An Evaluation of Aquifer and Well Characteristics of Municipal Well Fields in Los Alamos and Guaje Canyons, Near Los Alamos, New Mexico

By R. L. CUSHMAN

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1809-D

Prepared in cooperation with the U.S. Atomic Energy Commission and published with the permission of the Commission

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1965

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $1 (paper cover)

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By R. L. CUSHMAN

ABSTRACT

The main aquifer tapped by the municipal supply wells of Los Alamos, N. Mex., is the Tesuque Formation and younger rocks of the Santa Fe Group of middle(?) Miocene to Pleistocene(?) age. These rocks comprise a series of unconsolidated to slightly consolidated sedimentary rocks consisting of silt, sand, gravel, and conglomerate having a saturated thickness of more than 2,000 feet. Recharge to the aquifer is principally by seepage from streamflow in the canyons. Water in the aquifer moves from west to east in the Los Alamos area. The principal area of natural discharge, the Rio Grande, is a hydrologic boundary for the aquifer, and ground water in the Los Alamos area does not move eastward beyond the river.

The main aquifer terminates on the west against relatively impermeable latites of the Tschicoma Formation. The exact position of this geologic boundary is not known. There are no known geologic or hydrologic boundaries to the north and south that are close enough to the Los Alamos area to influence the movement of ground water near the municipal well fields. Water in the main aquifer is under water-table conditions except near the eastern hydrologic boundary where artesian conditions occur. In this latter area the water in the aquifer is under increasing pressure with depth, and water levels in deep wells rise to higher altitudes than levels in shallow wells at the same location. Wells 19.7.13.114(LA-1), 13.114b(LA-1B), 14.221(LA-3), and 14.222(LA-2) flowed when they were completed.

Average values for hydraulic coefficients of the aquifer determined from pumping tests of wells were T (transmissibility) =15,000 gallons per day per foot and S (storage) =0.0003. These aquifer coefficients may not be uniform throughout the Los Alamos area; basaltic rocks in the central and western parts of the plateau probably cause higher transmissibility. The coefficient of storage probably is larger throughout the area than that computed from aquifer tests, and probably is as much as 0.005, the lowest range for water-table conditions.

A method of estimating transmissibility and storage is described whereby the Theis nonequilibrium formula is adapted for computations of water-level changes using past pumping expressed in cycles of one-half year duration and boundary conditions simulated with image wells. Computation of water-level

decline by trial-and-error use of assumed values for transmissibility and storage and assumed locations of the western boundary of the aquifer would continue until the computed declines coincide with the amount of decline measured at each well. These computations were not carried to completion in this report because the large number of combinations of assumed conditions would require an electronic computer or an electrical analog model to compute the data in a reasonable length of time. Additional wells should not be placed in Los Alamos and Guaje Canyons, with the possible exception of one additional well that should be at least 2,500 feet upgradient from well 5.112(G–5). The water-level decline might accelerate and substantially reduce the life of the well fields if additional wells were added. This restriction does not preclude the placement of other supply wells on the Pajarito Plateau but additional wells should be at distances more than 2 miles south of the Los Alamos and Guaje Canyons well fields.

Wells in Los Alamos and Guaje Canyons having specific capacities of less than 10 gpm (gallons per minute) per ft probably can be rehabilitated to attain specific capacities above 10. A properly constructed supply well in the main aquifer should have a specific capacity of 10 to 15 gpm per foot of drawdown.

INTRODUCTION

LOS ALAMOS AREA

The Los Alamos area covers about 100 square miles of the Pajarito Plateau on the eastern flank of the Jemez Mountains (fig. 1). The Jemez Mountains consists of a volcanic center surrounded by an apron of volcanic rocks that are principally Bandelier Tuff of Pleistocene age (Griggs, 1964) and that are as much as 1,000 feet thick around the volcanic center. The Pajarito Plateau, the eastern apron, slopes gently eastward from the base of a steep ridge (Sierra de los Valles) that forms the eastern rim of the volcanic center. The eastern edge of the plateau is a 500- to 1,000-foot high escarpment approximately 10 miles east of Los Alamos and near the southward-flowing Rio Grande. Streams draining the eastern slope of the Jemez Mountains toward the Rio Grande have cut deep narrow eastward-trending canyons that dissect the plateau into long fingerlike mesas. The lower reaches of the canyons cut through the Bandelier Tuff and into rocks of the Santa Fe Group. Guaje and Los Alamos Canyons are two of these canyons.

The Jemez Mountains are on the west side of the Rio Grande valley, a long north-south trending structural trough in which several thousand feet of alluvium and some interbedded igneous rocks were deposited.

The Guaje Canyon and Los Alamos Canyon well fields are in the middle and lower reaches of their respective canyons. The altitude of the land surface at the wells is between 5,600 and 6,300 feet above mean sea level; the altitude of the town of Los Alamos is about 7,100 feet.

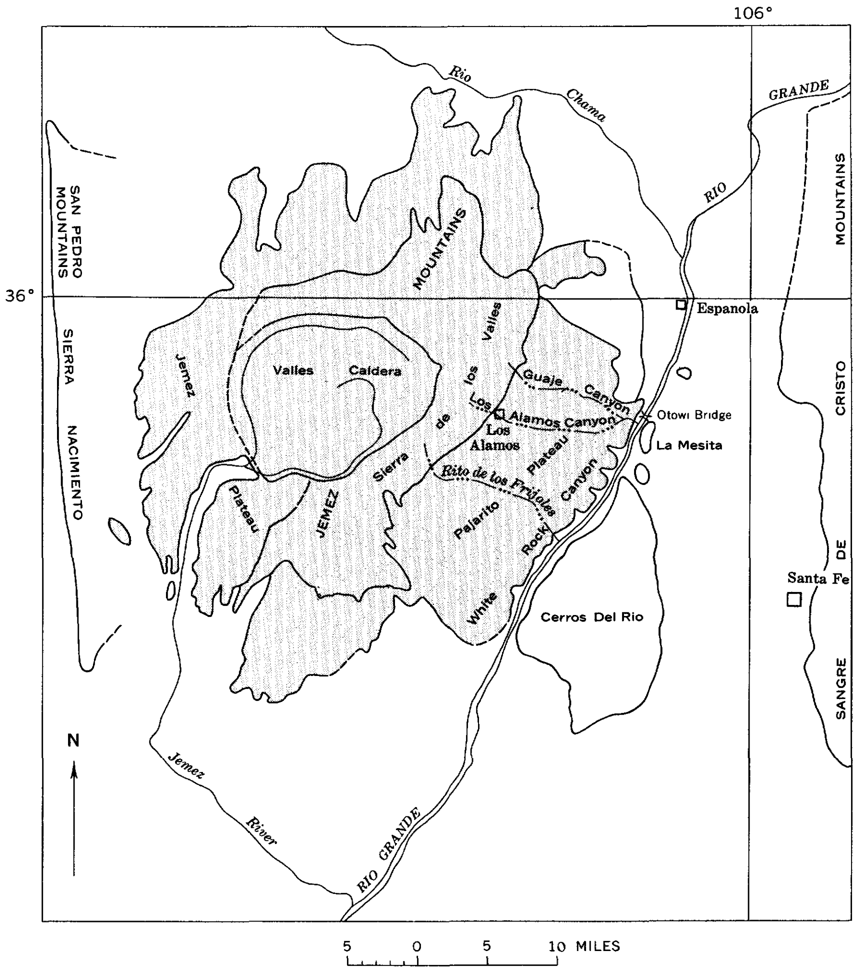

FIGURE 1.—The Los Alamos area, New Mexico, showing the volcanic rocks (shaded) of the Jemez Mountains. Base from U.S. Geol. Survey, geologic map of New Mexico, 1928. Geology modified from R. L. Griggs (1964).

Wells have been the main source of water for the town of Los Alamos, N. Mex., since 1946. The supply wells obtain their water from a ground-water reservoir that is principally in the Tesuque Formation and younger rocks of the Santa Fe Group of middle(?) Miocene to Pleistocene(?) age.

PURPOSE AND SCOPE

Twelve supply wells are now (1961) being pumped at their optimum production capacity, which is adequate to meet the municipal water needs in 1961 but will be inadequate if the water demand increases

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appreciably above the 1961 requirements. Estimates indicate that additional wells will be needed in the near future. The annual review of water-level changes with respect to pumpage and the doubtful information about hydraulic characteristics of the main aquifer are inadequate as a basis on which to select sites for additional well fields and to plan pumping schedules. The Atomic Energy Commission at Los Alamos asked the Geological Survey to compile and analyze the available data for the period 1946–61 about water-level changes, pumpage, pumping tests, and construction of the supply wells. The report was to determine, if possible, the hydraulic characteristics of the main aquifer and to predict effects on the main aquifer and on the Rio Grande of pumping in the Los Alamos area. This report is to be a guide to the Commission in planning ground-water development in the future.

The two principal hydraulic characteristics to be determined are aquifer potentials for the transmission and storage of water. Numerical values for these are referred to as "coefficient of transmissibility (T)" and "coefficient of storage (S)," respectively.

The "magnitude of the pumping effect" refers to the amount of decline in water levels that has occurred and may occur in the supply wells in response to pumping.

The "effect on the Rio Grande" refers to reduction of recharge to the river and possible depletion in flow of the river caused by pumping of the Los Alamos municipal supply wells.

ACKNOWLEDGMENTS

This report could not have been prepared without access to well and water records in the files of the Atomic Energy Commission, the Zia Co., and the consulting engineering firm of Black and Veatch. The time and effort by their personnel in locating and making available necessary information are gratefully acknowledged.

SYSTEM OF NUMBERING WELLS

Well numbers used in this report are based on the common system of subdivision of public lands. A number consists of four segments. (See fig. 2.) The first segment denotes the township north of the New Mexico base line; the second segment denotes the range east of the New Mexico principal meridian; the third segment denotes the number of the section within the township; and the fourth segment denotes subdivisions of the section.

The section is considered as being divided into four quarters, 1, 2, 3, and 4 for the northwest, northeast, southwest, and southeast quarters, respectively. The first digit of the fourth segment of the location

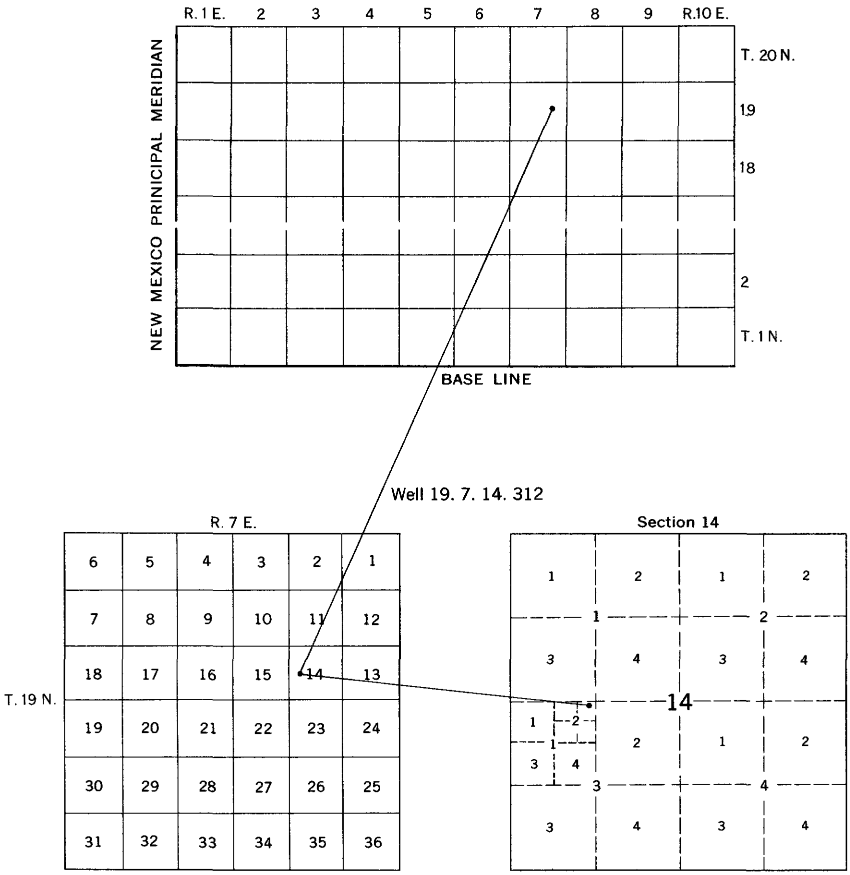

FIGURE 2.—System of numbering wells in New Mexico. Left, section within a township; right, tracts within a section.

numbers refers to the appropriate quarters of the section, or 160-acre tract. Similarly, each quarter section is divided into four quarters, or 40-acre tracts. These 40-acre tracts are numbered in the same manner as the 160-acre tracts. The second digit of the fourth segment of the location number refers to the appropriate 40-acre tract. The 40-acre tract is divided into 10-acre tracts which are numbered in the same manner as the 160 and 40-acre tracts. Thus location number 19.7.14.312 identifies the well located in NE¼NW¼SW¼ sec. 14, T. 19 N., R. 7 E.

If more than one well is in a single 10-acre tract, lower case letters (a, b, c, and so forth) are added to the fourth segment to identify the additional wells in that tract.

The supply wells in the Guaje and Los Alamos Canyon well fields are known to the water-management officials of Los Alamos by the following numbering system: Guaje 1 (G–1), Los Alamos 3 (LA–3), are wells 1, 3, and so forth in Guaje and Los Alamos Canyon well fields, respectively. These numbers in parentheses follow the location number on maps and in the text of this report.

The township and range segment of the well number is dropped after its use to shorten the number for succeeding wells in that township, and it is not repeated unless a different township and range number is used later. The reader can assume that a shortened well number refers to a well in the last mentioned township and range.

The system of subdivision of the public lands by section, township, and range was extended arbitrarily into land grants in the Los Alamos area to facilitate well numbering within the boundaries of the grants. This extended land net is shown by dashed lines on plate 1 in this report.

PREVIOUS INVESTIGATIONS NEAR THE WELL FIELDS

In 1950, Theis and Conover (1962) tested the Los Alamos Canyon municipal supply wells that were less than 1,000 feet deep and concluded that the coefficients of transmissibility and storage in the upper 1,000 feet of the aquifer were about 2,500 gpd (gallons per day) per ft and 0.003 respectively. They predicted that the average decline in water level in those wells would be about 112 feet by 1962.

The most comprehensive report on the geology and hydrology of the area is by Griggs (1964). He mapped the geology of the Pajarito Plateau, analyzed samples of drill cuttings from most of the supply wells in Guaje Canyon, and made pumping tests on those wells. He concluded that the coefficients of transmissibility and storage of the upper 2,000 feet of the main aquifer is about 10,000 to 12,000 gpd per ft and 0.0003 respectively.

Little was known about the hydrology, geology, and extent of the ground-water reservoir or main aquifer in the Los Alamos area prior to the construction of the first well field. The six wells in this field were drilled during the period 1946–48 in the lower reach of Los Alamos Canyon, 6 to 8 miles east of Los Alamos. (See pl. 1.) Some data were obtained about the geology and hydrology of the lower part of Los Alamos Canyon during the construction of the first three wells in that field. Drillers' logs described in general the upper 1,000 feet of the Tesuque Formation. Short-term pumping tests made to determine the size of pumps and motors for the wells indicated that wells capable of yielding 500 gpm probably could be obtained by drilling deeper. Later, three additional wells were drilled in Los Alamos Canyon and each proved to be capable of yielding more than 500 gpm.

The maximum depth drilled was 2,030 feet. These data were inconclusive as to the hydrology and geology of the main aquifer and were inadequate for sound planning of additional wells and well fields. The moderate net declines of water levels in the Los Alamos Canyon well field in the period 1947–49 encouraged the Atomic Energy Commission to have a second well field of six wells constructed 2 to 4 miles northwest of the Los Alamos Canyon field in Guaje Canyon in the period 1950–54 to meet the increased municipal water demand.

Geologists studied electrical and drillers' logs and the drill cuttings to learn about the type, distribution, and relative permeability of rocks in the Tesuque Formation. Pumping tests, ranging in duration from 8 hours to as much as 14 days, were made on the Guaje Canyon wells to determine hydraulic characteristics of the main aquifer. Interpretation of geologic and hydrologic information obtained in the area prior to 1955 indicated that (1) the supply wells tap a sequence of water-bearing rocks having a thickness greater than that penetrated by any of the wells, (2) faults in the vicinity of some wells probably affect the local movement of ground water near those wells, (3) aquifer hydraulic characteristics obtained from the analysis of pumping tests could not be extrapolated throughout the well fields with any degree of assurance, (4) location and extent of the recharge area is unknown, and (5) natural discharge of water from the main aquifer is to the Rio Grande.

Water levels were measured at least once a week from 1946–51 in most of the supply wells and the amount of water pumped daily by each well was metered at the well. Recording gages were installed in 1951 on each well to obtain a continuous record of water-level changes. These data were analyzed at least once each year to check for signs of local or regional overdevelopment of the aquifer.

LOS ALAMOS MUNICIPAL WELL FIELDS

In 1961 Los Alamos obtained its supply of ground water from two well fields located several miles east of town. The older field consists of six wells along the bottom of Los Alamos Canyon (pl. 1). Wells 19.7.13.114(LA–1), 14.222(LA–2) were completed and in operation by the latter part of 1946. Well 14.221(LA–3) was operative in 1947. These three wells are the most closely spaced (950 to 1,200 ft) of all the supply wells and are near the confluence of Los Alamos and Guaje Canyons Wells 14.312(LA–6), 15.434(LA–5), and 22.114(LA–4) were added to the field in 1948. The latter three wells were placed upgradient in Los Alamos Canyon and a spacing of at least 2,500 feet was maintained between adjacent wells. Well 13.114b(LA–1B) was drilled in 1960 as a replacement well 150 feet east of well 13.114 (LA–1). The distance spacing of the supply wells is given in table 1.

TABLE 1.—*Distance, in feet, between municipal supply wells and between wells and the Rio Grande near Los Alamos, N. Mex.*

Well	19.7.14.221(LA-3)	14.222(LA-2)	14.312(LA-6)	15.434(LA-5)	22.114(LA-4)	4.133(G-3)	4.411(G-2)	4.441(G-1A)	4.444(G-1)	5.112(G-5)	5.231(G-4)	Rio Grande
19.7.13.114(LA-1)	2,100	1,200	5,700	9,300	12,000	18,800	16,000	14,800	13,700	23,800	21,300	4,600
14.221(LA-3)	----------	950	4,050	7,700	10,400	16,900	14,100	12,900	11,700	21,700	19,300	6,200
14.222(LA-2)	950	----------	4,850	8,450	11,200	17,700	14,900	13,700	12,500	22,600	20,100	5,500
14.312(LA-6)	4,050	4,850	----------	3,650	6,300	16,200	13,600	12,400	11,200	20,700	18,300	7,200
15.434(LA-5)	7,700	8,450	3,650	----------	2,700	15,900	13,700	12,600	11,600	20,100	17,600	9,600
22.114(LA-4)	10,400	11,200	6,300	2,700	----------	16,100	14,200	13,300	12,400	19,800	17,400	11,200
4.133(G-3)	16,900	17,700	16,200	15,900	16,100	----------	2,800	4,000	5,200	4,950	2,700	22,800
4.411(G-2)	14,100	14,900	13,600	13,700	14,200	2,800	----------	1,350	2,500	7,750	5,450	20,100
4.441(G-1A)	12,900	13,700	12,400	12,600	13,300	4,000	1,350	----------	1,200	8,950	6,600	18,800
4.444(G-1)	11,700	12,500	11,200	11,600	12,400	5,200	2,500	1,200	----------	10,100	7,700	17,600
5.112(G-5)	21,700	22,600	20,700	20,100	19,800	4,950	7,750	8,950	10,100	----------	2,500	27,700
5.231(G-4)	19,300	20,100	18,300	17,600	17,400	2,700	5,450	6,600	7,700	2,500	----------	25,200

Six wells were constructed in Guaje Canyon in the period 1950–54. Well 4.444(G–1) was drilled and tested in 1950 but was not operated in the supply system until 1951. The large distance between this well and well 14.221(LA–3) is not the result of spacing to prevent interference between wells, but was dictated by the necessity of placing well 4.444(G–1) outside of the San Ildefonso Indian Reservation. Wells 4.133(G–3), 4.411(G–2), 5.112(G–5), and 5.231(G–4) were drilled in 1951 and placed into the system in 1952. These first five wells were spaced along the canyon floor at intervals of about 2,500 feet. When a site for well 4.441(G–1A) was selected, the minimum spacing was disrupted because it was believed at that time that a well farther up the canyon than well 5.112(G–5) might encounter the relatively impermeable Tschicoma Formation at too shallow a depth for a successful supply well.

Each field has a pipeline to Los Alamos and booster stations are spaced along those lines to lift the water from the well fields to the townsite. The differences in altitude between the land surface at wells 4.444(G–1) and 13.114b(LA–1B), the topographically lowest wells in each field, and the water level in storage tanks at Los Alamos are about 1,410 and 1,760 feet, respectively. Pipeline distances between these two wells and Los Alamos are about 7 and 8½ miles, respectively.

WELL CONSTRUCTION

Construction of the supply wells was principally by rotary drilling. About the first hundred feet of some holes was drilled by cable-tool methods, the holes were cased with blank pipe, and cement was poured into the annular space around the casing to shut out surface water and shallow ground water that might pollute or contaminate the main source of water to the well. An 8-inch-diameter pilot hole was drilled to final depth and then the hole was reamed to 20 inches or more in diameter to the depth that was to be cased. Blank casing with sections of screen integrated in the casing string at selected points was lowered into the hole. The annular space between the borehole and the outside of the casing was filled with gravel to form a gravel pack at least 6 inches thick around the casing and screen. The blank casing in wells 13.114(LA–1), 14.221(LA–3), and 14.222(LA–2) was slotted with a knife perforator after the well had been tested in hopes of increasing the rate of yield of those wells. The construction dimensions of all the supply wells are given in table 2.

TABLE 2.—*Construction dimensions of the municipal supply wells in Los Alamos and Guaje Canyons near Los Alamos, N. Mex.*

Well	Completion date	Altitude of land surface above mean sea level (ft)	Depth of pilot hole below land surface (ft)	Depth in feet below land surface to bottom of casing		Length of perforated or screened section (ft)	Depth below land surface to top of upper screen (ft)	Bottom of lowest screen	
				12-inch diameter	10-inch diameter			Depth below land surface (ft)	Altitude above mean sea level (ft)
Los Alamos Canyon well field									
19.7.13.114(LA-1)	1946	5,624	1,001	([1])	870	[2] 805	60	865	4,759
13.114b(LA-1B)	1960	5,622	2,256	650	1,750	591	326	1,694	3,928
14.221(LA-3)	1947	5,672	910	([1])	870	[3] 760	105	865	4,807
14.222(LA-2)	1946	5,651	882	([1])	870	[4] 760	105	865	4,786
14.312(LA-6)	1948	5,770	2,030	597	1,790	400	420	1,778	3,992
15.434(LA-5)	1948	5,840	2,024	630	1,750	350	440	1,740	4,100
22.114(LA-4)	1948	5,975	2,019	754	1,965	350	754	1,964	4,011
Guaje Canyon well field									
19.7.4.133(G-3)	1951	6,139	1,997	695	1,792	400	441	1,785	4,354
4.411(G-2)	1951	6,056	2,006	600	1,970	425	281	1,960	4,096
4.441(G-1A)	1954	6,014	2,071	663	1,519	563	272	1,513	4,501
4.444(G-1)	1950	5,973	2,020	490	2,000	490	282	1,980	3,993
5.112(G-5)	1951	6,306	1,997	739	1,840	400	462	1,830	4,476
5.231(G-4)	1951	6,228	2,002	720	1,930	360	426	1,925	4,303

[1] 12-in. diameter casing and 10-inch diameter screen alternate through depth of well.
[2] 115 ft of 10-in. diameter commercial screen and 690 ft of slotted 12-in. diameter casing.
[3] 140 ft of 10-in. diameter commercial screen and 620 ft of 12-in. diameter slotted casing.
[4] 195 ft of 16-in. diameter commercial screen and 565 ft of 12-in. diameter slotted casing.

PARTIAL PENETRATION OF THE MAIN AQUIFER

The supply wells constructed prior to 1961 only partially penetrate the main aquifer. The deepest hole drilled in either well field was the pilot hole of well 13.114b(LA-1B) (pl. 2 and table 2). The hole bottomed 2,256 feet below land surface at an altitude of 3,366 feet above mean sea level. Drill cuttings and electrical logs of the hole indicate that the base of the water-bearing part of the Tesuque Formation was not reached. The well is cased to a depth of 1,750 feet and the bottom of the lowest screen is at a depth of 1,694 feet or an altitude of 3,928 feet above mean sea level. The altitude of this screen is lower than the lowest screen in any of the other supply wells. If the lower limit of the main aquifer is below an altitude of 3,366 feet throughout both well fields, the lower screens in the supply wells range from about 560 to more than 1,440 feet above the base of the aquifer. The percentage of partial penetration of any well in either field cannot be computed because the total thickness of the aquifer is unknown.

CHANGES IN EFFECTIVE DEPTH OF WELLS

The lengths of screens and perforations given in table 2 are not a true indication of the effective lengths of screens and perforations in some wells in 1961. Silt, clay, and sand accumulating in wells to a depth of several tens of feet bury some of the lower screens. The screens that are buried cease to contribute water to the well and result in a decrease in the effective depth of the well. The water movement through those screens generally is restored when the accumulated sediment is removed from the well.

Sand and other sediment accumulate in some wells more rapidly than others. Wells 13.114(LA-1), 14.221(LA-3), and 14.222(LA-2) pump appreciable quantities of sand, and a trap was built to keep the sand from entering the water-distribution line. Accumulations of sediment have been cleaned out of these three wells several times since the wells were put into use. In the spring of 1949, well 13.114(LA-1) contained about 170 feet of sediment. A bailer that was used to clean about 80 feet of the sediment from the well became stuck and was left in the well with the remaining 90 feet of sand. The well was pumped sparingly in the period 1950–56 and remained idle from February 1956 until it was abandoned in 1960. A depth measurement in 1960 showed 280 feet of sediment in the well.

The pump was removed from well 14.221(LA-3) during June and July 1949 and an unrecorded quantity of sand was bailed from the well. In February 1961 a depth measurement indicated that sediment, principally sand, had filled the well to a depth of 198 feet. The sediment was cleaned out before the well was replaced in operation.

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The depth of well 22.114(LA-4) was measured in March 1962 as 1,962 feet which is only 3 feet less than the cased depth of the well (pl. 2); thus negligible amounts of sediment had accumulated in this well.

The depth of well 15.434(LA-5) was measured in December 1961 as 1,954 feet below land surface, or 204 feet below the bottom of the cased part of the well (pl. 2). The amount of sediment accumulation in the borehole has been negligible. Inasmuch as the uncased borehole may be contributing some water to the well, the well may be tapping the main aquifer at an altitude as low as 3,886 feet, or about 42 feet lower than the lowest screen in well 13.114b(LA-1B).

The depth of well 14.312(LA-6) has not been measured since 1948. The sustained good performance of the well shows that, if sand is accumulating in the well, it has not blocked producing screens.

Well 4.133(G-3) contained sand to a level 1,654 feet below land surface in April 1961. At that level, the sand is 138 feet into the cased part of the well and had blocked about 20 feet of screen (pl. 3). An attempt to clean the well failed because the bailer could not pass a metallic obstruction at a depth of 1,657 feet.

The depths of wells 4.411(G-2) and 4.441(G-1A) have not been measured since the wells were put in operation. Almost constant discharge-drawdown ratios in these two wells indicate that any accumulation of sediment that has occurred has not blocked much, if any, of the screen.

A depth measurement made in well 4.444(G-1) in February 1962 showed that sediment had accumulated to about 1,745 feet below land surface. That level was about 255 feet into the cased part of the well and about 75 feet of screen was blocked (fig. 5). The fact that blocking of these screens apparently had not affected the performance of the well indicates that these lower screens probably were not contributing water to the well. If they were not, the lower part of the well probably was not fully developed.

A depth measurement in well 5.112(G-5) in November 1953 indicated that the well was filled with sediments to about 1,421 feet below land surface. About 15 feet of silt, sand, and gravel was bailed from the well. At the 1,436-foot level only gravel was being removed. Bailing was stopped, because it was concluded that a rupture of the casing at that level was letting the gravel pack into the cased part of the well. Approximately 125 feet of the 400 feet of screen (pl. 3) is buried and probably is not contributing water to the well. In July 1958 a 4-inch diameter pipe used to sound the well depth would not pass below a depth of 673 feet. It is concluded that the casing may be ruptured and offset at that level. The well probably is producing water from below the 673-foot level; however, the gradual decline in specific capacity of the well indicates that sand- and gravel-pack materials probably are accumulating in the well below the 673-foot level.

A measurement of well 5.231(G-4) in November 1953 showed that the well was filled with sediment to about 1,129 feet below land surface. Attempts at removal of this material from the well were abandoned at a depth of 1,486 feet because the bailer would stick at that depth. In October 1954 a measurement showed that the well was open to a depth of 1,380 feet below land surface. No further attempt was made to remove the sand accumulation from the well. Approximately 110 of 360 feet of screen (pl. 3) is buried beneath the 1,380-foot level; there is 250 feet of unobstructed water-yielding screen. The buried screen probably does not yield water to the well and this lack of contribution is reflected in a low discharge-drawdown ratio (less than 5 gpm per foot of drawdown).

SPECIFIC CAPACITY

Specific capacity is the ratio of discharge rate to drawdown and in this report is expressed as gallons per minute of discharge per foot of drawdown. The amount of drawdown is equal to the head loss in the aquifer, in the screen, and in the well when the well is pumped. The largest increment of head loss is in the aquifer; however, unperforated casing opposite water-bearing beds in contact with the casing can increase the loss in the aquifer to more than that resulting from a properly perforated well. The head loss in the aquifer is at a minimum if the well is open to the aquifer through the full thickness of the aquifer. Partial penetration of the aquifer by the screened part of the well or incomplete development of all screens will cause water moving to the well to follow a circuitous path that will increase the head loss in the aquifer. Well construction and well development are factors over which control can be exercised in obtaining a specific capacity that is commensurate with the aquifer's true water-transmitting character.

Specific capacity is not constant but decreases with drawdown in a well as the well is pumped and with increase in discharge rate. Changes caused by these factors are slow and small compared to other factors that might cause a change in specific capacity. An appreciable change in head in the aquifer near the well as a result of depletion of water storage or interference from other wells will decrease specific capacity. Blocking of screens by sediment accumulation behind screens or in the well and a constriction in the well as a result of casing collapse or rupture will decrease the specific capacity.

The specific capacity of each supply well was computed for each month of record (figs. 3–14) as the ratio of the monthly average pump-

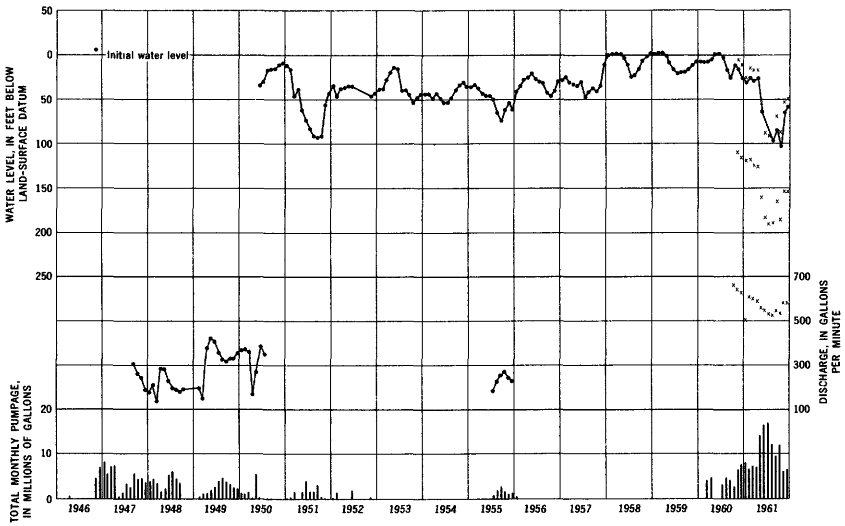

FIGURE 3.—Water levels, discharge rate, and pumpage for well 19.7.13.114 (LA–1), 1946–61 and for well 13.114b(LA–1B), 1960–61. Upper curve indicates water level (average daily high) during periods when well was not being pumped. X, water level (average daily low) during periods when well was being pumped and discharge rate for well 19.7.13.114b(LA–1B). Pumpage for 1960–61 also is for that well.

ing rate and the difference between monthly average nonpumping and pumping water levels. The specific capacity of the supply wells range from about 2 to as much as 14 gpm per foot of drawdown. In general, the specific capacity of these wells, except for the three shallowest wells 13.114(LA–1), 14.221(LA–3), and 14.222(LA–2), should be more than 10 gpm. The principal reason for values less than 10 gpm is poor well development.

There are no apparent physical construction deficiencies and no obvious aquifer differences by which to explain specific capacities of less than 10 gpm per foot of drawdown in wells 13.114b(LA–1B), 15.434(LA–5), and 22.114(LA–4)—5, 4, and 8 gpm per foot of drawdown respectively (figs. 3, 7, and 8)—except incomplete development. A water-velocity survey made in 1960 of the water yield from each screen in well 13.114b(LA–1B) indicated that about 21 percent of the discharge was from 30 feet of screen between 326 and 356 feet, none from 197 feet of screen between 356 and 914 feet, and about 79 percent from screens below 914 feet (fig. 15). The lack of water production between 356 and 914 feet may represent poor development of the screens in that interval. Water-velocity surveys were not made in wells 15.434(LA-5) and 22.114(LA-4); however, development probably has been incomplete opposite some screens in the latter two wells. Additional development probably would increase the specific capacities of those two wells and well 13.114b(LA-1B) to about the specific capacity of well 14.312(LA-6) which is 13 to 14 gpm per foot of drawdown.

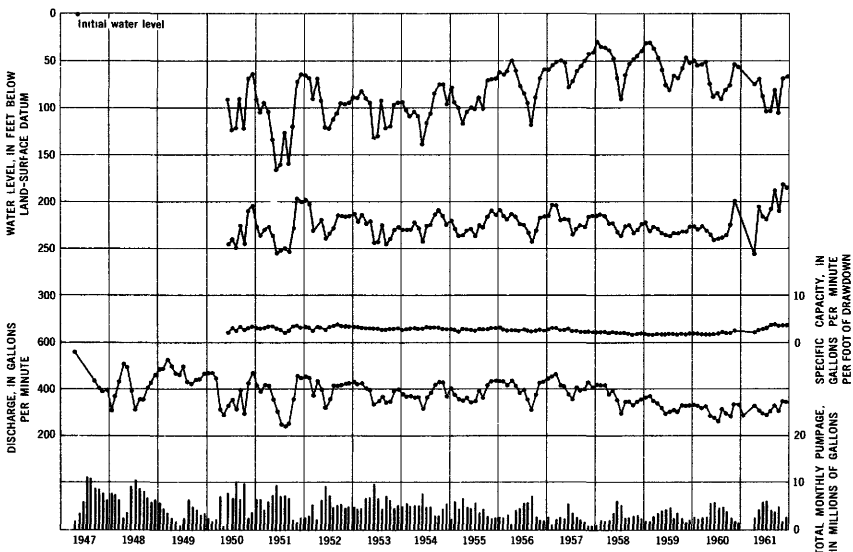

FIGURE 4.—Well 19.7.14.221 (LA-3), 1947–61.[1] See explanation below.

Figures 4–14, immediately following, show water levels, specific capacity, discharge rate, and pumpage for wells as indicated. In each figure, upper curve indicates water level (average daily high) during periods when well was not pumped; lower curve indicates water level (average daily low) during periods when well was being pumped.

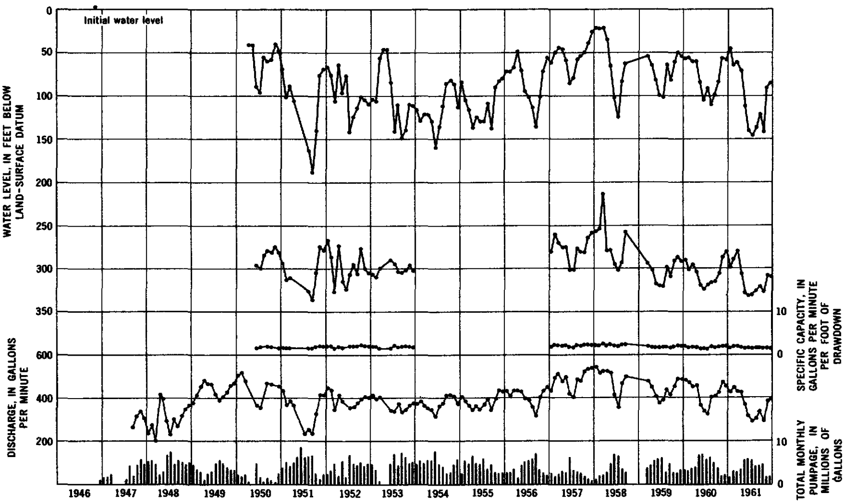

FIGURE 5.—Well 19.7.14.222 (LA-2), 1946–61.[1]

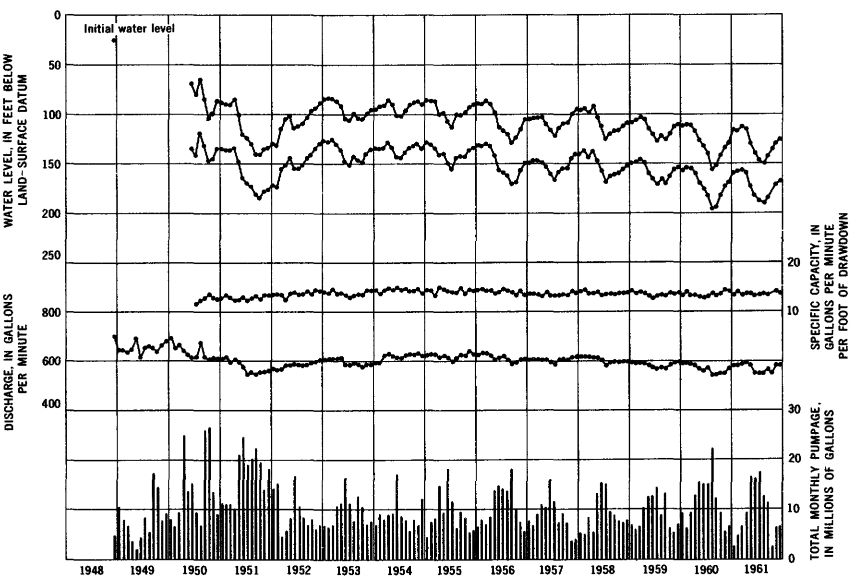

FIGURE 6.—Well 19.7.14.312 (LA-6), 1948–61.[1]

[1] See bottom of page D15 for explanation of figure.

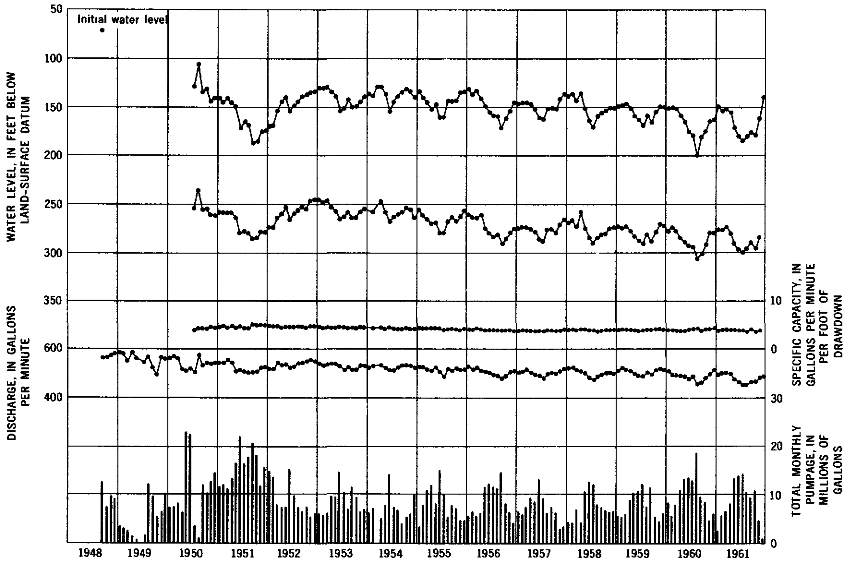

FIGURE 7.—Well 19.7.15.434 (LA-5), 1948–61.[1]

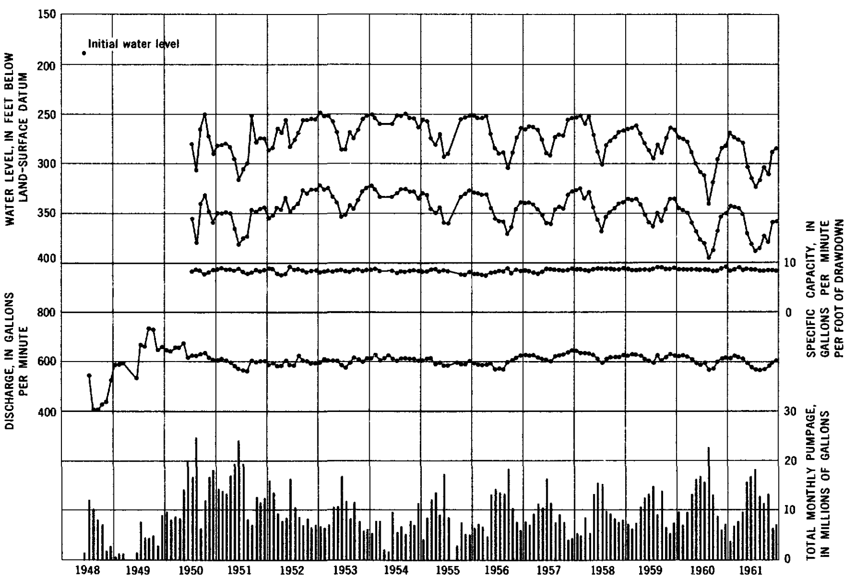

FIGURE 8.—Well 19.7.22.114 (LA-4), 1948–61.[1]

[1] See bottom of page D15 for explanation of figure.

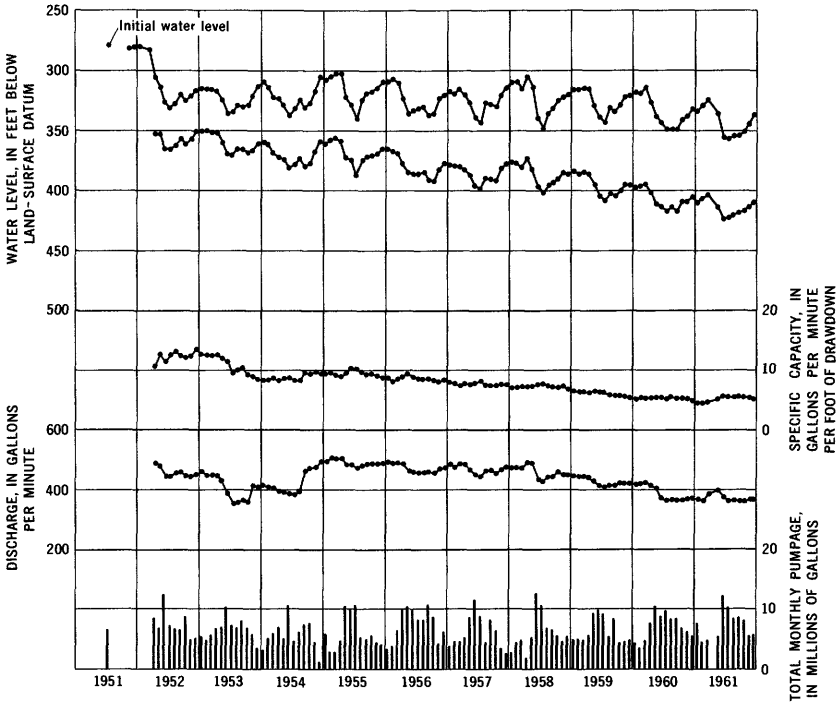

FIGURE 9.—Well 19.7.4.133(G-3), 1951-61. See bottom of page D15 for explanation.

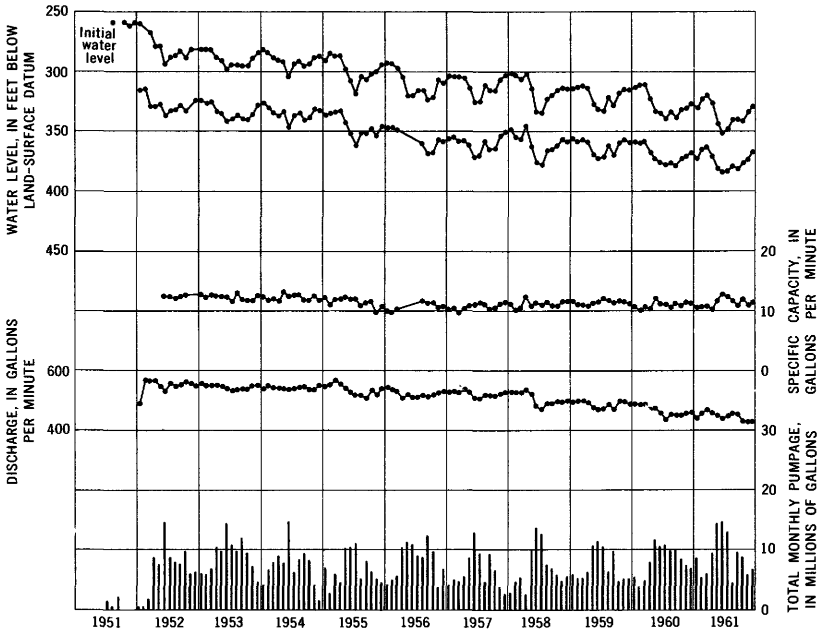

FIGURE 10.—Well 19.7.4.441(G-2), 1951-61. See bottom of page D15 for explanation.

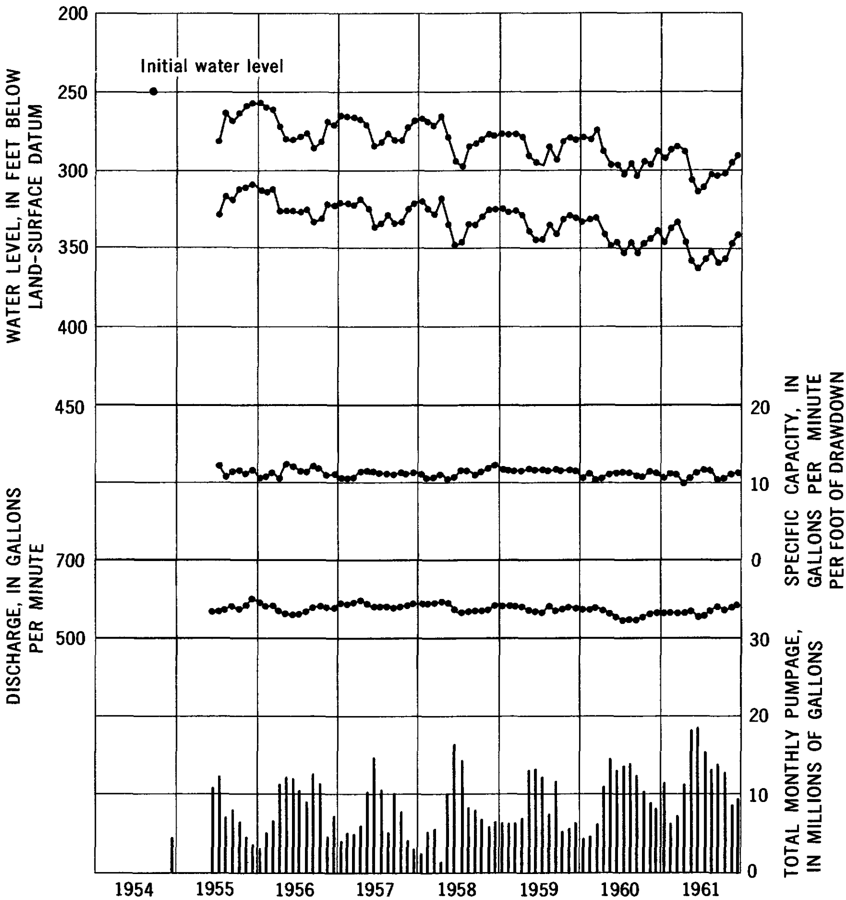

FIGURE 11.—Well 19.7.4.441(G–1A), 1954–61. See bottom of page D15 for explanation.

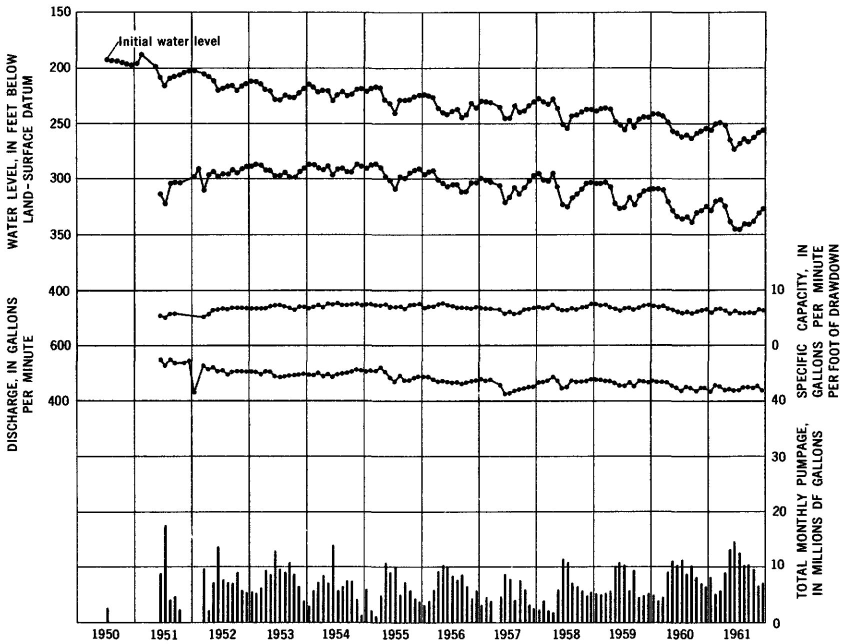

FIGURE 12.—Well 19.7.4.444(G–1), 1950–61. See bottom of page D15 for explanation.

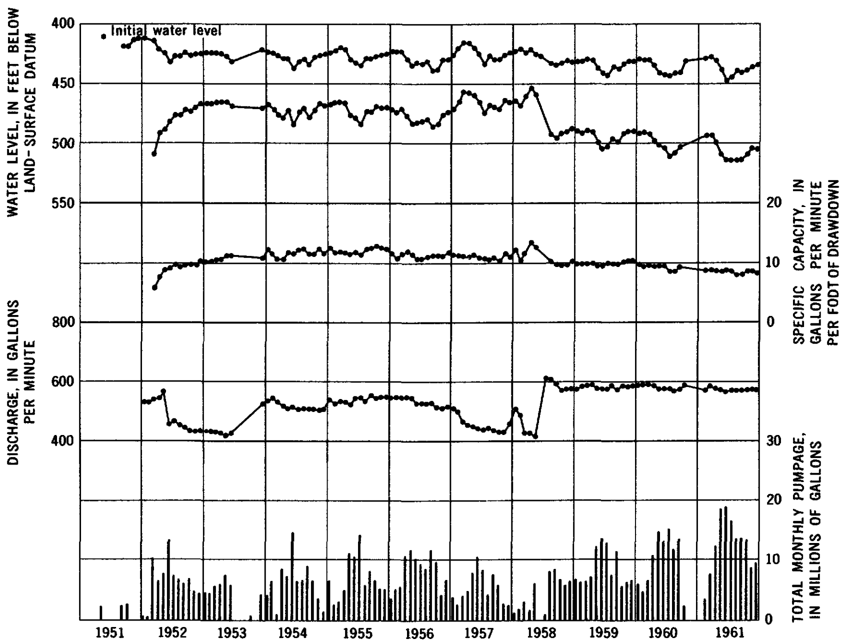

FIGURE 13.—Well 19.7.5.112(G-5), 1951-61. See bottom of page D15 for explanation.

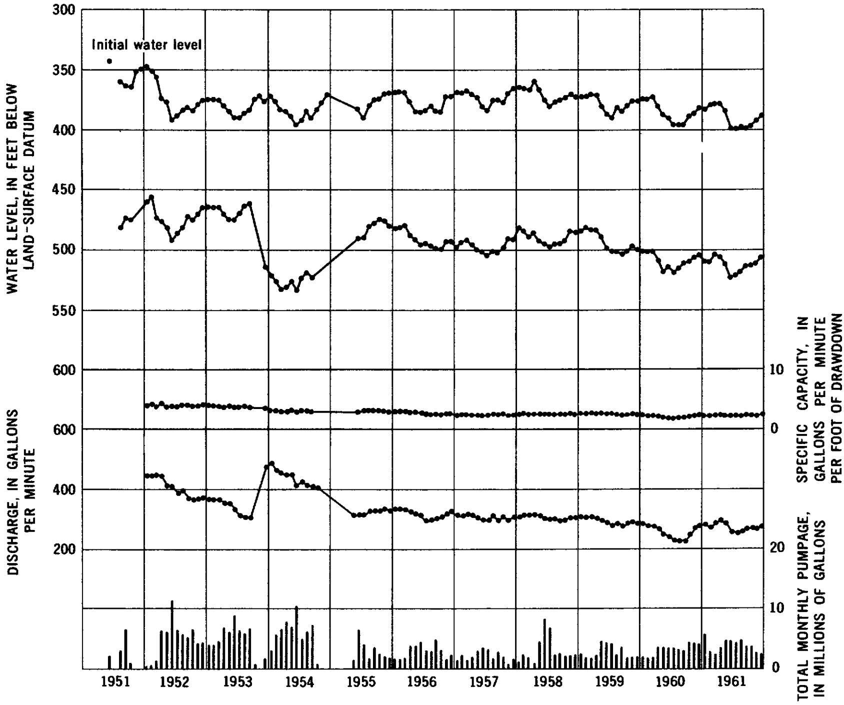

FIGURE 14.—Well 19.7.5.231(G-4), 1951-61. See bottom of page D15 for explanation.

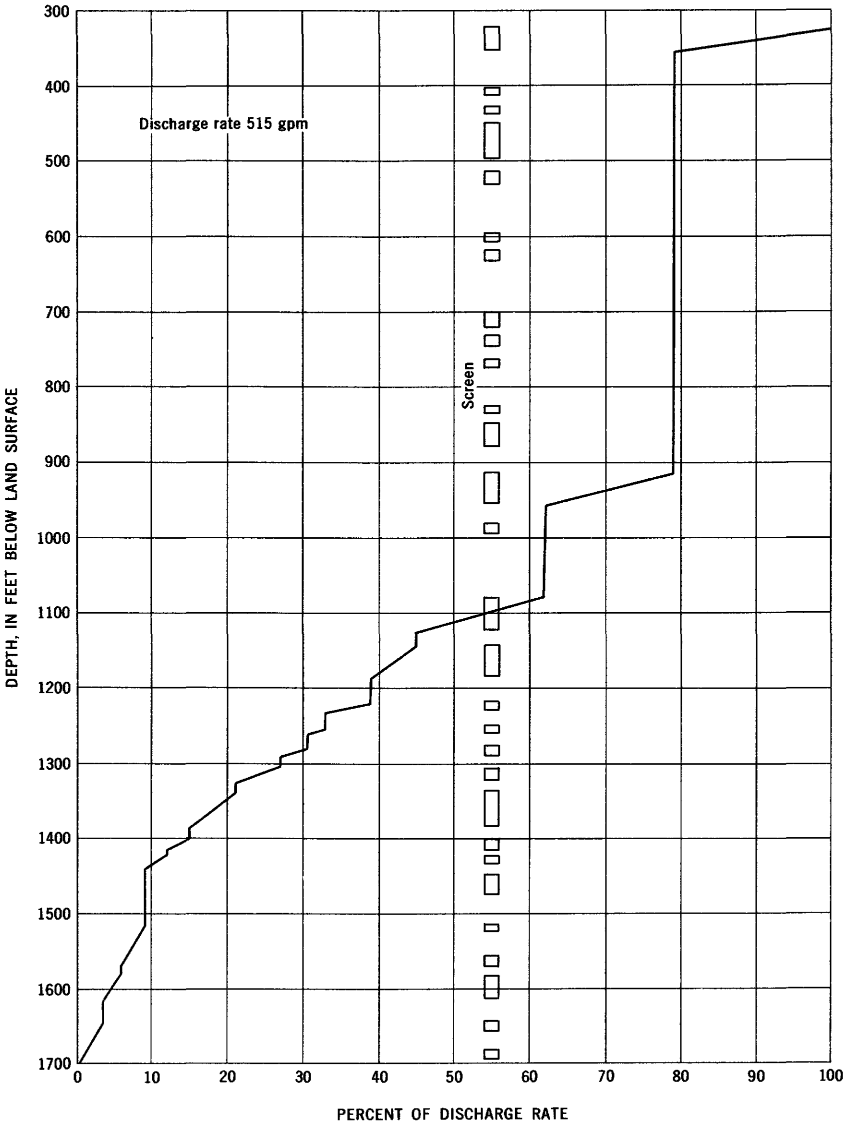

FIGURE 15.—Water yield from screens in well 19.7.13.114b(LA–1B), September 1960.

WELL-FIELD OPERATION

PUMPING INTERVALS

The supply wells are not pumped continuously, but generally operate part of each day. Some wells operate as much as 18 hours a day or even 2 to 3 days continuously during a warm dry month, such as June; however an 8- to 12-hour pumping day is more common during other months. An analysis of the pumping hours during 1961 indicated that the wells operated about 30 percent of the total possible time in January, February, March, November, and December; about 40 percent of the time in April and August; about 50 percent of the time in September and October; and 60 to 75 percent of the time in May, June, and July. The average pumping time for 1961 was about 40 percent. The largest percentage of operating time in a year by any of the supply wells was 68 percent by wells 14.312(LA–6) and 15.434 (LA–5) in 1951. An analysis of the percentage of time the wells were pumped is shown in table 3 for the years 1952 through 1961. In general, pumping in the 6-month period April through September is more intense than in the other 6 months of the year.

TABLE 3.—*Pumping time, in percent of total possible time each year, of the municipal supply wells, Los Alamos, N. Mex., 1952–61*

Well	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
Los Alamos Canyon well field										
19.7.13.114b(LA–1B)	------	------	------	------	------	------	------	------	------	42
14.221(LA–3)	29	35	30	25	21	12	18	21	25	22
14.222(LA–2)	24	25	30	25	22	12	13	18	25	24
14.312(LA–6)	36	36	33	33	39	32	34	35	47	37
15.434(LA–5)	39	37	29	36	40	33	34	35	47	40
22.114(LA–4)	39	35	24	30	39	32	34	35	47	42
Guaje Canyon well field										
19.7.4.133(G–3)	27	37	31	28	35	28	31	34	40	45
4.411(G–2)	27	36	31	27	36	29	29	33	41	41
4.441(G–1A)	------	------	------	------	36	28	30	34	42	49
4.444(G–1)	28	37	30	27	34	24	28	34	41	48
5.112(G–5)	29	16	30	29	37	27	17	33	32	45
5.231(G–4)	27	31	26	13	21	15	22	21	28	32
Average	30	32	29	27	33	25	26	30	38	39

PUMPING RATES

Most of the supply wells can be pumped at a discharge rate higher than their in-service pumping rate. Most of the wells except 13.114 (LA–1), 14.221(LA–3), and 14.222(LA–2) were pumped during either development or acceptance tests at rates as high as 950 gpm. The discharge rate at which each well is pumped under normal conditions is believed to be the optimum advisable rate considering the condition of the well.

The optimum discharge rate was determined by tests made after the well was developed. The range in average monthly pumping rates for the wells has been from 140 to 740 gpm (figs. 3–14). In 1961 the rate ranged from 250 to 620 gpm. In 1961, only well 5.231 (G–4) was pumped at less than 300 gpm; wells 4.133(G–3), 14.221(LA–3), and 14.222(LA–2) were pumped between 300 and 400 gpm; wells 4.411 (G–2), 4.444(G–1), and 15.434(LA–5) were pumped between 400 and 500 gpm; wells 4.441(G–1A), 5.112(G–5), 13.114b(LA–1B), 14.312 (LA–6), and 22.114(LA–4) were pumped between 500 and 600 gpm. (See figs. 3–14.)

AMOUNT OF WATER PUMPED

The amount of water pumped from wells each year to supply the town of Los Alamos has increased from about 13 million gallons in 1946 to 1,170 million gallons in 1961 as shown in table 4. The Los Alamos Canyon well field produced all the water withdrawn from wells until 1950, and produced 50 percent or more of the annual pumpage until 1956. Since 1956 the Guaje Canyon well field has produced 50 percent or more of the annual pumpage.

Some wells produce a greater percentage of the annual pumpage than others. (See table 5.) Wells 14.312(LA–6), 15.434(LA–5), and 22.114(LA–4) have been, until 1961, the most heavily pumped wells in the Los Alamos Canyon field. These three wells for the period 1946–61 yielded about 42 percent of the total pumpage from both fields. In the Guaje Canyon field pumping has been most intense in wells 4.411(G–2), 4.441(G–1A), and 5.112(G–5). Well 5.231(G–4) has been pumped lightly because of deteriorating well characteristics. The following tabulation lists the wells according to their yield with respect to total pumpage for the period 1946–61.

Well	*Pumpage, 1946–61 (million gallons)*
19.7.14.312(LA–6)	1,604
22.114(LA–4)	1,545
15.434(LA–5)	1,401
4.411(G–2)	891
4.444(G–1)	860
5.112(G–5)	825
14.221(LA–3)	760
4.133(G–3)	749
19.7.4.441(G–1A)	718
14.222(LA–2)	649
5.231(G–4)	414
13.114(LA–1)	163
13.114b(LA–1B)	161
Total	10,740

TABLE 4.—*Annual pumpage, in thousands of gallons, in Los Alamos and Guaje Canyons near Los Alamos, N. Mex., 1946–61*

Well	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
Los Alamos Canyon																
19.7.13.114(LA-1)	12,154	51,520	34,428	26,633	10,642	14,601	3,449	0	0	9,719	0	0	0	0	0	0
13.114b(LA-1B)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	36,343	124,745
14.221(LA-3)	---	65,281	81,790	42,633	58,627	66,859	58,562	69,672	57,312	48,653	42,129	26,077	33,629	34,953	38,397	35,742
14.222(LA-2)	605	27,766	58,689	41,699	17,793	57,714	49,486	47,179	56,821	49,377	44,168	29,614	31,136	40,734	51,608	44,397
14.312(LA-6)	---	---	4,859	95,815	167,923	201,476	110,333	113,837	107,106	107,959	125,794	102,406	106,930	108,319	138,627	112,512
15.434(LA-5)	---	---	40,368	58,458	130,077	187,397	109,588	103,929	80,104	97,252	104,519	86,042	89,909	93,499	119,060	100,310
22.114(LA-4)	---	---	42,728	37,489	164,949	173,648	119,572	109,115	78,194	94,484	120,222	105,371	110,341	113,503	145,595	129,685
Total	12,759	144,567	262,862	302,727	550,011	701,695	450,990	443,732	379,537	407,446	436,832	349,510	371,945	391,008	529,630	547,391
Guaje Canyon																
19.7.4.133(G-3)	---	---	---	---	---	7,300	65,450	76,356	66,062	69,438	87,945	70,207	69,490	74,593	82,466	79,932
4.411(G-2)	---	---	---	---	---	3,935	78,336	105,555	86,330	78,790	95,778	76,147	80,112	84,606	96,560	105,272
4.441(G-1A)	---	---	---	---	---	---	---	---	4,599	52,996	107,725	87,002	92,542	102,656	122,760	147,274
4.444(G-1)	---	---	---	---	2,770	37,750	75,463	97,278	77,779	70,480	83,190	55,876	68,055	82,409	96,022	112,419
5.112(G-5)	---	---	---	---	---	6,709	73,750	37,469	80,930	82,362	97,042	64,118	49,064	101,685	98,040	134,006
5.231(G-4)	---	---	---	---	---	12,546	56,873	55,234	58,773	22,703	33,902	24,176	35,933	31,614	36,986	45,024
Total	---	---	---	---	2,770	68,240	349,872	371,892	374,473	376,769	505,582	377,526	395,196	477,563	532,834	623,927

TABLE 5.—*Percentage of total annual pumpage in Los Alamos and Guaje Canyons near Los Alamos, N. Mex., 1946–61*

Well	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
Los Alamos Canyon																
19.7.13.114(LA-1)	95	36	13	9	2	2	1	0	0	1	0	0	0	0	0	0
13.114b(LA-1B)	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	3	10
14.221(LA-3)	--------	45	31	14	11	9	7	8	8	6	5	4	4	4	4	3
14.222(LA-2)	5	19	23	14	3	7	6	6	7	6	5	4	4	5	5	4
14.312(LA-6)	--------	--------	2	32	30	26	14	14	14	14	13	14	14	13	13	10
15.434(LA-5)	--------	--------	15	19	23	24	14	13	11	12	11	12	12	11	11	9
22.114(LA-4)	--------	--------	16	12	30	22	15	13	10	12	13	14	14	10	14	11
Total	100	100	100	100	99	90	57	54	50	51	47	48	48	43	50	47
Guaje Canyon																
19.7.4.133(G-3)	--------	--------	--------	--------	--------	1	8	9	9	9	9	10	9	9	8	7
4.411(G-2)	--------	--------	--------	--------	--------	1	10	13	11	7	10	10	11	10	9	9
4.441(G-1A)	--------	--------	--------	--------	--------	--------	--------	--------	1	10	11	12	12	12	12	12
4.444(G-1)	--------	--------	--------	--------	1	5	9	12	10	9	9	8	9	10	9	10
5.112(G-5)	--------	--------	--------	--------	--------	1	9	5	11	11	10	9	6	12	9	11
5.231(G-4)	--------	--------	--------	--------	--------	2	7	7	8	3	4	3	5	4	3	4
Total	--------	--------	--------	--------	1	10	43	46	50	49	53	52	52	57	50	53

The amount of water pumped from each well varies from month to month. (See figs. 3–14.) The months of largest pumpage generally are May, June, and July. The largest pumpage in any month from a single well was 26.5 million gallons from well 14.312(LA–6) in October 1950. The largest monthly pumpage from each well is summarized in the following table.

Well	*Date*	*Pumpage 1946–61 (millions gallons)*
19.7.14.312(LA–6)	October 1950	26.5
22.114(LA–4)	August 1950	24.8
15.434(LA–5)	May 1950	22.9
5.112(G–5)	June 1961	18.6
4.441(G–1A)	June 1961	18.4
4.444(G–1)	July 1951	17.6
13.114b(LA–1B)	July 1961	17.0
4.411(G–2)	June 1954	14.6
4.133(G–3)	June 1958	12.6
14.221(LA–3)	July 1947	11.9
5.231(G–4)	June 1954	11.3
14.222(LA–2)	June 1951	8.5
13.114(LA–1)	January 1947	8.1

GEOLOGY OF THE MAIN AQUIFER

The main aquifer is the Tesuque Formation and younger rocks of the Santa Fe Group of middle(?) Miocene to Pleistocene(?) age which comprise a thick accumulation of unconsolidated to slightly consolidated sedimentary rocks consisting of poorly sorted silt, sand, gravel, and conglomerate. The silt would be more accurately described as sandy silt and the sand as silty sand. All the rocks are partially cemented with calcium carbonate. Beds of clay are common; however, individual beds rarely are more than a few feet thick (pls. 2 and 3).

Igneous rocks consisting of basalt flows and breccias (basaltic rock of Chino Mesa, Griggs, 1964) are interbedded with the sedimentary rocks. The thickness of individual flows ranges from a few feet to several tens of feet. The combined thickness of the igneous rocks in a section of the aquifer is small compared with the total thickness of the aquifer. Basalt was reported in the logs of all wells in the Guaje Canyon field except well 4.411(G–2), and an interpretation of an electrical log (pl. 3) of that well indicates that some basalt probably was drilled between the depths of 575 and 585 feet in well 4.411(G–2) also. The log of well 4.444(G–1), about 2,500 feet west of well 4.411 (G–2), indicates that below the depth of 1,540 feet basalt flows and breccias form a single sequence about 270 feet thick. The transmissibility of the main aquifer probably is greater where a considerable thickness of basalt is a part of the main aquifer. No basalt is reported in the logs of wells in the Los Alamos Canyon field (pl. 2).

Fine sediments interbedded with coarser sediments make the vertical permeability much lower than the horizontal permeability. None of the beds in the Tesuque Formation are impermeable; however, the permeability of some beds is sufficiently low to restrict the upward movement in the discharge area near the river and causes artesian pressure in the main aquifer near the river. Water leaks through these beds of low permeability to the Rio Grande, the natural discharge point for the main aquifer in the Los Alamos area.

Beds of low permeability and of sufficient areal extent to isolate hydraulically some water-bearing beds from all others over an appreciable distance probably are not present in the Tesuque Formation in the Los Alamos area. A study of available data did not reveal a major separation of water-bearing beds in the main aquifer that could be traced throughout the Los Alamos area. Water-bearing beds in the upper 1,500 to 2,000 feet of the Tesuque Formation probably are sufficiently interconnected to form a common aquifer.

Griggs (1964) gives a more complete description of the rocks of the Santa Fe Group in the Los Alamos area.

BOUNDARIES OF THE MAIN AQUIFER

Some aquifers extend for tens of miles in all directions with hydrologic continuity and are considered to have infinite areal extent. The main aquifer of the Pajarito Plateau, however, has geologic and hydrologic boundaries on the east and west that limit the extent of the aquifer and affect the ground-water regime in the Los Alamos well fields.

The hydrologic continuity of the aquifer is interrupted on the east at the Rio Grande. Water moving eastward through the main aquifer is discharged naturally here, and no water in the aquifer moves further east than the river. If pressure in the aquifer west of the river were lowered sufficiently ground water probably could move westward from east of the river in the lower part of the aquifer. The river also might recharge the aquifer. There is no geologic discontinuity within the Tesuque Formation at the Rio Grande. The river boundary is purely hydrologic, but it forms an effective limit of eastward movement of water in the aquifer that exerts an influence on water pressure in the main aquifer in the well fields.

Although the exact nature and position of the western boundary of the main aquifer is not known, interpretations of available data indicate that a geologic boundary terminates the aquifer on the west side of the plateau. Data from two deep holes drilled in Los Alamos indicate that latite and quartz latite flows and pyroxene andesite flows of the Tschicoma Formation (Griggs, 1964) of the volcanic center abut and interfinger with the Tesuque Formation and younger rocks of the Santa Fe Group. The main aquifer probably terminates on the west at that contact, which may be 1 to 5 miles west of Los Alamos. Some water from the Valles Caldera of the Jemez Mountains (fig. 2) may move through fractures in rocks of the Tschicoma Formation and enter the main aquifer; however, the Tschicoma rocks are not a part of the main aquifer.

Several north-south trending faults have been mapped in the Los Alamos area (Griggs, 1964). Data from pumping tests are inconclusive as to effects of these faults on the movement of water in the main aquifer.

The Rito de los Frijoles at the southern limit of the area mapped on plate 1 has perennial flow, but the stream probably is not a hydrologic boundary for the main aquifer. Studies of gain and loss of flow show that the stream gains flow from seeps and springs in the Tschicoma Formation from the stream head eastward to the Pajarito fault zone (pl. 1) and loses flow between the fault zone and the Rio Grande. Most of the loss in flow is attributed to evapotranspiration and water use at the Bandelier National Monument headquarters. The Rito de los Frijoles probably does not constitute a hydrologic boundary for the main aquifer because water is not discharged from the aquifer to the Rito de los Frijoles, and the aquifer receives little if any recharge from the stream.

The northern and southern limits of the main aquifer are outside the area shown in plate 1. It is assumed that these boundaries are remote and have no appreciable control on ground-water movement near the supply wells.

The total thickness of the sedimentary and igneous rocks comprising the main aquifer in the Los Alamos area is unknown. Well 13.114b (LA–1B), the deepest hole drilled in the area, was bottomed in sandy silt at a depth of 2,256 feet and an altitude of 3,366 feet above mean sea level. The material at the 2,256-foot depth appeared to be water bearing and within the main aquifer. The lower limit of the aquifer is at greater depth, probably within the Santa Fe Group.

The Santa Fe Group is underlain by older rocks having much less permeability than those of the main aquifer. The older rocks are not known to be an aquifer in the Los Alamos area and probably constitute an underlying confining bed for water in the main aquifer.

The upper limit of the main aquifer is not well defined either throughout the Pajarito Plateau area or even in the well fields. The static water levels in wells are not necessarily an indication of the top of the aquifer in the plateau area because of the varied conditions of ground-water occurrence. Records of wells and test holes are incomplete in regard to identifying bodies of water perched above the main aquifer, artesian conditions, and change in head with depth in the main aquifer. The small number and poor distribution of these wells and test holes restrict the study of the aquifer limits.

HYDROLOGY OF THE MAIN AQUIFER

RECHARGE TO AND NATURAL DISCHARGE FROM THE MAIN AQUIFER

Recharge to the main aquifer may be entirely from precipitation between the eastern and western boundary of the aquifer and from streamflow moving eastward across the western boundary. A third source, however, may be water moving from the Valles Caldera (fig. 1) through the Tschicoma Formation.

Recharge by infiltration of water on the mesas probably is small, because the Tshirege Member of the Bandelier Tuff capping the mesas resists the downward movement of water to the underlying rocks. Abrahams and others (1961, p. 142–145) concluded that little or no water enters the Tshirege Member of the Bandelier Tuff from precipitation on the mesas where normal soil cover on the tuff is undisturbed. Much of the water that enters the Tshirege Member where the soil cover is absent probably moves laterally through joints in the tuff and discharges into the canyons or is evaporated from canyon walls.

Much of the recharge on the plateau is through the floor of canyons. Streamflow on canyon floors cut into the Otowi or Guaje Members of the Bandelier Tuff, the Puye Conglomerate of the Santa Fe Group, or into alluvium loses water readily to those rocks. Streamflow on the floor of canyons cut into the Tschicoma Formation or the Tshirege Member of the Bandelier Tuff loses little if any water as seepage into these rocks.

Studies of seepage losses in several canyons of the plateau show that more surface water infiltrates in the western one-third to one-half of the plateau than in the eastern half. Runoff from storms and snowmelt on the Sierra de los Valles seldom flows more than halfway across the plateau before infiltrating the permeable rock of the canyon floor. Storm runoff large enough to reach the Rio Grande is rare.

All water that infiltrates the canyon floors does not reach the main aquifer. Some is lost by evaporation and transpiration and some issues as springs in the lower reaches of the canyons.

The amount of recharge has not been determined by direct methods, but a rough estimate can be made by noting the gain in flow of the Rio Grande. Prior to pumping of the supply wells, the ground-water system was in dynamic equilibrium—the average annual recharge and natural discharge were equal. A measure of the discharge rate under these conditions would be an approximation of the recharge rate. The Rio Grande is the principal point for ground-water discharge; consequently a measure of the gain in flow of the Rio Grande in the plateau area would be the basis for estimating the recharge rate to the main aquifer. Griggs (1964) indicated that flow in the Rio Grande in the dry season before the supply wells were in use, increased 500 to 600 gpm per mile in the 21-mile reach immediately downstream from Otowi Bridge. All of this increase in flow does not come from west of the river, but is the sum of the ground-water discharge to the river from both east and west. If 250 to 300 gpm was entering the river from the west in each mile between Otowi Bridge and Rito de los Frijoles, a river distance of 11.5 miles, the average annual recharge to the main aquifer was about 4 to 5 million gallons per day, or 1,400 to 1,800 million gallons per year. All the water recharged to the aquifer is assumed as discharged to the river.

The average annual rate of natural discharge to the Rio Grande from the main aquifer will decrease by the amount of the average annual pumpage from the supply wells. The decrease in natural discharge will be gradual. If the average annual pumpage is less than the average annual recharge, the hydraulic system will, in time, reach a new dynamic equilibrium and water levels will cease to decline. The estimated annual recharge of 1,400 to 1,800 million gallons is more than the 1,170 million gallons pumped in 1961, the maximum pumpage on record. If the recharge and pumpage relationship is as expressed above, then continued pumping at the 1961 rate will result in a new dynamic equilibrium in the ground-water system.

OCCURRENCE OF WATER IN THE MAIN AQUIFER

ARTESIAN AND WATER-TABLE CONDITIONS

The main aquifer beneath the Pajarito Plateau is under water-table conditions near the western margin of the plateau and is artesian in a belt that is 2 miles or more wide along the eastern side of the plateau. Available data is insufficient for accurate location of the water-table-artesian boundary.

The westernmost deep holes drilled on the plateau, 19.6.9.443 and 17.243 (pl. 1), probably bottomed in the main aquifer. These holes were drilled into water-bearing rocks of the Tschicoma Formation and Puye Conglomerate above the Tesuque Formation. The water level reportedly rose several feet in both holes; however, this rise may be an illusion created by low rock permeability and consequent slow entry of water into the holes. Holes 23.411, 18.6.3.131, 3.241, and 3.443 were drilled into the main aquifer. Water levels reportedly rose 20 to 30 feet in these holes, but neither the driller nor the geologist working at the wells reported ground-water conditions as being artesian. The water levels were about 1,000 feet below land surface, and the difficulty of measuring levels at that depth during drilling may have cast some doubt about where the water was reached in relation to the actual static water level.

The municipal supply wells in Guaje Canyon are finished in the main aquifer. Drillers' logs do not mention artesian or water-table conditions; however, the rotary method of drilling these wells probably precluded identification of water levels until the well was cleared of drilling mud. Water levels upon completion of the wells were from 20 to 130 feet above the tops of upper well screens. These levels should not be interpreted to mean that the wells are artesian, because the upper screens probably were set opposite the uppermost water-bearing bed that in the consideration of the driller and geologist would yield water to the well in sufficient quantities to justify a screen. A study of electrical and lithologic logs (pl. 3) does not reveal a common and well-defined upper confining bed that would create artesian conditions in the main aquifer in the Guaje Canyon well field.

Coefficients of storage for the aquifer computed from tests of the Guaje Canyon wells, when the wells were new, are in the range that is associated with artesian conditions. An aquifer under water-table conditions in a formation like the Tesuque, where the vertical permeability is small and the thickness is large, probably would yield in a short-term aquifer test water from only a few water-bearing beds and a storage coefficient in the magnitude of that of an artesian aquifer. This aquifer, under a long-term period of pumping, probably would yield water from storage from all the saturated section by slow drainage and the coefficient of storage would be in the range associated with a water-table aquifer.

The main aquifer at the depth tapped by the Los Alamos Canyon wells is artesian, but it does not follow that the water in all water-bearing beds in the section in that area are artesian. Water in the aquifer in the vicinity of these wells and the Rio Grande has an upward component of movement; consequently, wells less than 100 feet deep in this area may be water-table wells, but wells of greater depth will be artesian. Wells 19.7.13.114(LA-1), 13.114b(LA-1B), 14.221(LA-3), and 14.222(LA-2) flowed when they were completed. Artesian conditions in the lower part of the Los Alamos Canyon field are in part the result of proximity to the natural discharge area.

In general, water in the main aquifer beneath the Pajarito Plateau is under water-table conditions except in the vicinity of the river where conditions vary from water table at shallow depth to artesian at greater depth.

The question of artesian versus water table condition is important in defining those areas in which waste contaminants from laboratory processes at Los Alamos could reach the main aquifer. Contaminants could reach the main aquifer where water-table conditions are present but not where artesian conditions prevail.

PRESSURE AND HYDRAULIC GRADIENT

The pressure of the water at a given point in the main aquifer is the pressure caused by water at higher altitude in the aquifer. Pressure decreases in the aquifer in the direction of water movement and may differ between two points, either laterally or vertically. Water, like any liquid that is free to move, will move from points of higher pressure to points of lower pressure. Vertical differences of pressure occur in the aquifer in the recharge and natural discharge areas. Pressure decreases with depth in the recharge area in the western part of the plateau and water moves downward in the aquifer. This decrease in pressure with depth is not documented by data from test holes drilled in the western part of the plateau. The lack of data probably can be attributed to the drilling techniques, the infrequency of measuring water levels during drilling because of the great depth (about 1,000 ft) to water, and the inaccuracy of measuring water-level changes at that depth. Perched water reported in some instances actually might have been within the main aquifer but the low permeability of the materials created the impression of separate water bodies. Drilling has not been sufficiently extensive in the western part of the plateau to explore the pressure difference in that part of the main aquifer.

Differences in pressure with depth near the natural discharge area have been observed in the Los Alamos Canyon wells. The best example is the difference in water levels between well 13.114(LA-1) having a well depth of 870 feet, and well 13.114b(LA–1B) having a well depth of 1,750 feet. The wells are about 150 feet apart and the water level in well 13.114b(LA–1B), when completed in 1960, was at least 30 feet higher than the level in well 13.114(LA–1). The difference probably was greater, inasmuch as a true pressure in the aquifer below 870 feet was not taken. Well 13.114b(LA–1B) has about 197 feet of screen in the interval of 320 to 880 feet, and water undoubtedly is moving up from depth and out through those screens. The measurement of shut-in pressure of well 13.114b(LA–1B) that showed a water level about 30 feet higher than the level in well 13.114 (LA–1) was too low by the amount of pressure relief that was created by the leakage of water through the upper screens.

An imaginary surface that coincides with the water level in wells tapping a common aquifer is called a piezometric surface. A contour map of the piezometric surface of the main aquifer of the Pajarito Plateau would be helpful in evaluating pressure distribution in and around the two well fields; however, such a map was not prepared for this study because the pressure in the aquifer is not known at a sufficient number of key points. A generalized concept of the pressure distribution in the main aquifer was obtained from a study of water levels in the supply wells and in test holes west and south of the well fields. The pressure is highest on the west side of the plateau and is lowest at the Rio Grande; consequently, the movement of water in the main aquifer is eastward beneath the plateau to the Rio Grande.

The slope of the piezometric surface, or hydraulic gradient, is not uniform eastward across the plateau. Prior to pumping in the well fields, the hydraulic gradient was about 130 feet per mile between test wells 19.6.17.243 and 9.443, 100 feet per mile between test wells 17.243 and 23.411, and 25 feet per mile between test well 23.411 and well 19.7.22.114(LA–4). The altitude of the water surface in well 22.114 (LA–4) was measured at the time the well was completed.

Profiles (pl. 4) of the piezometric surface in the main aquifer along a line through wells 5.112(G–5) and 13.114(LA–1) show the hydraulic gradient through the Guaje Canyon well field and changes in gradient that have occurred because of pumping. The alinement of these profiles probably is not parallel with the maximum hydraulic gradient in the vicinity of the well fields. Altitudes of water levels in wells of the Guaje Canyon well field are projected to the line as are those for three wells of the Los Alamos Canyon field.

The hydraulic gradient through the Guaje Canyon field prior to pumping of that field is approximated by the profile for the year 1952. The gradient is not uniform through the well field. The gradient is anomalously steep (about 110 feet per mile) between wells 4.133(G–3) and 4.411(G–2) compared with about 50 feet per mile immediately upgradient and downgradient. The reason for the steep gradient is not known. Griggs (1964) is of the opinion that a fault is between the two wells and acts as a partial barrier to the eastward movement of ground water. Analyses of pumping test data are inconclusive concerning such a barrier. The steep gradient may be associated with a change in transmissibility related to the thick section of basalt noted in wells to the west. The basalt may create a higher transmissibility in the aquifer west of wells 4.133(G–3) and 4.411(G–2).

The lowering of pressure in the aquifer near well 4.411(G–2), as the result of pumping in the Los Alamos Canyon well field, probably will be several feet by 1962. If there is an abrupt change in transmissibility just west of the well, either a decrease or an increase in transmissibility, the decline in water level would cause a steepening of the hydraulic gradient across the area of transmissibility change.

The anomalously steep gradient may be a combination of factors, but an abrupt change in transmissibility is a highly probable key factor.

Hydraulic pressure and gradient in the Guaje Canyon well field change primarily in response to pumping in that field; however, some changes occur in response to pumping in the Los Alamos Canyon well field. Plate 4 illustrates the changes in pressure and gradient that have occurred in the Guaje Canyon field. Interpolation of the gradient and changes in gradient between wells 4.444(G–1) and 14.221 (LA–3) may be in error because of the distance in which there is no water-level information.

The profiles of the hydraulic gradient were not extrapolated to the Rio Grande because of the pressure change with depth. The water level in a well near the river would vary with the depth of the well. In general, the deeper the well, the higher the head.

WATER-LEVEL FLUCTUATIONS IN THE SUPPLY WELLS

The ground water in the main aquifer beneath the Pajarito Plateau was in approximate dynamic equilibrium prior to the construction of the supply wells as natural discharge equaled recharge. Changes in the amount of ground water in transient storage in the main aquifer were small and were caused primarily by changes in rates of recharge. Pumping of wells disturbed the natural equilibrium by increasing the rate of discharge. The effect of pumping on pressure in the aquifer was manifested by a lowering of the pressure in the vicinity of the wells, a lowering that decreased with distance from the wells and increased with the length of time the wells were pumped. Pumping of the municipal supply wells is the only pumping in the Los Alamos area that has measurably disturbed the natural equilibrium in the main aquifer of the Pajarito Plateau.

The amount of pressure decrease due to distance from the well field is unknown because a decrease that can be attributed to pumping of the well field has not been identified in water-level records from observation wells outside the well field. Observation wells in which water levels might be affected by the well-field pumping are well 19.6.23.411, about 4½ miles distant, and wells 18.6.3.131, 3.241, and 3.443, about 6 miles distant. Water-level observations will be made periodically in these wells to monitor the pressure changes caused by pumping supply wells in the Pajarito Plateau.

Good to excellent records of water-level fluctuations in the supply wells are available for much of the time the wells have been in operation. Graphic representations of those fluctuations condensed to monthly average pumping and nonpumping water levels are shown in figures 3–14.

Water-level data are more complete and more reliable for the period 1951–61 than for the period 1947–51. Water levels were measured about once a week in the Los Alamos Canyon wells prior to 1951. Water-stage recorders connected to air lines were installed at each well in 1950; the recorder obtained a continuous trace of the water level.

The water level in a supply well fluctuates in response to pumping of the well and pumping of other supply wells. Spacing between wells is sufficient generally at least 2,500 feet, to minimize short-term fluctuations from one well to another resulting from intermittent daily pumping.

Nonpumping and pumping levels, averaged by months in figures 3–14, have a seasonal cycle that is characterized by the yearly high level occurring between January and April and the yearly low level occurring between June and September. The magnitude of the difference between high and low levels, either in the nonpumping or in the pumping level, varies from well to well and is governed by the specific capacity of the well and the pumping intensity. The largest range in fluctuation in a nonpumping level during a year was about 150 feet in well 19.7.14.222(LA–2) in 1951. Nonpumping level fluctuations of 50 to 100 feet are common in wells 14.221(LA–3) and 14.222(LA–2), both wells having low specific capacities. Fluctuations each year in nonpumping levels in other supply wells generally range from 20 to 40 feet.

Pumping levels fluctuate through a range similar to that of the nonpumping levels; the hydrographs of nonpumping and pumping levels in a well show a parallel relationship, even when the pumping rate changes. (See figs. 3–14.) A divergence from that parallel relationship generally indicates that some screens are becoming blocked by fine material accumulating back of the screens or accumulating in the well and burying some screens. This accumulation results in a reduction in effective screen area. An example of a divergence of the nonpumping and pumping levels is shown in the hydrograph of water levels in well 4.133(G–3). (See fig. 9.)

A study of figures 3–14 shows that net annual changes in water level in each well is related to the trend in the amount of water pumped from that well each year. Approximately equal annual pumpage causes a persistent but progressively decreasing annual decline in water level. The net decline increases when the pumpage is increased appreciably. A net rise in water level for a year or a series of years generally results when the amount of water pumped annually is appreciably reduced from that of the preceeding year or years. The nonpumping water levels in wells 13.114(LA–1), 14.221(LA–3), 14.222 (LA–2), and 5.231(G–4) rose after pumping had been reduced. A net rise in water level occurred in 1952 in wells 14.312(LA–6), 15.434 (LA–5), and 22.114(LA–4) in response to a reduction in pumping of these wells when the Guaje Canyon field was put into operation.

A comparison of initial water levels (level at the time the well was drilled) with the highest nonpumping levels in 1961 (not given in figs. 3–14) shows net declines in levels in all wells. Declines in the Alamos Canyon field were about 40 feet, or 3 feet per year, in wells 13.114 (LA–1), 14.221(LA–3), and 14.222(LA–2), and about 80 to 90 feet, or 7 feet per year, in wells 14.312(LA–6), 15.434(LA–5), and 22.114(LA–4). Declines in the Guaje Canyon field were about 55 to 60 feet, or 5 to 6 feet per year, in wells 4.411(G–2) and 4.444(G–1); about 45 feet, or 5 feet per year, in well 4.133(G–3); about 35 feet, or 6 feet a year, in well 4.441(G–1A); about 35 feet, or 4 feet per year, in well 5.231(G–4); and about 20 feet, or 2 feet per year, in well 5.112 (G–5).

HYDRAULIC CHARACTERISTICS OF THE MAIN AQUIFER

COEFFICIENTS OF TRANSMISSIBILITY AND STORAGE COMPUTED FROM AQUIFER TESTS

An aquifer test is the collection of data concerning water-level, or head changes, with respect to time of occurrence in an aquifer in response to pumping, cessation of pumping, or recharging a well tapping that aquifer, and the analysis of that data with respect to geologic and hydrologic parameters to determine the water storage and transmission characteristics of the aquifer.

The data-collection phase of aquifer tests using the Los Alamos municipal supply wells generally consisted of: (1) Pumping a well at a constant discharge rate for a selected period of time that ranged from 8 hours to 14 days, a common length of time being 48 hours; (2) measuring the water-level decline in the pumped well with an air line and pressure gage and in nearby supply wells with a steel tape; and (3) measuring the water-level rise in these wells with a steel tape after pumping was stopped. Aquifer characteristics computed from water-level recovery measured by the wetted tape method were more reliable than the characteristics computed from air-line measurements of drawdown in the pumped well.

Computation of aquifer characteristics was by the Theis nonequilibrium and recovery formulas (Theis, 1935; Ferris and others, 1962, p. 92–102). Coefficients of transmissibility and storage computed from the aquifer test of a single well are applicable only to the aquifer in the vicinity of the well, and, because of only partial penetration of the aquifer by the well, probably are representative only of that part of the aquifer which has been penetrated.

Coefficients of transmissibility computed from aquifer tests made in the Los Alamos Canyon well field prior to 1961 ranged from 1,400 to 17,000 gpd per ft. Coefficients of transmissibility determined by Theis and Conover (1962) from a 14-day test involving wells 13.114(LA–1), 14.221(LA–3), and 14.222(LA–2) ranged from 1,400 to 4,100 gpd per ft and coefficients of storage were between 0.0033 and 0.0035. These three wells are only 870 feet deep and penetrate less than one-third of the full thickness of the main aquifer. Theis and Conover concluded that these coefficients probably are indicative only of the hydraulic properties in the upper 1,000 feet of the main aquifer near those wells and that the coefficient of transmissibility for that part of the aquifer probably is about 2,500 gpd per ft.

Coefficients of transmissibility computed from aquifer tests made in wells 13.114b(LA–1B), 14.312(LA–6), 15.434(LA–5), and 22.114(LA–4) prior to 1961 ranged from 13,000 to 18,000 gpd per ft, and averaged about 16,000. Coefficients of storage were not computed because water levels were measured only in the pumped well in each test.

Coefficients of transmissibility computed from aquifer tests made in the Guaje Canyon well field ranged from 7,500 to 25,000 gpd per ft according to Griggs (1964). The average is about 15,000 gpd per ft. Computed coefficients of storage are between 0.0002 and 0.0004 and average about 0.0003.

Aquifer characteristics computed from aquifer tests that have been made in the supply wells seemingly are not reliable for predicting the effect that future pumping will have on ground water in the main aquifer. The results of the aquifer tests are deficient because they are not representative of the full thickness of the aquifer and are applicable only to the aquifer in the vicinity of the well. All evidence indicates that the coefficient of transmissibility is not the same throughout the Los Alamos area, and that, in general, the true values are higher than those obtained from aquifer tests. Probably the coefficient of storage varies in the Los Alamos area, and is more nearly that of a water-table aquifer than an artesian aquifer.

COEFFICIENT OF TRANSMISSIBILITY ESTIMATED FROM NATURAL DISCHARGE

The coefficient of transmissibility can be estimated from the amount of natural discharge. Discharge to the Rio Grande was estimated as 250 to 300 gpm per mile of river or 360,000 to 430,000 gpd per mile of river. The hydraulic gradient near the river cannot be used to compute transmissibility because of the vertical component of water movement in that part of the aquifer. The gradient used to compute transmissibility should be measured where the vertical movement of water in the aquifer is at a minimum and should be representative of the gradient when undisturbed by pumping. The gradient of 25 feet per mile between wells 19.6.23.411 and 19.7.22.114(LA–4) probably is more representative of these conditions than that obtained from other data available. The coefficient of transmissibility computed using a gradient of 25 feet per mile is between 14,000 and 17,000 gpd per ft.

A METHOD OF DETERMINING AQUIFER CHARACTERISTICS FROM WATER-LEVEL AND PUMPAGE DATA

Part of this study was concerned with outlining a method by which aquifer coefficients might be determined from water-level changes that have occurred in the well fields as the result of pumping. Solution of the problem is complicated in that the coefficients may not be constant from place to place and some aquifer boundaries are poorly defined in respect to location and nature.

The coefficient of transmissibility and the coefficient of storage may have two values each; one for the western part of the plateau where the thick sequence of basaltic rocks form a part of the aquifer, and another for the central and eastern part of the plateau where the basaltic rocks are thin or absent in the aquifer. Formulas used in analyzing an aquifer system in respect to pumping and water-level fluctuations have these coefficients (two unknowns in this main aquifer) in one equation.

Boundary conditions if identified as to nature and location, can be simulated in aquifer-analysis formulas by applying the theory of images (Ferris and others, 1962, p. 144–166). The discharge boundary at the Rio Grande can be treated as a recharge boundary. This boundary can be simulated in an aquifer analysis with a series of hypothetical recharging wells located east of the river and forming a mirror counterpart of the real supply wells as to position and distance from the river.

The western boundary probably is an impermeable one that could be analyzed as a series of discharging image wells west of the boundary. Such analysis can be done only by trial-and-error estimates of the location of this boundary. The boundary effects that faulting may have created between the eastern and western boundaries probably can be ignored in determining aquifer coefficients until additional data are available to refine the computation of aquifer coefficients. The thickness of the aquifer is many times greater than the known displacement of faults between the Rio Grande and the Pajarito Faults; consequently, faulting probably has not interrupted the aquifer continuity in the plateau.

The hydraulic coefficient of the main aquifer can be determined by a method described in part by Theis and Brown (1954) whereby the drawdown is the result of cyclic pumping. The method would be one of trial-and-error assumption of coefficients and boundary conditions, and computing the drawdown for each set of assumed values. Trial-and-error is continued until the amount of water-level decline computed for all wells approximates the measured decline. Time did not permit the computations to be made to the desired end product; such an effort should be assigned to an electronic computer or an electrical analog analysis.

The basic formula used is the Theis nonequilibrium formula and written in the units used in this report is:

$$s=\frac{114.6Q}{T}\int_{1.87r^2S/Tt}^{\infty}\frac{e^{-u}}{u}\,du \tag{1}$$

where

$u=1.87r^2S/Tt$,
s=change in water level, in feet, at point of observation,
Q=discharge or recharge rate of well, in gallons per minute,
T=transmissibility, in gallons per day per foot,
r=distance, in feet, between discharge or recharge well and point of observation,
S=storage, expressed as a decimal fraction,
t=elapsed time, in days, since discharge or recharge started at rate Q.

Although the integral expression cannot be integrated directly, its value is given by the series:

$$\int_{1.87r^2S/Tt}^{\infty}\frac{e^{-u}}{u}\,du=W(u)=0.577216-\log_e u+u-\frac{u^2}{2.2!}+\frac{u^3}{3.3!}\cdot \tag{2}$$

The accuracy of this series for the purpose of the report is given by

$$W(u)=-0.577-\log_e u \tag{2a}$$

and expressed in common logarithms is

$$W(u)=-0.577-2.3\log u=-2.3(0.251+\log u). \tag{2b}$$

Equation 1 can be written

$$s=\frac{114.6Q}{T}W(u) \tag{3}$$

$$s=-\frac{114.6Q}{T}[2.3(0.251+\log u)] \tag{3a}$$

$$s=\frac{-264Q}{T}(0.251+\log u) \tag{3b}$$

$$s=\frac{-264Q}{T}[0.251+\log(1.87r^2S/Tt)]. \tag{3c}$$

Equation 3b is used to compute the net change in water level in a well when the discharge or recharge rate Q is constant; however, it can be adapted to compute the net change in water level where various discharge and recharge rates are used. When a well is discharging, the resultant change in water level is a decline; conversely, if the well is recharging, the resultant change in water level is a rise. If a well has been discharging at a constant rate and the rate is increased, the rate of water-level decline will increase. The total decline after a period of discharge would be equal to the decline that would result if the well had continued to pump at the initial rate for the entire period and a second well had started to pump beside the first well at the time the rate was increased and at a rate equal to the increment of increase. Consider again a well that has been pumping at a constant rate, but whose rate is decreased instead of increased. The total decline after a period of discharge would be equal to the decline caused by the continued pumping of the well at the initial rate minus the rise that would result if a well at the same place were recharged at a rate equal to the increment of decrease.

The net water-level change in an observation well after n periods at varying pumping rates of (Q_1, Q_2, Q_3 . . . Q_n) in equation 3 is

$$s_n=\frac{114.6}{T}[Q_1W(u)_1+\Delta Q_1W(u)_2+\Delta Q_2W(u)_3\ .\ .\ .\ \Delta Q_{n-1}W(u)_n] \quad (4)$$

where Q_1 is the original discharge rate, ΔQ_1 is the increment of change from Q_1 to Q_2, ΔQ_2 is the increment of change from Q_2 to Q_3, and ΔQ_{n-1} is the increment of change from Q_{n-1} to Q_n. Whenever the increment of change from one rate to the next is a decrease in rate, a minus sign is used before that segment in the equation to indicate a rising water level equivalent to that caused by a recharging well.

The computation of net change in water level is simplified when the duration of the period of discharge or recharge at each rate is equal. The record for each well was subdivided into 6-month periods—April through September and October through March. The basis of this subdivision was the large difference in pumping during the summer from that of the winter months. A period of less than a year was desirable because each well did not enter the supply system at the same time of year. A period shorter than 6 months could have been used, but the increase in volume of computations would not be justified by the refinement in accuracy. The initial 6-month period for a well was that period in which the well first entered the supply system; the final period was ended arbitrarily as of March 1962.

In the expression $u=1.87r^2S/Tt$ in equation 3b, t is in days; however, t can be replaced by t_p where $t=182.5t_p$ if the pumping period for each rate is 6 months. The number 182.5 is the number of days in a

6-month period, and t_p denotes the number of 6-month periods a well was pumped at a selected rate. Equation 3c now becomes

$$s=\frac{-264Q}{T}[0.251+\log(0.0102r^2S/Tt_p)]. \quad (5)$$

The pumping rate of a well in each 6-month period was computed as the total pumpage in that period divided by 262,800, the number of minutes in 182.5 days. The pumping rate for each well in each 6-month period together with the increment of change in rate from one period to another is given in table 6. The "B" columns show the increment of change in pumping rate that would be used in computing water-level changes.

The net water-level change that would occur in any supply well from the time it started pumping until March 1962, under assumed values for transmissibility and storage and an assumed location for the western boundary, is the sum of the changes caused by pumping of that well, pumping of other supply wells, and "pumping" of image wells that simulate the assumed boundary conditions. An extremely large number of computations are involved in computing water-level changes in the well fields under each assumption of coefficients and boundary location. Many combinations of conditions are possible; therefore the unknown coefficients were not determined for the period of this report. The massive task of following through to the end result could be done by programming an electronic computer or an electrical analog model. A sufficient number of computations were made using $T=15{,}000$ gpd per ft and $S=0.0003$, the average of the coefficients from aquifer tests, to determine that computed water-level declines were much greater than the measured declines. Coefficients of $T=15{,}000$ gpd per ft and $S=0.0003$ probably are too small. The coefficient of storage probably is as large as 0.005, a value in the lowest range for water-table conditions. The coefficient of transmissibility probably is more than 20,000 gpd per ft.

FUTURE WATER LEVELS IN WELLS PREDICTED FROM PAST WATER-LEVEL FLUCTUATIONS

The net change in the annual high nonpumping water levels that occurred from the time the well started pumping until the end of 1961 were studied to determine whether the future altitude of the water surface in the wells could be predicted from past water-level changes. The changes were plotted against the logarithm of time similar to the plotting of measured water levels when a well is being pumped in an aquifer test. The time unit was taken as a year instead

TABLE 6.—*Average rate of discharge for each 6-month period of record and change in rate from one period to the next in municipal supply wells, Los Alamos, N. Mex.*

[The average rate of discharge in a period is the total gallonage pumped divided by 262,800—the number of minutes in a 6-month period; discharge rate and change in rate are expressed in gallons per minute. Column A is average discharge rate; column B is change in rate and a minus (−) sign denotes a decrease in rate. All wells are in T. 19 N., R. 7 E., and segments in the well number designating township and range are omitted in the table heading]

6-month period	13.114(LA-1)		14.222(LA-2)		14.221(LA-3)		22.114(LA-4)		15.434(LA-5)		14.312(LA-6)		4.444(G-1)		4.441(G-1A)		4.411(G-2)		4.133(G-3)		5.231(G-4)		5.112(G-5)	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
10-46 to 3-47	80	80	22	22																				
4-47 to 9-47	79	−1	25	3	160	160																		
10-47 to 3-48	92	13	118	93	168	8																		
4-48 to 9-48	95	3	110	−8	162	−6	118	118	49	49														
10-48 to 3-49	5	−90	98	−12	123	−39	58	60	142	93	113	113												
4-49 to 9-49	67	62	79	−19	68	−55	67	9	100	−42	153	40												
10-49 to 3-50	47	−20	62	−17	61	−7	166	99	175	75	207	54												
4-50 to 9-50	22	−25	31	−31	138	77	346	180	261	86	363	156												
10-50 to 3-51	7	−15	62	31	125	−13	336	−10	253	−8	312	−51												
4-51 to 9-51	48	41	148	86	166	41	363	27	405	152	445	133	134	134							44	44		
10-51 to 3-52	7	−41	62	−86	63	−103	288	−75	313	−92	324	−121	47	−87			6	6			9	−35	48	48
4-52 to 9-52	6	−1	95	33	128	65	224	−64	205	−108	213	−111	172	125			208	202	180	180	155	146	179	131
10-52 to 3-53	.5	−5.5	84	−11	104	−24	161	−63	141	−64	153	−60	143	−29			154	−54	127	−53	104	−51	118	−61
4-53 to 9-53	0	−.5	88	4	155	51	263	102	239	98	262	109	231	88			251	97	174	47	154	50	72	−46
10-53 to 3-54	0		117	29	117	−38	154	−109	138	−101	186	−76	134	−97			150	−101	110	−64	68	−86	59	−13
4-54 to 9-54	0		112	−5	116	−1	118	−36	171	33	216	30	186	52			208	58	152	42	162	94	196	137
10-54 to 3-55	0		95	−17	92	−24	194	76	166	−5	176	−40	84	−102			106	−102	90	−62	2	−160	88	−108
4-55 to 9-55	22	22	113	18	111	19	197	3	212	46	263	87	179	95	145	145	185	79	170	80	63	61	205	117
10-55 to 3-56	15	−7	61	−52	58	−53	144	−53	130	−82	153	−110	102	−77	115	−30	110	−75	101	−69	41	−22	117	−88
4-56 to 9-56	0	−15	107	46	103	45	292	148	259	129	312	159	206	104	262	147	237	127	213	112	86	45	237	120
10-56 to 3-57	0		51	−56	47	−56	180	−112	146	−113	173	−139	105	−101	147	−115	127	−110	119	−94	43	−43	117	−120
4-57 to 9-57	0		76	25	67	20	252	72	205	59	246	73	126	21	218	71	190	63	175	56	59	16	164	47
10-57 to 3-58	0		30	−46	24	−43	129	−123	106	−99	125	−121	76	−50	110	−108	96	−94	88	−87	34	−25	65	−99
4-58 to 9-58	0		102	72	84	60	260	131	210	104	252	127	167	91	225	115	197	101	164	76	95	61	93	28
10-58 to 3-59	0		15	−87	54	−30	168	−92	137	−73	159	−93	119	−48	147	−78	121	−76	112	−52	46	−49	143	50
4-59 to 9-59	0		109	94	87	33	282	114	232	95	271	112	200	81	249	102	205	84	180	68	77	31	246	103
10-59 to 3-60	[1] 15	[1] 15	68	−41	48	−39	173	−109	142	−90	164	−107	106	−94	126	−123	108	−97	95	−85	41	−36	133	−113
4-60 to 9-60	[1] 62	[1] 47	130	62	100	52	371	198	299	157	351	187	233	127	303	177	231	123	200	105	74	33	300	167
10-60 to 3-61	[1] 147	[1] 85	57	−73	25	−75	151	−220	128	−171	135	−216	155	−78	203	−100	160	−71	131	−69	86	12	50	−250
4-61 to 9-62	[1] 295	[1] 148	109	52	98	73	323	172	263	135	317	182	265	110	344	141	244	84	168	37	99	13	350	300
10-61 to 3-62	[1] 175	[1] −120	55	−54	61	−37	163	160	108	−155	138	−179	115	−150	216	−128	151	−93	129	−39	72	−27	222	−128

[1] Data for replacement well 13.114b(LA-1B).

of the minute or day used in an aquifer test. The curves obtained by the plot were irregular until about 1957 at which time the curves began to assume a straight-line character. A straight line in this type of plot could signify steady-state conditions (no change in rate of decline as a function of time) in the hydraulic system near the wells. If steady-state had been achieved by 1957 or 1958 and pumping in the future were maintained at a reasonably uniform annual rate, the extrapolation of the straight line might forecast future water levels. The water-level data in most of the suppy wells is plotted for the 1957–61 period in figures 16 and 17 and the curves are extrapolated to 1980. Water-level decline curves were not prepared for wells 14.221(LA–3) and 14.222(LA–2) because of the interference in water levels in those wells resulting from the operation of well 13.114b(LA–1B) since 1960.

These curves indicate the amount of decline for the period of record; however, the depth to water in each well (nonpumping highs and pumping lows) also can be computed. The tabulation of pumping and nonpumping levels shown in table 7 is based on the assumption that the discharge rate at which a well is now (1961) being pumped

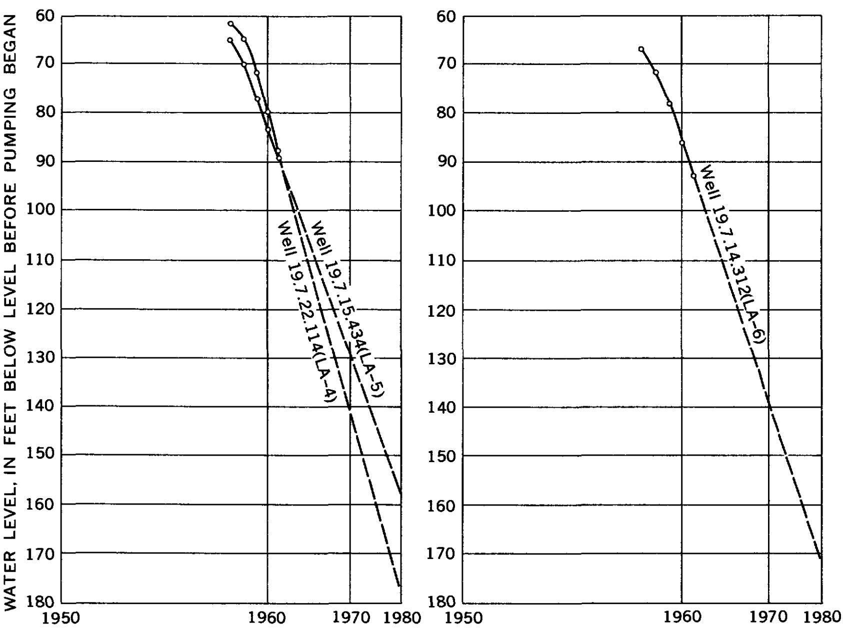

FIGURE 16.—Graph of water-level decline extrapolated from 1961 to 1980 for selected wells in Los Alamos Canyon near Los Alamos, N. Mex. Assumed basis for extrapolation: average annual pumping rate will not change after 1961; no new boundary effects will be reflected in water-level changes after 1961.

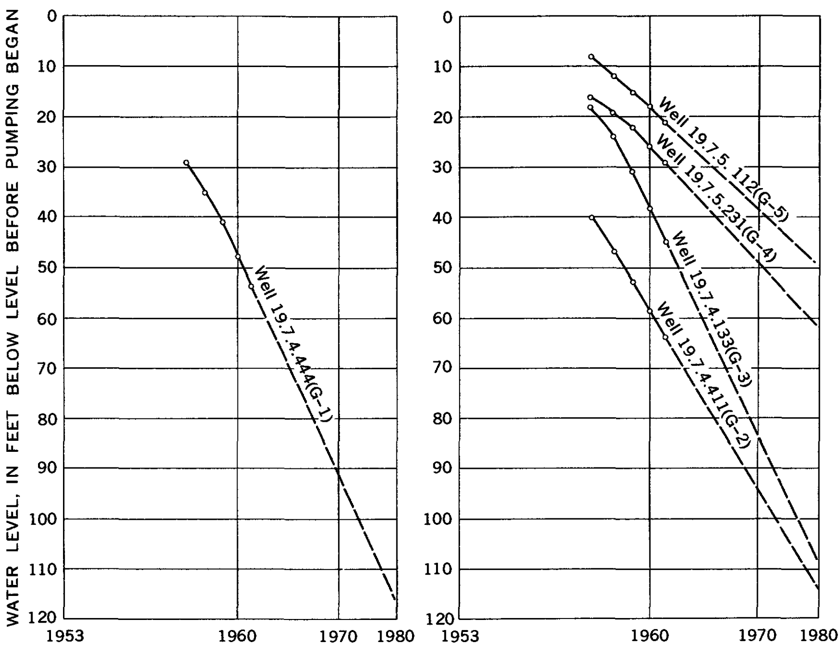

FIGURE 17.—Graph of water-level decline extrapolated from 1961 to 1980 for selected wells in Guaje Canyon near Los Alamos, N. Mex. Assumed basis for extrapolation: average annual pumping rate will not change after 1961; no new boundary effects will be reflected in water-level changes after 1961.

will continue to be the same in 1970 and 1980 and the specific capacity of the wells will remain constant.

TABLE 7.—*Estimated pumping and nonpumping water levels in municipal supply wells, Los Alamos, N. Mex., for the years 1970 and 1980*

Well	Discharge rate when pumped (gpm)	Water level, in feet below land surface			
		1970		1980	
		Non-pumping high	Pumping low	Non-pumping high	Pumping low
19.7.14.312(LA-6)	600	165	255	190	280
15.434(LA-5)	500	200	325	230	355
22.114(LA-4)	590	330	450	365	485
4.133(G-3)	470	370	470	395	495
4.411(G-2)	450	350	420	370	440
4.444(G-1)	560	245	355	290	400
5.112(G-5)	450	450	550	460	560
5.231(G-4)	300	400	540	410	550

The estimated depths to water in well 5.112(G-5) and 5.231(G-4) probably are too small if another supply well is added upgradient from well 5.112(G-5) and if well 5.231(G-4) is replaced by a well that can be pumped at a higher rate. The water level in well 22.114 (LA–4) probably would be no more than 5 feet lower in 1970 and no more than 10 feet lower in 1980 if one or two supply wells are placed along State Route 4 about 2 miles southwest of well 22.114(LA–4) in the years 1963–65. The decline caused by pumping these additional wells along State Route 4 would be less in other wells in the Los Alamos and Guaje Canyon fields.

CONCLUSIONS

The coefficient of transmissibility of the main aquifer near Los Alamos, N. Mex., probably is more than 20,000 gpd and the coefficient of storage probably is at least 0.005. Coefficients of transmissibility and storage computed from aquifer tests are not sufficiently accurate for predicting future well-field operation. Aquifer characteristics can be determined by the trial-and-error method described in this report. The computation should be done by an electronic computer or by an electrical analog model because of the large number of combinations of conditions that would have to be given a trial computation.

Water-level declines in most of the wells for the period 1961–80 were estimated by extrapolating the water-level trend of 1957–61. Pumping and nonpumping water levels in wells 14.312(LA–6), 15.434 (LA–5), and 22.114(LA–4) probably will decline about 45 to 50 feet from 1961 to 1970 and about 80 feet from 1961 to 1980. Water levels in wells 4.133(G–3), 4.411(G–2), 4.441(G–1A), and 4.444(G–1) probably will decline about 35 feet from 1961 to 1970 and about 50 feet from 1961 to 1980. Water levels in wells 5.112(G–5) and 5.231 (G–4) probably will decline at least 20 feet from 1961 to 1970 and at least 30 feet from 1961 to 1980.

Additional supply wells should not be placed in the Los Alamos field. One additional well probably can be placed in the Guaje Canyon field but it should be at least 2,500 feet upgradient from well 5.112(G–5).

The specific capacities of wells having less than 10 gpm per ft of drawdown can be increased to more than 10 gpm per ft by rehabilitation of the well. A possibility for rehabilitating wells having damaged casing would be to pull the damaged casing from those wells, clean the holes out to their original depths, and install new casing and screens. The specific capacity of well 13.114b(LA–1B) probably can be improved by additional development, particularly in the section between 356 and 914 feet. Wells 14.221(LA–3) and 14.222(LA–2) probably will not respond to additional development. Production from wells in sections 13 and 14 probably could be maintained at the 1961 rate if well 14.222(LA–2) were abandoned and well

14.221(LA–3) were deepened to about 1,700 feet. The casing might be pulled from 14.221(DA–3) at the time the hole is deepened to 1,700 feet and the hole cased from land surface to 600 feet with new 12-inch blank casing and with 8-inch casing below 600 feet. The casing and screens should be enveloped by a gravel pack. Sand pumping probably could be eliminated by this method.

The specific capacities of wells 4.444(G–1) and 15.434(LA–5) probably could be increased to more than 10 gpm per foot of drawdown by additional development.

The nature of the obstruction in wells 4.135(G–3), 5.112(G–5), and 5.231(G–4) should be determined. Pictures taken in the wells probably would show the obstructions. If the obstructions could not be removed or repaired, replacement wells could be drilled nearby when the rate of pumping in the existing well decreases below a permissible minimum rate.

Other supply wells can be drilled on the Pajarito Plateau but they should be more than 2 miles south of the Los Alamos and Guaje well fields.

Pumping of wells on the Pajarito Plateau eventually will decrease the flow of the Rio Grande. The amount of decrease will be equal to the pumping rate if dynamic equilibrium is established. If the quantity of water moving through the aquifer cannot satisfy the pumping demand, then equilibrium will not occur and some of the pumpage will come from ground-water storage; the flow of the river would then be decreased by the pumping rate minus the rate that water is taken from storage.

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