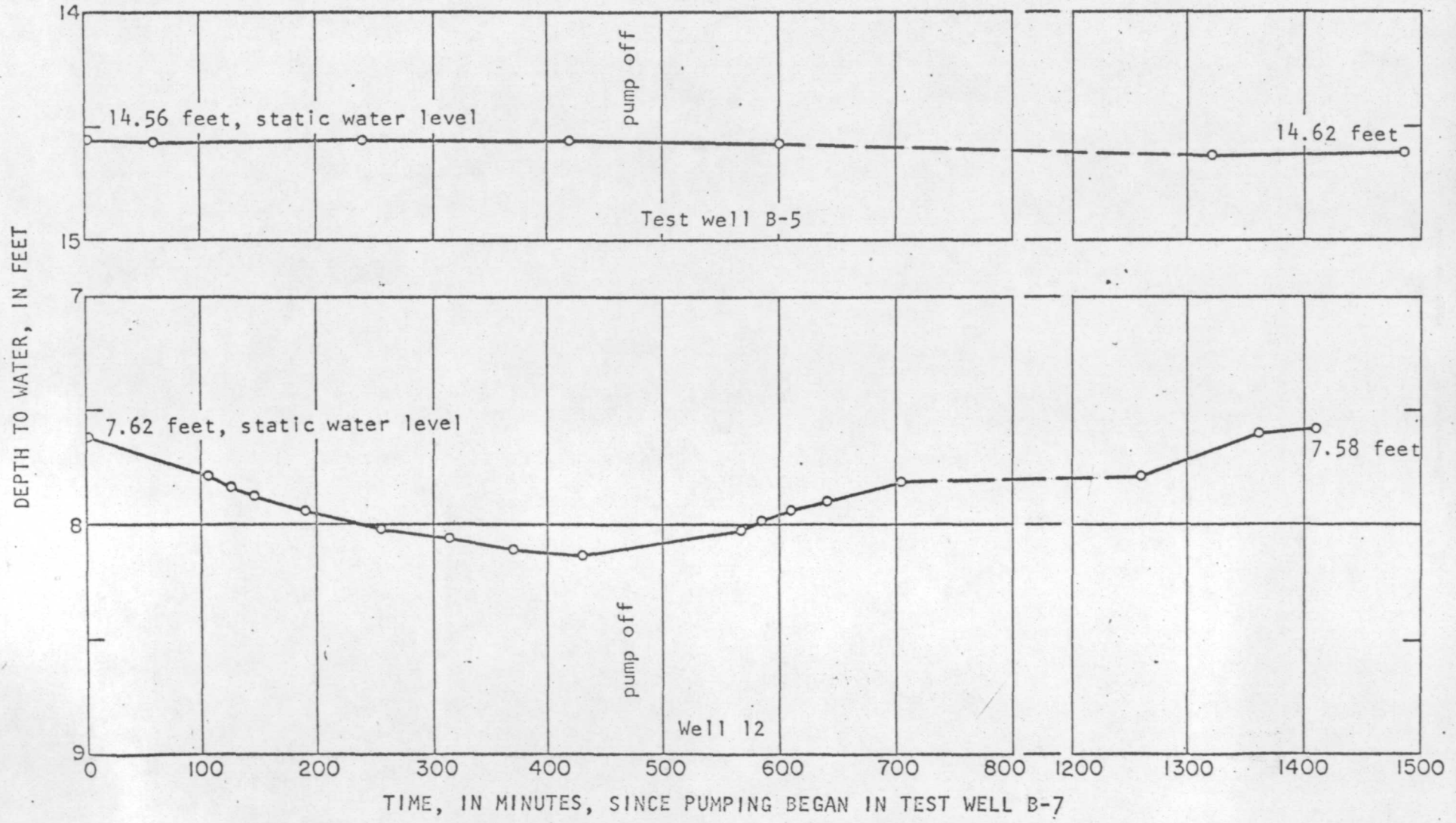

Figure 9.--Depth to water in test well B-5 and in well 12 during the pumping test on test well B-7, September 22-23, 1967.

Figure 10 is a graph showing the depth to water in test well B-7 and the daily mean gage-height of water level in the Rio Grande conveyance channel. The station at San Acacia is about 30 miles upstream from the well, and the station at San Marcial is about 10 miles downstream.

Examination of the graphs on figure 10 indicates a rather close correlation between the rise and decline of water level in the conveyance channel and the rise and decline of water level in test well B-7. The fluctuations of water level in the well are much less pronounced than are the fluctuations of water level in the channel. However, a slight decline of water level in the well about the middle of October 1967 is correlative with a decline of water level in the channel, and in November 1967, a rather abrupt rise of water in both the well and the channel is obvious. The abrupt decline of water level the first part of December 1967 in the channel is not reflected by water level in the well; the water level in the well continued to rise gradually and evenly from the end of November 1967 to near the end of February 1968.

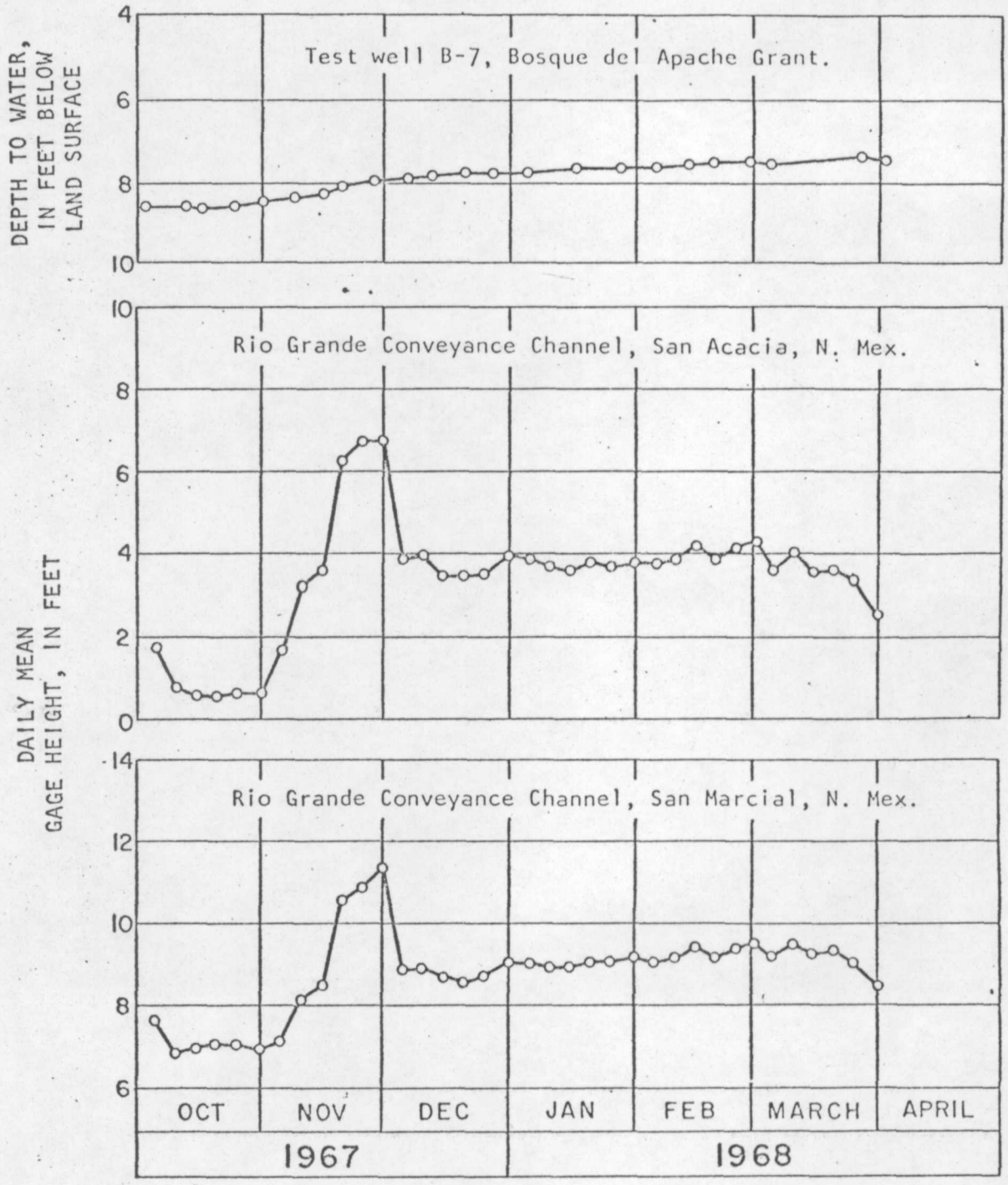

Figure 10.--Depth to water in test well B-7 and daily mean gage-height of water level in the Rio Grande Conveyance Channel.

Conclusions and summary

Test drilling on both sides of the Rio Grande in the Bosque del Apache Grant has shown that the area is hydrologically complex and that the quality of the ground water varies greatly both laterally and vertically within short distances. These relationships are illustrated on figure 11 which is a diagrammatic section across the Rio Grande.

Below a general depth of about 300 feet saline water is present at all sites where wells have been drilled this deep. This body of saline water is thought to be continuous in depth and to underlie large areas beneath and on both sides of the Rio Grande in the Bosque del Apache Grant. Its extent to the north and south has not been fully investigated.

At a depth of about 200 feet, in part of the area where test wells were drilled, a zone of potable to near-potable water 75 to 100 feet in thickness overlies the main body of saline water. This zone contains water of very good chemical quality west of the Rio Grande (test well B-7) and beneath the old channel of the Rio Grande (test well B-5). However, it contains near-potable water east of the Rio Grande (test well B-1) and is believed to merge with the main body of saline water at some point east of test well B-1 (fig. 11).

Above the lowermost body of potable water a zone of saline water 25 to 75 feet thick is present in test holes B-1, B-5, and B-7. This zone thickens eastward and merges with the main body of saline water (fig. 11).

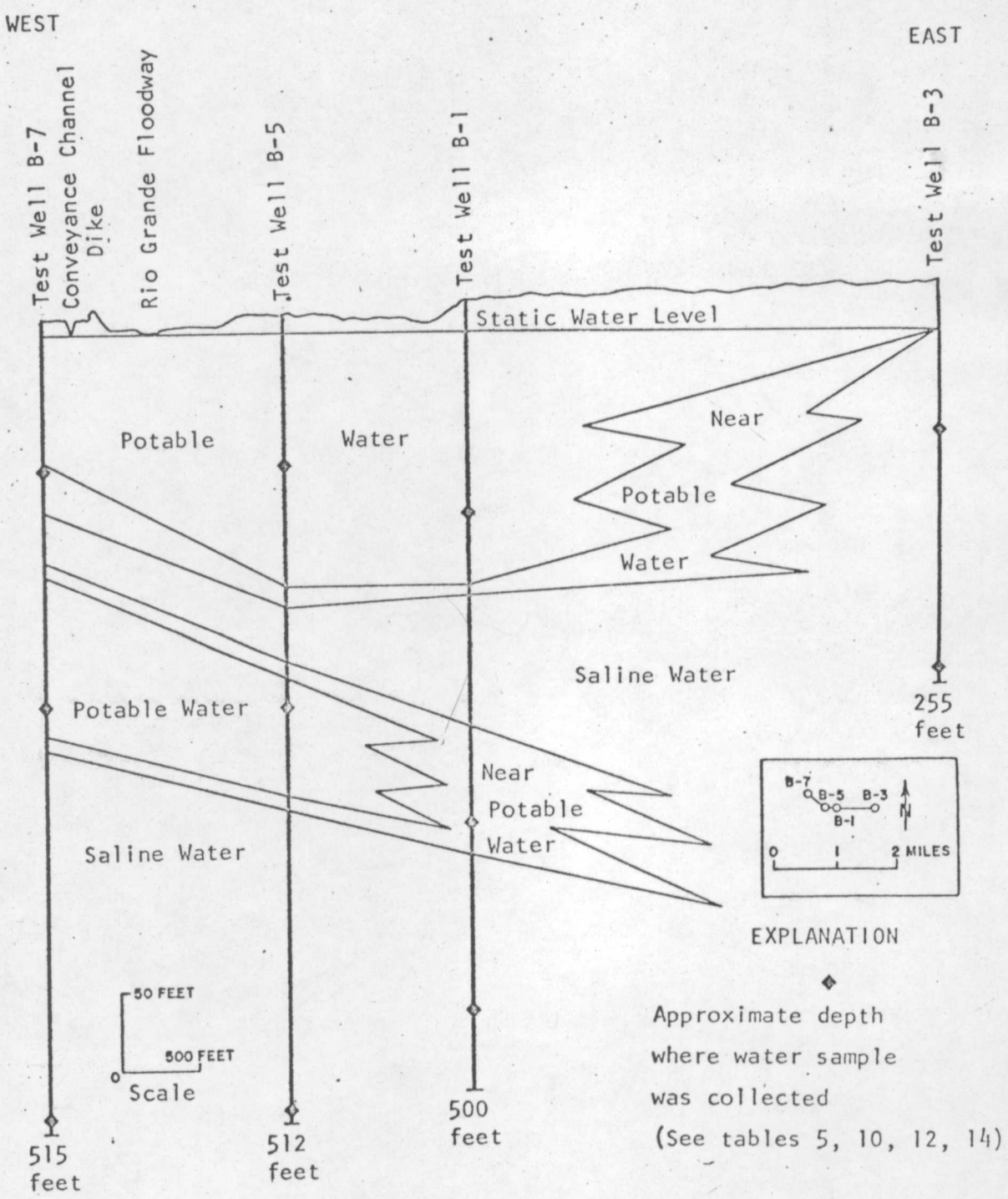

Figure 11.--Diagrammatic section across the Rio Grande in the Bosque del Apache Grant showing relation of ground water of different chemical quality.

Potable water is present to an approximate depth of 170 feet in test wells B-1 and B-5. This zone thins rapidly eastward, and in test well B-3 it is believed to be only a few feet thick, if present at all. It also thins rather abruptly westward and in test well B-7 may be only about 60 feet thick. Near-potable water apparently is present beneath the potable water and the uppermost zone of saline water as indicated by a water sample collected near 100 feet in test well B-7 (fig. 11).

The upper zone of potable water in test wells B-1, B-5, and B-7 no doubt receives direct recharge from the Rio Grande. The zone is thickest near the middle of the old channel of the river. The lower zone of potable water apparently is not recharged locally. It is thought to receive recharge at some point, perhaps several miles, upstream.

Though it appears that the upper zone of saline water is connected with the main body of saline water to the east, a possibility exists that it may not be directly recharged from this source. The geophysical logs and drilling logs of the test wells indicate the presence of clay beds 10 to 20 feet in thickness below a depth of 150 feet. The dual induction-laterologs made in test wells B-5 (fig. 3) and B-7 (fig. 6) and the induction-electrical log made in test well B-1 (Doty, 1968, p. 32) indicate that water in and near these clay beds is of very poor chemical quality. These clay beds probably are derived from formations of Permian and Cretaceous age, which crop out nearby, and contain gypsiferous material, which has not yet been flushed away by fresh water. Clay beds in the upper zone of potable water are not indicated to be associated with water of poor chemical quality. These upper clay beds are either derived from nongypsiferous source material or have been thoroughly flushed by fresh water.

Figure 12, which is a diagrammatic section from test well B-5, through several wells of the Fish and Wildlife Service, to well 7 at the northern end of the waterfowl refuge, shows the inferred lateral and vertical changes in the quality of the ground water in this area. Clay beds, logged in several of the wells, appear to be correlative and to be associated in most instances with saline or with near-potable water. The clay beds dip southward at gradients of from 20 to 40 feet per mile. This high angle of dip may possibly indicate deltaic conditions in this reach of the river valley at the time of deposition of the clay. The present gradient of the Rio Grande is about 5 feet per mile.

As the clay beds and intervening sand and gravel beds rise higher stratigraphically from south to north through the waterfowl refuge, the water yielded by the wells gradually becomes of better chemical quality. The clay bed near 150 feet in test well B-5, which is indicated to contain water of poor chemical quality, is cased out of the well and is not believed to have an effect upon water produced from the well. This clay bed, however, is not cased out of well 11. Water from well 11 is appreciably higher in sulfate than is water from other wells in the refuge; the clay bed is thought to be the source of sulfate. This clay bed continues northward and is also exposed in well 6; here, however, the bed is thinner and the top of the bed is some 40 feet higher than in well 11. Much of the sulfate probably has been flushed out of the clay bed by fresh water at the site of well 6, however, water moving through the clay bed still may contribute some of the sulfate contained in water from the well. The clay bed is cased out of well 4 and apparently rises to the land surface a short distance north of well 4.

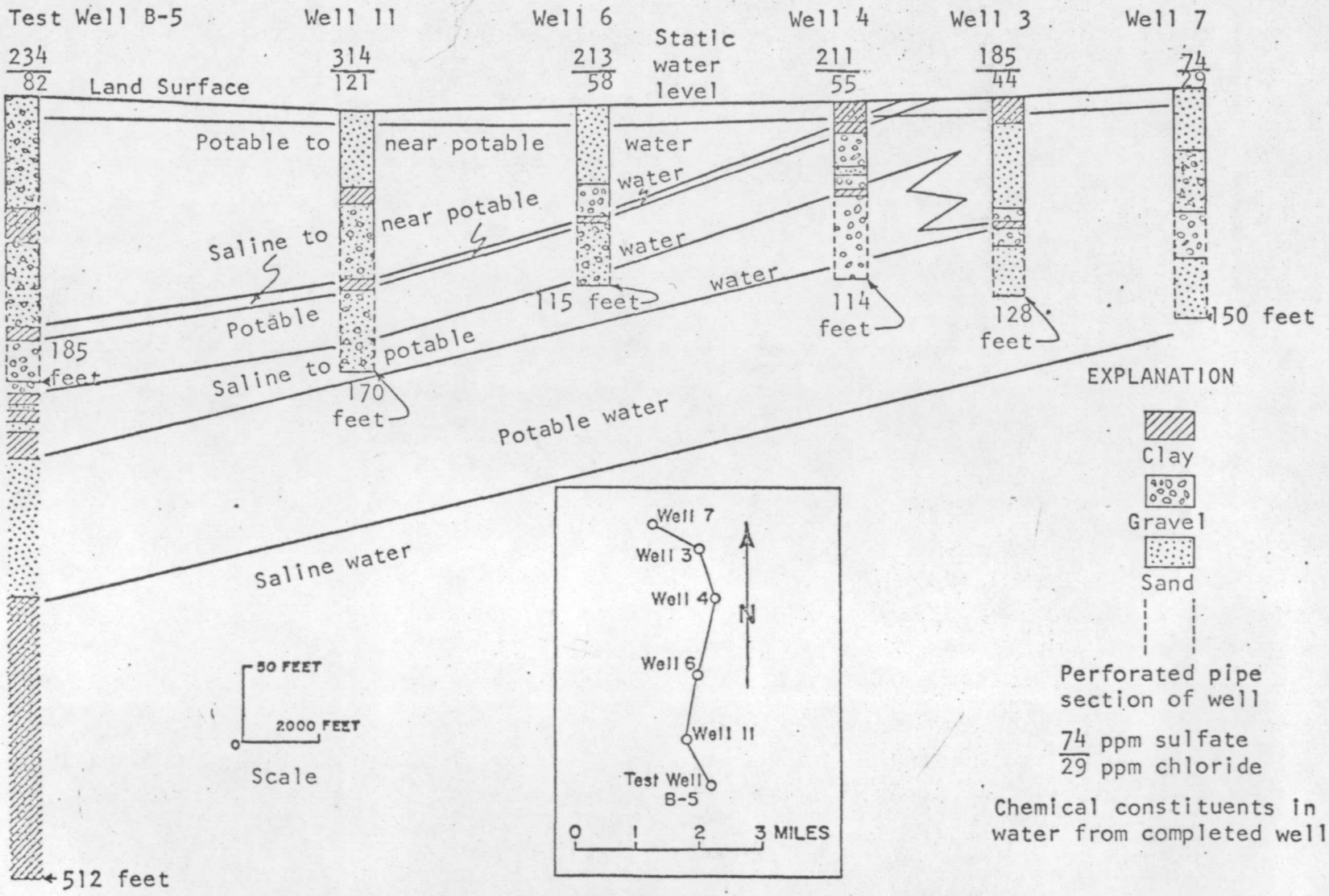

Figure 12.--Diagramatic section showing inferred lateral and vertical changes in the quality of the ground water in the Wildlife Refuge area of the Bosque del Apache Grant.

The clay beds from about 190 to 260 feet in test well B-5, which are indicated to contain water of very poor chemical quality, apparently are absent, or were not logged, in the bottom of well 11 and well 6. In well 4 and well 3 thin clay beds that are inferred to be correlative were present. The clay bed is reported to be cased out of well 4, however, the clay bed may be contributing to the sulfate in the water from the well. The clay bed is exposed in well 3 where it may contribute some sulfate to the water. In well 7 no clay was logged.

The clay beds may also be aquicludes, at least in parts of the area, and prevent or retard the movement of water between beds of sand and gravel. The lower zone of potable water tapped by test well B-7 is under sufficient artesian head to cause the level of the water to rise to about 8 feet below the land surface. (fig. 11). The aquifer tapped in the well is at depths of about 170 feet to 260 feet.

Results of the pumping test on test well B-7 and observations of water level in test well B-5 and in well 12 (fig. 9) indicate that the aquifer tapped by test well B-7 is artesian and is separated from the uppermost zone of potable water. The log of well 12 (table 3) and the chemical quality of water yielded by the well (table 2) indicate that it taps the lower zone of potable water. Test well B-5 (table 9) taps the upper zone of potable water. Water in the upper zone occurs under water-table conditions, or under local artesian conditions.

The correlation of fluctuations of water level in test well B-7 and water level in the Rio Grande conveyance channel (fig. 10) indicate that the surface water in the channel is in contact at some point with the aquifer containing the potable water in the test well. The response of water level in the test well to water in the channel is a pressure response caused by the loading effect of the surface water upon the outcrop of the aquifer. (Ferris and others, 1962, p. 85). Figure 12 indicates that this condition may occur near the north line of the refuge in the vicinity of wells 3 and 7 where the aquifer is believed to be near the land surface.

The principal source of recharge for the upper zone of potable and near-potable water in wells 11, 6, and 4, and test well B-5 is thought to be the Rio Grande and canals in the vicinity of the wells. Well 3 may also receive recharge from these sources. Some of the recharge to well 7 may be from canals, however, the chemical quality of the water from well 7 (74 ppm sulfate and 29 ppm chloride) indicates that it may receive major recharge from another source. This source is suggested to be surface drainage from the west. The largest surface drainage course on the west side of the Rio Grande in this area terminates in the general vicinity of well 7. This drainage course heads 7 to 8 miles west of well 7 at an altitude 1,300 feet higher than well 7, where granitic rocks of Precambrian age and volcanic rocks of Tertiary age crop out over a large area. The drainage course is ephemeral; however, flash floods from precipitation in the higher altitudes occasionally cause considerable volumes of water to reach the vicinity of well 7.

The water that recharges well 7 also is thought to recharge the lowermost zone of potable water that was found in the test wells--it may also add recharge to well 3 and to the lower part of the upper potable water zone in wells 4, 6, and 11 and test well B-5 (fig. 12).

The lowermost potable water zone in the area tested and from there northward, at least as far as well 7, is thought to be the best aquifer in the waterfowl refuge area in which to construct a well for a permanent supply of water for Stallion Range Center. In test wells B-5 and B-7 this aquifer contained the best chemical quality of water sampled in the wells (tables 10 and 14). In test well B-7 the aquifer has high permeability (fig. 6) and is capable of yielding more than 300 gpm at a specific capacity of 10.5 gallons per minute of water per foot of water-level drawdown (table 13). The aquifer apparently has an adequate source of recharge of water of good quality by surface-water runoff and from canals. The recharge area is near the northern end of the waterfowl refuge where the near-surface water is less likely to be contaminated. Probably no more than 4 or 5 of the high-yield wells of the Fish and Wildlife Service tap the aquifer.

The lateral extent of the potable water in the aquifer is not known, except that between test well B-5 and test well B-1, the quality deteriorates. Apparently the potable water in the aquifer extends at least for a mile from west to east at the northern end of the refuge as water from wells 1, 2, and 7 (fig. 2 and table 2) is of good chemical quality. It also extends at least a distance of from 5 to 6 miles northward from test well 5. The aquifer probably averages 100 feet in thickness. Thus, the apparent volume of aquifer thought to contain potable water is at least 320,000 acre feet or nearly 3 billion cubic feet. If the aquifer has a porosity of 20 percent about 5 billion gallons of potable water is now in storage in the aquifer.

The anticipated volume of water needed to supply Stallion Range Center is 200 gpm for 8 hours per day. Thus, over a period of 20 years the total volume of water withdrawn from the aquifer would amount to only about three-quarters of a billion gallons. It has been calculated that this amount of water could be supplied from an aquifer having a thickness of 100 feet, a porosity of 20 per cent, and a radius of slightly over 1,200 feet.

Little doubt exists that potable water is present in sufficient quantities in the waterfowl refuge area west of the Rio Grande and east of the managed lands of the refuge to supply the needs of Stallion Range Center for many tens of years in the future. It is possible that an individual well may, after several years of use, begin to yield water of undesirable chemical quality and need to be abandoned. However, continuous production of potable water could be assured by constructing one or more wells, in areas underlain by potable water, in advance of actual need.

It is recommended that a well to supply Stallion Range Center with 200 gpm per 8 hour day of potable water be drilled approximately 3,700 feet north of test well B-7 in the SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 5, T.6 S., R. 1 E. (projected section, fig. 2) The anticipated depth of the well is 250 feet.

A supply well at this location would be located outside the managed lands of the waterfowl refuge and at a distance of more than 1,500 feet from the nearest well on the refuge. Only minor modifications in the planned pipeline construction would be required. Access to the well would be excellent as the site is adjacent to the roadway along the conveyance channel.

References

Cooper, J. B., and Doty, G. C., 1966, Test wells east of the Rio Grande, Bosque del Apache Grant, Socorro County, New Mexico: U. S. Geol. Survey open-file rept., 26 p., 5 figs.

Doty, G. C., 1968, Bosque del Apache Area, in Summary of test wells drilled by White Sands Missile Range from June 1962 to January 1965: U. S. Geol. Survey open-file rept., p. 28-39, 3 figs.

Ferris, J. G.; Knowles, D. B.; Brown, R. H.; and Stallman, R. W., 1962, Theory of aquifer tests: U. S. Geol. Survey Water-Supply Paper 1536-E, 174 p., 45 figs.

Weir, J. E., Jr., 1965, Geology and availability of ground water in the northern part of the White Sands Missile Range and vicinity, New Mexico: U. S. Geol. Survey Water-Supply Paper 1801, 78 p., 11 figs.

BASIC DATA

Table 1.-- Records of high-yield wells of the Fish and Wildlife Service at the Bosque del Apache National Wildlife Refuge, Socorro County, N. Mex.

Well number: Number assigned to the well by the Fish and Wildlife Service.
Location: From San Antonio, N. Mex., 1:62500, U.S.G.S. topographic quadrangle (projected sections). All wells are in T. 5 S., R. 1 E.
Depth and water levels: Reported depths, given to nearest foot below land surface.
Diameter: Outside diameter of casing.

Well Number	Location	Depth (feet)	Diameter (inches)	Casing perforations (Depth, in feet)		Pump-test data					
				From	To	Yield (gpm)	Nonpumping water level (feet)	Pumping Water level (feet)	Time pumped (hours)	Date	Driller
1	SE¼ SW¼ SE¼ sec. 18	149	-	-	-	1,350	-	-	-	-	-
2	SE¼ SE¼ SW¼ sec. 17	125	-	-	-	1,125	-	-	-	-	-
3	NW¼ SE¼ NE¼ sec. 20	128	14	77	127	1,420	12	80	6	8-6-58	Oliver and Houston Drlg. Co.
4	NW¼ NW¼ NW¼ sec. 28	114	14	63	113	1,050	10	82	6	7-26-58	Do.
5	NW¼ SW¼ SW¼ sec. 28	115	14	-	-	660	11	80	15.5	7-24-58	Do.
6	SE¼ NW¼ NE¼ sec. 32	115	14	64	114	1,150	13	80	6.5	7-17-58	Do.
7	SW¼ SW¼ SW¼ sec. 17	150	16	76	150	1,750	12	67	5	7-14-60	E. L. Brawley
8	NE¼ SE¼ SW¼ sec. 20	142	16	70	142	1,800	9	66	8	6-23-60	Do.
9	SW¼ NE¼ NE¼ sec. 30	142	16	70	142	1,730	10	50	8	7-10-60	Do.
10	NE¼ SE¼ SW¼ sec. 29	142	16	70	142	1,820	8	58	8	7-4-60	Do.
11	SW¼ SW¼ NE¼ sec. 5	170	16	80	170	2,000	8	59	8	6-2-61	Boyd and Son Drlg. Co.
12	SW¼ NE¼ NW¼ sec. 8	150	16	72	150	2,170	3	61	6	6-12-61	Do.

Table 2.--Partial chemical analyses of water samples from high-yield wells of the Fish and Wildlife Service at the Bosque del Apache National Wildlife Refuge, Socorro County, N. Mex.

(Analyses by the U. S. Geological Survey. Chemical constituents are in parts per million)

Well Number: Number assigned to the wells by the Fish and Wildlife Service

Well Number	Date Collected	Specific Conductance (Micromhos at 25° C)	Sulfate	Chloride
1	8-10-66	883	182	67
2	8-10-66	735	79	108
3	8-10-66	817	185	44
4	8-10-66	888	211	55
5	8-10-66	923	219	50
6	8-10-66	914	213	58
7	8-10-66	475	74	29
8	8-10-66	614	105	48
9	8-10-66	1,340	285	83
10	8-23-66	1,290	290	108
11	8-10-66	1,360	314	121
12	8-23-66	716	91	71

Table 3.--Drillers' logs of high-yield wells of the Fish and Wildlife Service at the Bosque del Apache National Wildlife Refuge, Socorro County, N. Mex.

Well number: Number assigned to the well by the Fish and Wildlife Service

Material	Depth interval (feet)	
Well number 3		
NW¼ SE¼ NE¼ sec. 20, T. 5 S., R. 1 E.		
Topsoil	0	6
Sand	6	14
Gumbo	14	17
Sand	17	71
Boulders	71	76
Coarse sand	76	79
Clay	79	82
Fine gravel	82	94
Boulders	94	96
Coarse sand	96	128
Well number 4		
NW¼ NW¼ NW¼ sec. 28, T. 5 S., R. 1 E.		
Topsoil	0	6
Clay	6	12
Black gumbo	12	19
Coarse gravel	19	41
Gumbo	41	47
Fine gravel	47	56
Clay	56	61
Fine gravel	61	114
Well number 6		
SE¼ NW¼ NE¼ sec. 32, T. 5 S., R. 1 E.		
Topsoil	0	8
Sand	8	47
Gravel	47	71
Clay	71	74
Gravel and sand	74	115
Well number 7		
SW¼ SW¼ SW¼ sec. 17, T. 5 S., R. 1 E.		
Topsoil	0	3
Sand	3	40
Sand and gravel	40	79
Gravel	79	110
Sand	110	150

Table 3.--Drillers' logs of high-yield wells of the Fish and Wildlife Service at the Bosque del Apache National Wildlife Refuge, Socorro County, N. Mex. - Concluded

Well number: Number assigned to the well by the Fish and Wildlife Service

Material	Depth interval (feet)	
Well number 8		
NE¼ SE¼ SW¼ sec. 20, T. 5 S., R. 1 E.		
Topsoil	0	2
Sand	2	4
Clay	4	5
Fine sand	5	15
Sand and gravel	15	41
Big gravel	41	51
Sand and gravel	51	142
Well number 9		
SW¼ NE¼ NE¼ sec. 30, T. 5 S., R. 1 E.		
Topsoil	0	7
Sand	7	70
Sand and gravel	70	90
Coarse gravel	90	142
Well number 10		
NE¼ SE¼ SW¼ sec. 29, T. 5 S., R. 1 E.		
Topsoil	0	3
Sand	3	60
Sand and gravel	60	142
Well number 11		
SW¼ SW¼ NE¼ sec. 5, T. 5 S., R. 1 E.		
Fine sand and mud, blue	0	47
Clay, yellow	47	60
Sand and gravel, brown	60	108
Clay, yellow	108	117
Large boulders and gravel, brown	117	170
Well number 12		
SW¼ NE¼ NW¼ sec. 8, T. 5 S., R. 1 E.		
Mud and sand, blue	0	56
Clay, yellow	56	86
Gravel, brown	86	150

Table 4.--Record of test well B-1

Location: NW¼NW¼NW¼ sec. 9, T. 6 S., R. 1 E., (projected section) Bosque del Apache Grant, Socorro County, N. Mex.

Altitude: Land-surface altitude 4,530 feet (interpolated from USGS topographic map).

Depth: Drilled to 500 feet, finished at 167 feet.

Date drilled: November 5-15, 1963

Drilling contractor: Layne Texas Co., Inc., El Paso, Texas

Drilling method: Hydraulic rotary.

Well record: Drilled to 500 feet with 9 7/8-inch diameter bit. Cased to 500 feet with 6-inch pipe perforated with 1/8 x 4-inch milled slots from 100 to 160, 320 to 340, and 440 to 460 feet. Well backfilled to 167 feet after sampling lower zones by air jetting beneath a packer; packer seized in casing at 271 feet with three 30-foot lengths of 4-inch pipe attached and could not be pulled; well was not developed by bailing because sand ran into casing.

Yield: The well was pumped at 150 gpm for 8 hours with 37 feet of drawdown. Nonpumping depth to water 20.65 feet below land surface.

Water samples: See table 5.

Completion record: Concrete slab 4-foot square by 1-foot thick centered around casing. Top of casing is fitted with a hinged metal cover to permit water-level measurement.

Table 4.-- Record of test well B-1 - Concluded

Sample-description log: (samples described by G. C. Doty)

Material	Depth interval (feet)	
Sand, tan, very fine	0	11
Gravel, pebble to cobble, well rounded, and very fine sand	11	41
Gravel and sand as in interval 11-41 and some clay	41	68
Gravel, pebble, well-rounded, and very fine to very coarse sand	68	113
Sand, gray, very fine to very coarse, and pebble gravel; small percentage of clay	113	173
Gravel and sand, as in interval 113-173	173	200
Gravel and sand, as in interval 113-173, with an increased percentage of clay	200	205
Clay, sandy, and pebble gravel	205	245
Gravel, sandy, clayey	245	255
Clay, gravel, and sandy clay	255	265
Clay, and hard layers of gravel	265	325
Sand, gray, very fine to very coarse, tan to gray-green clay, and some granule to pebble gravel, in thin beds	325	340
Clay, with thin interbeds of sand and gravel	340	365
Sand, gravel, and clay in thin beds	365	380
Clay, and sand, some gravel	380	385
Sand, gravel and clay	385	445
Clay, gravel and sand	445	500

Table 5.--Results of chemical analyses of water samples from test well B-1

Analyses by Geological Survey, United States Department of the Interior
(parts per million)

36631

	2/	3/	4/	5/		
Date of collection	11/12/63	11/13/63	11/15/63	6/17/66		
Silica (SiO_2)	-	-	35	-		
Iron (Fe), dissolved 1/	-	-	.11	-		
Iron (Fe), total	-	-	-	-		
Manganese (Mn), dissolved 1/	-	-	-	-		
Manganese (Mn), total	-	-	-	-		
Calcium (Ca)	-	-	6.4	-		
Magnesium (Mg)	-	-	1.5	-		
Sodium (Na)	-	-	230	-		
Potassium (K)	-	-	8.3	-		
Bicarbonate (HCO_3)	-	-	230	-		
Carbonate (CO_3)	-	-	0	-		
Sulfate (SO_4)	704	258	245	240		
Chloride (Cl)	905	236	56	55		
Fluoride (F)	-	-	1.4	-		
Nitrate (NO_3)	-	-	.2	-		
Dissolved solids						
Sum	-	-	697	-		
Residue on evaporation at 180°C	-	-	-	-		
Hardness as $CaCO_3$	-	-	22	-		
Non-carbonate	-	-	0	-		
Specific conductance (micromhos at 25°C)	4,350	1,620	1,060	1,050		
pH	-	-	8.1	-		
Color	-	-	-	-		

1/In solution at time of analysis.
2/ Collected through packer from depths of 440-462 feet.
3/ Collected through packer from depths of 320-340 feet.
4/ Collected during aquifer pump-test on completed well.
5/ Collected from pump on well.

Table 6.--Record of test well B-2

Location: SE¼NW¼SE¼ sec. 4, T. 6 S., R. 1 E., (projected section) Bosque del Apache Grant, Socorro County, N. Mex.

Altitude: Land-surface altitude 4,540 feet (interpolated from USGS topographic map).

Depth: Drilled to 255 feet (plugged and abandoned)

Date drilled: June 3-20, 1966.

Drilling Contractor: Layne-Texas Co., Inc., El Paso, Texas.

Drilling method: Hydraulic rotary.

Well record: To collect water sample from 104 to 130 feet with a collapsible rubber packer the hole was drilled to 130 feet with a 6 3/4-inch bit, then reamed to 85 feet with a 10½-inch bit. To collect a water sample from 227 to 255 feet the hole was drilled to 255 feet with a 6 3/4-inch bit, then reamed to 220 feet with a 10½-inch bit.

Water samples: Water samples were collected during drilling by expanding a rubber packer against the walls of the hole and air-jetting through a 1-inch pipe, inside a 4-inch pipe which was attached to the packer. A torch-slotted 3-inch pipe 11-feet long was in place at the bottom of the hole and was attached to the packer with blank pipe. The water sample from 104 to 130 feet was collected after jetting water at a rate of 10 gpm for 1½ hours. The water sample from 227 to 255 feet was collected after jetting water at rate of 8 gpm for 2¼ hours. (See table 12)

Table 6.--Record of test well B-2 - Continued

Water level: Depth-to-water below land surface, measured through packer pipe, after 20 minute recovery period when the hole was 130 feet deep, was 26.10 feet. Depth-to-water below land surface, measured through packer pipe, after 25 minutes recovery period when the hole was 255 feet deep, was 25.57 feet.

Completion record: The hole was filled with 10 pound, 80 viscosity drilling mud. The upper 40 feet of hole was filled with heavy drill cuttings and the drill site was levelled with a bulldozer.

Table 6.--Record of test well B-2 - Concluded

Drillers log:

Material	Depth interval (feet)	
Fine sand	0	3
Fine gravel and coarse sand streaks	3	17
Coarse sand	17	28
Coarse gravel and clay	28	35
Fine sand	35	40
Fine gravel and sand	40	45
Hard coarse gravel	45	50
Gravel and sand	50	63
Coarse gravel and clay streaks	63	70
Coarse sand and layers gravel	70	85
Coarse sand	85	90
Coarse sand and fine gravel	90	120
Fine gravel and sand with clay streaks	120	130
Coarse sand	130	135
Fine gravel and sand	135	150
Coarse sand and gravel	150	180
Gravel and sand	180	190
Coarse sand and clay streaks	190	195
Clay and gravel	195	200
Gravel and sand and clay streaks	200	211
Clay and gravel layers	211	225
Coarse sand and gravel	225	255

Table 7.--Record of test well B-3

Location: NE¼NW¼NE¼ sec. 9, T. 6 S., R. 1 E., (projected section) Bosque del Apache Grant, Socorro County, N. Mex.

Altitude: Land-surface altitude 4,540 feet (interpolated from USGS topographic map).

Depth: Drilled to 255 feet. (plugged and abandoned).

Date drilled: June 22-29, 1966

Drilling contractor: Layne-Texas Co., Inc., El Paso, Texas.

Drilling method: Hydraulic rotary.

Well record: To collect a water sample from 71 to 100 feet with a collapsible rubber packer the hole was drilled to 100 feet with a 6 3/4-inch bit, then reamed to 68 feet with a 10½-inch bit. To collect a water sample from 225-255 feet the hole was drilled to 255 feet with a 6 3/4-inch bit, then reamed to 218 feet with a 10½-inch bit.

Water samples: Water samples were collected during drilling by expanding a rubber packer against the walls of the hole and air-jetting through a 1-inch pipe, inside a 4-inch pipe which was attached to the packer. A torch-slotted 3-inch pipe 11-feet long was in place at the bottom of the hole and was attached to the packer with blank pipe. The water sample from 71 to 100 feet was collected after jetting water at a rate of 5 gpm for 2 hours. The water sample from 225 to 255 feet was collected after jetting water at rate of 4 gpm for 1¼ hours. (See table 12)

Table 7.--Record of test well B-3 --Continued

Water level: Depth-to-water below land surface, measured through packer pipe, after 25 minute recovery period when the hole was 100 feet deep, was 30.55 feet. Depth-to-water below land surface, measured through packer pipe, after 25 minute recovery period when the hole was 255 feet deep was 41.20 feet.

Completion record: The hole was filled with 10 pound, 80 viscosity drilling mud. The upper 40 feet of the hole was filled with heavy drill cuttings and the drill site was levelled with a bull-dozer.

Table 7.--Record of test well B-3 -- Concluded

Drillers log:

Material	Depth interval (feet)	
Sand	0	8
Sand and gravel	8	16
Gravel and a few cobbles	16	20
Coarse gravel	20	34
Gravel and clay	34	40
Gravel and sand	40	50
Coarse gravel and sand	50	66
Gray clay	66	72
Coarse sand and a few clay streaks	72	85
Coarse sand and fine gravel	85	100
Coarse sand	100	102
Clay	102	105
Coarse sand and fine gravel	105	116
Fine gravel and coarse sand	116	135
Sand and gravel and a few clay streaks	135	150
Coarse sand	150	162
Fine gravel and coarse sand	162	180
Coarse sand and a few clay streaks	180	198
Gravel and clay	198	200
Coarse sand and fine gravel	200	207
Sand and gravel - clay layers	207	215
Sand and clay streaks	215	234
Clay	234	236
Coarse sand and clay streaks	236	244
Coarse sand	244	255

Table 8.--Record of test well B-4

Location: SW¼SW¼SW¼ sec. 9, T. 6 S., R. 1 E. (projected section) Bosque del Apache Grant, Socorro County, N. Mex.

Altitude: Land-surface altitude 4,510 feet (interpolated from USGS topographic map).

Depth: Drilled to 256 feet (plugged and abandoned).

Date drilled: July 6-13, 1966.

Drilling contractor: Layne-Texas Co., El Paso, Texas.

Drilling method: Hydraulic rotary.

Well record: To collect a water sample from 91 to 102 feet with a collapsible rubber packer the hole was drilled to 102 feet with a 6 3/4-inch bit, then reamed to 68 feet with a 10½-inch bit. To collect a water sample from 237 to 252 feet the hole was drilled to 256 feet with a 6 3/4-inch bit, then reamed to 218 feet with a 10½-inch bit.

Water samples: Water samples were collected during drilling by expanding a rubber packer against the walls of the hole and air-jetting through a 1-inch pipe, inside a 4-inch pipe which was attached to the packer. A torch-slotted 3-inch pipe 11 feet long was in place at the bottom of the hole and was attached to the packer with blank pipe. The water sample from 91 to 102 feet was collected after jetting water at an average rate of about 1 gpm for 3 hours. An additional 4 feet of slotted pipe was used in collecting the sample from 237 to 252 feet, which was collected after jetting 3 gpm for 2½ hours (See table 12).

Table 8.--Record of test well B-4 - Continued

Water level: Depth-to-water below land surface, measured through the packer pipe, after 80 minutes recovery period when the hole was 102 feet deep was 12.3 feet. Depth-to-water below land surface, measured through the packer pipe after 60 minute recovery period, when the hole was 256 feet deep was 10.8 feet.

Completion record: The hole was filled with 10 pound, 80 viscosity drilling mud. The upper 40 feet of the hole was filled with heavy drill cuttings and the drill site was levelled with a bulldozer.

Table 8.--Record of test well B-4 - Concluded

Drillers log:

Material	Depth interval (feet)	
Sand	0	5
Sandy clay	5	7
Sand and gravel	7	21
Clay	21	27
Coarse gravel and sand	27	50
Sand and gravel; few streaks of clay	50	85
Coarse sand and fine gravel	85	100
Coarse sand	100	110
Coarse sand and fine gravel	110	149
Coarse sand and fine gravel; few streaks of clay	149	155
Coarse sand and fine gravel	155	189
Sand, gravel, and layers of clay	189	200
Coarse sand and fine gravel	200	244
Layers of rock	244	244.5
Sand and streaks of clay	244.5	256

Table 9.--Record of test well B-5

Location: SW¼NE¼NE¼ sec. 8, T. 6 S., R. 1 E. (projected section) Bosque del Apache Grant, Socorro County, N. Mex.

Altitude: Land-surface altitude 4,523 feet (established by instrument levelling from interpolated altitude of 4,530 feet at test well B-1).

Depth: Drilled to 512 feet, completed at 185 feet.

Date drilled: April 17 to May 26, 1967.

Drilling contractor: Layne Texas Co., Inc., El Paso, Texas

Drilling method: Hydraulic rotary

Well record: The hole was drilled to 455 feet; with a 12½-inch bit; a 6 5/8-inch hole was drilled from 455 to 512 feet. A cement plug was placed in the hole from 185 to 205 feet; the hole below the cement plug was filled with drilling mud. Hole was cased to 185 feet with 8 5/8-inch O. D. standard plain-end line pipe with welded joints, perforated with 1/8 x 2-inch mill-cut slots (32 slots per foot around pipe) as follows: 55 to 95 feet, 125 to 150 feet, and 160 to 170 feet. Canvas-wrap packer placed around pipe near 55 feet. The well was bailed and surged for 26 hours with bailer and sand pump. It was then surged and pumped with air jet (2-inch pipe inside 4-inch pipe) for 10 hours and surged and pumped with a turbine pump with 8-inch bowls (tailpipe set at 113 feet below surface) at rates up to 400 gpm for 13 hours.

Yield: The well was test pumped for 8 hours on May 26, 1967. Static water level, below land surface, was 13.65 feet; pumping level at end of 8 hours was 32.96 feet at a pumping rate of 300 gpm. Specific capacity of the well is about 15 gallons per foot of drawdown.

Table 9.--Record of test well B-5 - Continued

Water samples: Water samples were collected, as the hole was deepened, at hole depths of 100 feet, 250 feet, and 512 feet. The water samples were collected by expanding a rubber packer against the walls of the drill hole and air-jetting through a 1-inch pipe, inside a 4-inch pipe which was attached to the packer. A torch-slotted 4-inch pipe 23 feet long was in place at the bottom of the hole and was attached to the packer with 11 feet of blank 4-inch pipe. The packer was set in 6 5/8-inch diameter hole, a few feet below the bottom of $12\frac{1}{4}$-inch diameter hole. The water sample at 100 feet was collected after jetting water at a rate of 6 gpm for 1.5 hours; the sample at 250 feet was collected after jetting water at a rate of 5 gpm for 1 hour and 10 minutes; the sample at 512 feet was collected after jetting water, intermittently, for 2 hours at an average rate of 2 gpm. Field specific conductance and temperature of the water stabilized prior to collecting each sample. Samples at 100 and 250 feet were clear; the sample at 512 feet was turbid.

Water samples were also collected during well development and at the end of $7\frac{1}{2}$ hours of pumping during the aquifer test on the completed well.

Chemical analyses of water samples collected during the drilling and testing of test well B-5 are shown in table 10.

Table 9.--Record of test well B-5 - Continued

Water levels: Water levels were measured through the packer pipe following air jetting of each sample. When the packer was set at 62 feet the water level stabilized at 12.6 feet below land surface in 25 minutes. When the packer was set at 212 feet the water level was measured as 11.40 feet below land surface after an overnight recovery period. When the packer was set at 474 feet the water level was measured as 36.30 feet below level surface after an overnight recovery period. The water level in the well after casing and development was 13.65 feet below land surface.

Completion record: Concrete slab 4-foot square by 9-inches thick centered around casing. Top of casing is fitted with a hinged metal cover to permit water-level measurements.

Table 9.--Record of test well B-5- Continued

Driller's log:

Material	Depth interval (feet)	
Top soil and sand	0	5
Clay and sand	5	9
Coarse sand	31	40
Hand sand	10	50
Coarse gravel and sand	20	70
Coarse gravel, sand, and layers of clay	30	100
Coarse sand	19	119
Fine gravel and sand	36	155
Clay, gravel, and sand	34	189
Clay and sandy clay	18	207
Sand	18	225
Clay	13	238
Sand	14	252
Fine gravel, sand, and layers of clay	43	295
Coarse sand and fine gravel	20	315
Sand (cut good) trace of clay	60	375
Sand (cut good)	15	390
Sand with boulder layers and thin layers of clay	25	415
Sand	10	425
Sand and layers of blue shale	30	455
Sand	37	492
Sand and gravel	20	512

Table 9.--Record of test well B-5 - Continued

Sample description log:

Material	Depth interval (feet)	
Alluvium:		
Sand, very fine to fine, well sorted, quartz, light brown	10	10
Sand, very fine to fine, some coarse, medium well sorted, quartz, much magnetite, light-brown	10	20
Sand and gravel, very fine to fine sand comprises 50% of sample, 50% is fine gravel. Gravel is mostly angular to sub-angular quartz, dark gray dolomite, some greenish to pink volcanic rock, and some feldspar. Sand is quartz, light brown.	5	25
Sand, fine to medium, well sorted, quartz, light-grayish brown.	5	30
Gravel, fine. Mostly angular to subangular quartz, dark-gray dolomite, some greenish to pink volcanic rock. Occasional chip to ¼-inch diameter.	5	35
Sand, fine to medium, trace coarse, fairly well sorted quartz, much magnetite, light brown	15	50

Table 9.--Record of test well B-5 - Continued

Material	Depth (feet)	interval
Santa Fe Group:		
Gravel and sand, light-to-dark gray. Gravel is subrounded to rounded with a fraction angular, quartz and dark igneous and volcanic rock, 50% of sample is between 5/32-inch and 5/16-inch in diameter, fraction is 5/16-inch to 3/4-inch, and fraction is between 3/32-inch and 5/32-inch. Remainder is very fine sand to fine gravel, well sorted.	20	70
Gravel, light to dark gray. Sample is nearly 100% subrounded to rounded gravel from 5/16-inch to 1-inch diameter.	15	85
Gravel and sand light to dark gray. Sample is 50% subrounded to rounded gravel from 5/16-inch to 1-inch diameter, fraction coarser than 5/32-inch. Remainder is fine sand to fine gravel.	10	95
Gravel and sand, as above, except sample contains gray silty clay	5	100
Sand, coarse to very fine, some very coarse, trace clay. Quartz and volcanic rocks, light-gray with dark-gray to black grains.	20	120

Table 9.--Record of test well B-5 - Continued

Material	Depth interval (feet)	
Gravel and sand. Nearly all of sample is finer than 5/32-inch. One-half of sample is finer than 3/32-inch. Remainder is fine gravel with much very fine to fine sand. Quartz and volcanic rocks, light-gray with some dark-gray grains.	20	140
Sand and gravel, very fine to fine well sorted sand comprises 75% of sample. Nearly one-fourth of sample is gravel between 3/32-inch and 5/32-inch, remainder is gravel from 5/32-inch to ½-inch.	15	155
Gravel and sand. Sample is 50% gravel from 5/32-inch to ½-inch, fraction is 3/32-inch to 5/32-inch. Remainder is silt and very fine sand, quartz and volcanic rocks, light-gray with dark-gray grains.	35	190
Silt, gray, some very fine sand	15	205
Sand, fine to medium, well sorted, minor very coarse sand and fine gravel, light-gray.	20	225
Sand and silt, very fine to fine sand, light-gray. Gray silt.	13	238
Sand, very fine to fine. Sample is 80% sand finer than 0.02 inches, remainder is between 0.02 and 0.07 inches with minor coarser fraction, light-gray.	62	300

Table 9.--Record of test well B-5 - Concluded

Material	Depth interval (feet)	
Sand, very fine to medium. Sample is 60% finer than 0.02 inches, 30% between 0.02 and 0.04-inches, remainder is between 0.04 and 0.07 inches with coarser fraction.	190	490
Sand and gravel. Sample is 80% sand finer than 0.02-inches, remainder is poorly sorted sand and gravel to ¼-inch.	20	510

Table 10.--Results of chemical analyses of water samples from test well B-5

Analyses by Geological Survey, United States Department of the Interior
(parts per million)

36631

	2/	3/	4/	5/	6/	
Date of collection	4/21/67	4/27/67	5/9/67	5/19/67	5/26/67	
Silica (SiO_2)	-	-	-	-	35	
Iron (Fe), dissolved 1/	-	-	-	-	.20	
Iron (Fe), total	-	-	-	-	.37	
Manganese (Mn), dissolved 1/	-	-	-	-	-	
Manganese (Mn), total	-	-	-	-	-	
Calcium (Ca)	-	-	-	-	29	
Magnesium (Mg)	-	-	-	-	9.1	
Sodium (Na)	80	178	-	193	200	
Potassium (K)	4.7	5.5	-	-	10	
Bicarbonate (HCO_3)	-	168	-	238	242	
Carbonate (CO_3)	-	4	-	-	0	
Sulfate (SO_4)	160	125	955	232	234	
Chloride (Cl)	33	180	1300	79	82	
Fluoride (F)	-	-	-	-	.7	
Nitrate (NO_3)	-	-	-	-	.1	
Dissolved solids						
Sum	-	-	-	-	719	
Residue on evaporation at 180°C	-	-	-	-	-	
Hardness as $CaCO_3$	190	120	-	115	110	
Non-carbonate	-	-	-	-	0	
Specific conductance (micromhos at 25°C)	719	1130	6100	1090	1120	
pH	-	8.3	-	8.2	8.0	
Color	-	-	-	-	-	

1/In solution at time of analysis.
2/ Packer at 62 feet; screen from 77 to 100 feet
3/ Packer at 212 feet; screen from 227 to 250 feet
4/ Packer at 474 feet; screen from 489 to 512 feet
5/ Collected during well development
6/ Collected during aquifer pump test on completed well

Table 11.--Record of test well B-6

Location: $SW\frac{1}{4}NW\frac{1}{4}SE\frac{1}{4}$ sec. 8, T. 6 S., R. 1 E., (projected section) Bosque del Apache Grant, Socorro County, N. Mex.

Altitude: Land-surface altitude 4,525 feet (established by instrument levelling from interpolated altitude of 4,530 feet at test well B-1)

Depth: Drilled to 115 feet. (plugged and abandoned).

Date drilled: May 27 - June 13, 1967.

Drilling contractor: Layne-Texas Co., Inc., El Paso, Texas.

Drilling method: Hydraulic rotary.

Well record: The hole was drilled to 115 feet with a 6 3/4-inch bit, then reamed to 75 feet with a 9 7/8-inch bit.

Water sample: A water sample was collected by seating a cone shoulder packer, attached to 4-inch pipe, in the 6 3/4-inch hole at a depth of 75 feet. Slotted 4-inch pipe was attached below the packer from depths of 89 to 112 feet. A 1-inch pipe was lowered into the 4-inch pipe and compressed air was forced down the 1-inch pipe. The water sample was collected after air-jetting water at a rate of about 40 gpm for 1 hour. (See table 12)

Water level: Depth-to-water below land surface, measured through the packer pipe, after 102 minutes recovery period was 9.70 feet.

Completion record: The hole was filled with 10 pound, 80 viscosity drilling mud. The upper 40 feet of hole was filled with heavy drill cuttings and the drill site levelled with a bulldozer.

Table 11.--Record of test well B-6 - Concluded

Driller's log:

Material	Depth interval (feet)	
Top soil, sandy,and clay	0	5
Sand	5	20
Coarse sand and clay layers	20	25
Hard sand and boulders	25	49
Gravel and sand	49	54
Gravel and clay	54	91
Gravel and sand, coarse	91	115

Table 12.--Results of chemical analyses of water samples from test wells B-2, B-3, B-4, and B-6

Analyses by Geological Survey, U. S. Dept. of the Interior (Chemical constituents in parts per million)

Well number	B-2	B-2	B-3	B-3	B-4	B-4	B-6
Date of collection	6/11/66	6/17/66	6/23/66	6/28/66	7/7/66	7/12/66	6/14/67
Sample interval	1/	2/	3/	4/	5/	6/	7/
Sulfate (SO_4)	1,250	756	1,060	1,380	1,230	1,500	960
Chloride (Cl)	1,150	1,350	905	1,920	1,540	2,380	995
Specific conductance (micromhos at 25°C)	6,350	5,760	5,060	8,190	6,560	9,660	5,290

1/ Packer at 104 feet; screen from 119-130 feet.
2/ Packer at 227 feet; screen from 242-253 feet.
3/ Packer at 71 feet; screen from 86-97 feet.
4/ Packer at 225 feet; screen from 241-252 feet.
5/ Packer at 76 feet; screen from 91-102 feet.
6/ Packer at 227 feet; screen from 237-252 feet.
7/ Packer at 75 feet; screen from 89-112 feet.

Table 13.--Record of test well B-7

Location: NW¼NW¼NE¼ sec. 8, T. 6 S., R. 1 E., (projected section) Bosque del Apache Grant, Socorro County, N. Mex.

Altitude: Land-surface altitude 4,520 feet interpolated from USGS topographic map.

Depth: Drilled to 515 feet, completed at 255 feet.

Date drilled: August 25 to September 22, 1967.

Drilling contractor: Layne Texas Co. Inc., El Paso, Texas

Drilling method: Hydraulic rotary.

Well record: The hole was drilled to 464 feet with a 12¼-inch bit. A 6 5/8-inch hole was drilled from 464 to 515 feet. A cement plug was placed in the hole from 255 to 275 feet; hole below the cement plug was filled with drilling mud. Hole was cased to 255 feet with an 8 5/8-inch O.D. standard plain-end line pipe with welded joints, perforated at intervals with 1/8 x 2-inch mill-cut slots (32 slots per foot around pipe) as follows: 175 to 215 feet and 235 to 250 feet. A canvas-wrapped packer was placed around pipe near 170 and 230 feet. The well was bailed and surged for 12 hours with a bailer. It was then surged with air jet (2-inch diameter airline inside a 4-inch eductor pipe) for 8 hours and surged and pumped with a turbine pump with 8-inch bowls (top of bowls set at 50 feet below land surface) at rates up to 350 gpm for 8 hours.

Yield: The well was test pumped for 8 hours on September 22, 1967. Static water level below land surface was 8.20 feet; pumping water level at end of 8 hours was 38.76 feet at a pumping rate of 320 gpm. Specific capacity of the well is about 10.5 gallons per foot of drawdown.

Table 13.--Record of test well B-7 - Continued

Water samples: Water samples were collected, as the hole was deepened, at hole depths of 102 feet, 255 feet, and 504 feet. The water samples were collected by expanding a rubber packer against the wall of the drill hole, or by setting a rubber cone packer on a shoulder prepared during drilling. The sample was then air-jetted using a 1-inch pipe for the airline and the 4-inch packer pipe for the eductor pipe. A torch-slotted 4-inch pipe 23 feet long was placed at the bottom of the hole and was attached to the packer with 11 feet of blank 4-inch pipe. The packer was set in a 6 5/8-inch diameter hole a few feet below the bottom of the $12\frac{1}{4}$-inch diameter hole, or when using the cone packer, set on the shoulder at the bottom of the $12\frac{1}{4}$-inch diameter hole. The water sample at 102 feet was collected using an expansion packer and jetting water at a rate of 10 gpm for 2 hours and 45 minutes. The sample at 255 feet was collected using a cone packer and jetting water at a rate of 50 gpm for 1 hour and 30 minutes. The sample at 504 feet was collected using a cone packer and jetting water at a rate of 20 gpm for 1 hour. Field specific conductance and temperature of the water stabilized and the water was allowed to clear of drilling mud before collecting each sample. A water sample was collected at the end of 8 hours of pumping during the aquifer test on the completed well. Chemical analyses of water samples collected during the drilling and testing of test well B-7 are shown in table .

Table 13.--Record of test well B-7 - Continued

Water levels: Water levels were measured through the packer pipe following air jetting of each sample. When the packer was set at 63 feet the water level stabilized at 90 feet below land surface in 15 minutes. When the packer was set at 211 feet the depth to water was not measured because when jetting was ceased the packer seal was broken and the heavy mud in the annulus forced the formation water up in the packer pipe, making measurement of the true water level impossible. When the packer was set at 464 feet the water level stabilized at 9.5 feet below land surface in 15 minutes. The water level in the well after casing and development was 8.20 feet below land surface.

Completion record: Concrete slab 4-foot square by 9 inches thick centered around casing. The top of the casing is fitted with a hinged metal cover to permit water-level measurements.

Table 13.--Record of test well B-7 - Continued

Driller's log:

Material	Depth interval (feet)	
Top soil and loose sand	0	10
Sand, wood and clay layers	10	15
Sand, coarse, and medium coarse	15	20
Sand and boulders	20	23
Sand, coarse and medium coarse and boulders	23	48
Gravel, very coarse and medium coarse, some sand	48	102
Gravel, sand, and some clay	102	135
Clay and sandy clay	135	142
Gravel and clay	142	151
Clay and streaks of gravel	151	165
Gravel, fine, and clay layers	165	181
Clay and gravel streaks	181	185
Gravel, fine, sand and clay streaks	185	205
Sand, fine gravel and a few clay streaks	205	225
Clay	225	228
Sand and fine gravel	228	260
Clay and fine gravel	260	264
Gravel, fine and some clay streaks	264	276
Clay and fine gravel	276	284

Table 13.--Record of test well B-7 - Continued

Driller's log:

Material	Depth interval (feet)	
Sand and a few clay streaks	284	309
Clay, with sand streaks	309	318
Sand and fine gravel	318	324
Sand, fine gravel, and a few clay streaks	324	344
Sand and fine gravel, thin clay layers	344	444
Sand, coarse to medium coarse	444	515

Table 13.--Record of test well B-7 - Continued

Sample description log: (samples described by J. A. Basler)

Material	From (feet)	To
No sample	0	5
Sand, very fine to very coarse, poorly sorted, angular to sub-angular to sub-rounded quartz, magnetite and dark volcanic rocks. Little silt, brown.	5	20
As above, with few cuttings to 6mm.	20	25
As 5-20.	25	48
Gravel and gravel-size cuttings to 20 mm 75%, and sand 25%, poorly sorted, angular to rounded w/little silt. Quartz, magnetite, dark volcanic rocks and dolomite.	48	50
Gravel 90% and sand 25% as above. Little dolomite.	50	60
Gravel 75% and sand 25%. Poorly sorted, angular to rounded, Quartz, magnetite, and dark volcanic rocks. Gray	60	80
Gravel and gravel size cuttings to 20 mm 50% and sand, very fine to very coarse. Poorly sorted angular to subrounded. Quartz, dark volcanic rocks and some magnetite	80	90
Gravel and gravel size cuttings to 25 mm, angular to rounded. Quartz, dark volcanic rocks and some magnetite. (very little sand).	90	95
Gravel and gravel size cuttings to 25 mm 95%, angular to rounded and sand, very fine to medium 5%. Dark volcanic rocks, some quartz. (Volcanic rocks have highly calc. material in fractures.	95	100

Table 13.--Record of test well B-7 - Continued

Material	From (feet)	To
Gravel 50% and sand, vf to vc, poorly sorted, angular to sub-rounded. Quartz, dark volcanic rocks and magnetite.	100	102
Gravel and gravel-size cuttings 50% (most to 6 mm) and sand 50%, vf - vc, angular. Quartz, dark volcanic rocks and some magnetite. Gravel-gray and sand light brown.	102	117
Gravel, sand and brown clay, about equal proportions. Gravel and sand subrounded, poorly sorted. Quartz, dark volcanic rocks and some magnetite. Clay calcarous.	117	135
Clay, sandy, whitish-gray and few gravel. Clay highly calc.	135	141
Gravel (and few gravel-size cuttings) 50%, sand vf - vc 40%, and clay, light brown, calc. 10%. Quartz, dark volcanic rocks and magnetite.	141	151
Clay, sandy, whitish-gray. Few gravel.	151	165
Sand, 60% vf - vc, angular to subrounded, poorly sorted, with little silt/clay and gravel, 40% to 7-8 mm, Subrounded. Quarts, magnetite and dark volcanic rocks.	165	181
Clay, sandy, whitish-gray with few gravel.	181	185

Table 13.--Record of test well B-7 - Continued

Material	From (feet)	To
Sand, vf - vc, poorly sorted, subrounded, 95% and gravel to 8mm, subrounded 5%. Quartz, magnetite and dark volcanic rocks.	185	205
Sand, vf - vc, poorly sorted, subrounded, 75% and gravel to 10 mm, angular to subrounded 25%. Quartz, magnetite and dark volcanic rocks.	205	215
As 185 - 205.	215	233
As 205 - 215.	233	243
As 185 - 205.	243	255
Sand, vf - vc, poorly sorted, angular to subrounded, 95% and gravel to 15 mm, 5%. Quartz, magnetite and dark volcanic rocks.	255	260
Sand, vf - vc, gravel to 15 mm and clay, brown in about equal proportions. Quartz, magnetite and dark volcanic rocks.	260	264
Sand, vf - vc, poorly sorted, angular to subrounded, 95% and gravel subrounded to 15 mm 5%. Quartz, magnetite, dark volcanic rocks and some dolomite	264	276

Table 13.--Record of test well B-7 - Continued

Material	From (feet)	To (feet)
Sand, vf - vc, poorly sorted, angular to subrounded, 75% clay, light brown 20%, and gravel 5%. Quartz, magnetite, and dark volcanic rocks.	276	284
Sand, vf - vc, poorly sorted, angular to subrounded. Quartz, magnetite dolomite and dark volcanic rocks. Light brown. Little gravel. (some muscovite)	284	309
Sand, vf - vc, angular to subrounded, 60% and clay, light brown. Less than 5% gravel. Quartz, magnetite and dark volcanic rocks.	309	318
Sand, vf - vc, poorly sorted, angular to subrounded. Quartz, dark volcanic rocks, magnetite and dolomite. Less than 5% gravel (to 5mm).	318	324
Sand, vf - vc, poorly sorted, angular to subrounded, 80%, and gravel to 10 mm 20%. Quartz, dark volcanic rocks, magnetite and some dolomite.	324	334
Sand, vf - vc, poorly sorted, angular to rounded, 90% and gravel to 15 mm 10%. Quartz, dark volcanic rocks, magnetite and dolomite.	334	349
Sand, vf - vc, poorly sorted, angular to rounded, 80% and gravel to 12 mm 20%. Quartz, dark volcanic rocks magnetite and dolomite.	349	364
Sand, vf - vc, poorly sorted, angular to subrounded, 90%, clay 5%, light brown and gravel to 5 mm, 5%. Quarts, magnetite and dark volcanic rocks.	364	384

Table 13.--Record of test well B-7 - Concluded

Material	From (feet)	To (feet)
Sand, vf - vc, poorly sorted, angular to subrounded. Quarts, dark volcanic rocks and magnetite. (Little dolomite) Little clay and gravel to 3mm.	384	404
Sand, vf - vc, poorly sorted, angular to subrounded, 90% and gravel, angular to rounded, to 4mm, 10%. Little brown clay. Quartz, dark volcanic rocks magnetite and dolomite. (Gravel to 9mm 414-424)	404	424
Sand, vf - vc, poorly sorted, angular to subrounded 90% and clay, brown 10%. Gravel less than 5% to 10 mm, subangular to rounded. Quartz, magnetite, dark volcanic rocks and dolomite .	424	454
Sand, vf - vc, poorly sorted, angular to rounded, 100%. Little gravel 1 - 2%, angular to rounded to 5mm. Quartz, dark volcanic rocks, magnetite and little dolomite. (Sand predominately vf - m.)	454	515

Table 14.--Results of chemical analyses of water samples from test well B-7

Analyses by Geological Survey, United States Department of the Interior
(parts per million)

	2/	3/	4/	5/		
Date of collection	8/30/67	9/5/67	9/9/67	9/22/67		
Silica (SiO_2)	-	-	-	56		
Iron (Fe), dissolved 1/	-	-	-	.1		
Iron (Fe), total	-	-	-	-		
Manganese (Mn), dissolved 1/	-	-	-	-		
Manganese (Mn), total	-	-	-	-		
Calcium (Ca)	-	-	-	34		
Magnesium (Mg)	-	-	-	9.5		
Sodium (Na)	-	-	-	134		
Potassium (K)						
Bicarbonate (HCO_3)	-	-	-	163		
Carbonate (CO_3)	-	-	-	0		
Sulfate (SO_4)	299	127	1,064	106		
Chloride (Cl)	137	130	1,410	120		
Fluoride (F)	-	-	-	.5		
Nitrate (NO_3)	-	-	-	1.2		
Dissolved solids						
Sum	-	-	-	541		
Residue on evaporation at 180°C	-	-	-	528		
Hardness as $CaCO_3$	-	-	-	124		
Non-carbonate	-	-	-	0		
Specific conductance (micromhos at 25°C)	1,490	944	6,530	854		
pH	-	-	-	7.9		
Color	-	-	-	-		

1/In solution at time of analysis.
2/ Packer at 66 feet; screen from 77 to 100 feet
3/ Packer at feet; screen from 227 to 251 feet
4/ Packer at 464 feet; screen from 481 to 502 feet
5/ Collected during aquifer pump test on completed well

Ground-water exploration in the Bosque del Apache Grant

Socorro County, New Mexico