Pumping Tests in the Los Alamos Canyon Well Field Near Los Alamos, New Mexico

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-I

Prepared in cooperation with the U.S. Atomic Energy Commission

Theis and Conover—PUMPING TESTS, LOS ALAMOS CANYON WELL FIELD, LOS ALAMOS, N. MEX.—Geological Survey Water-Supply Paper 1619-I

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By C. V. THEIS *and* C. S. CONOVER

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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PUMPING TESTS IN LOS ALAMOS CANYON WELL FIELD NEAR LOS ALAMOS, NEW MEXICO

By C. V. THEIS and C. S. CONOVER

ABSTRACT

The town of Los Alamos, N. Mex., founded in 1943, obtained its first water supply from surface sources in canyons draining the eastern slopes of the Sierra de los Valles, a part of the Jemez Mountains. The water demands of the town soon outgrew the water supply available from these sources, and explorations began early in 1946 to find a supply of ground water in the Recent alluvium of the Rio Grande, about 9 miles east of town, and in rocks of the Santa Fe group of middle(?) Miocene to Pleistocene(?) age in the lower reaches of Los Alamos Canyon, about 7 miles east of town. The Los Alamos Canyon site proved to be more favorable, and six supply wells ranging in depth from 870 feet to 1,975 feet were constructed in the period 1946–48.

The growth in the demand for water was such, however, that it became apparent that the surface sources and the six wells would become inadequate by 1950, so that additional wells would be required.

The rapid search for a ground-water supply leading to the 1946–48 drilling was not accompanied by a quantitative evaluation of the water-production potential of the Santa Fe group. Additional wells probably will be constructed in nearby Guaje Canyon, and their position relative to the Los Alamos Canyon well field should be soundly planned. The pumping tests described in this report were a first step toward this planning.

The pumping tests were not made under ideal conditions because the pumping operation in the well field could not be completely regulated to eliminate irregular water-level fluctuations in the wells during the tests, and the results, therefore, are considered only approximate. The results of the tests indicated that the coefficient of transmissibility probably is about 2,500 gpd per foot in the uppermost 1,000 feet of the Sante Fe group in the Los Alamos Canyon area; the aquifers in the next 1,000 feet may be separate from those in the upper 1,000 feet; and the coefficient of transmissibility for the uppermost 2,000 feet may be at least 9,000 gpd per foot.

Predictions of water-level trends in the well field indicated that, at the 1950 rate of pumping, the levels might decline about 100 feet between 1950 and 1988. The predictions were based on the assumption that the average pumping rate from the well field would be about 1,000 gpm after 1950—the coefficient of transmissibility is about 5,000 gpd per foot, all the water would be withdrawn from storage, and the boundary of the aquifer would not affect water levels in the period.

Radioactive wastes have been and are being discharged on the land surface in the vicinity of Los Alamos up the hydraulic gradient from the Los Alamos

Canyon well field and prospective supply wells in Guaje Canyon. Computations made on the basis of hydraulic coefficients determined from the pumping tests indicate that it will take at least 70 years for the waste to traverse the 5 miles through the aquifer and contaminate the well fields.

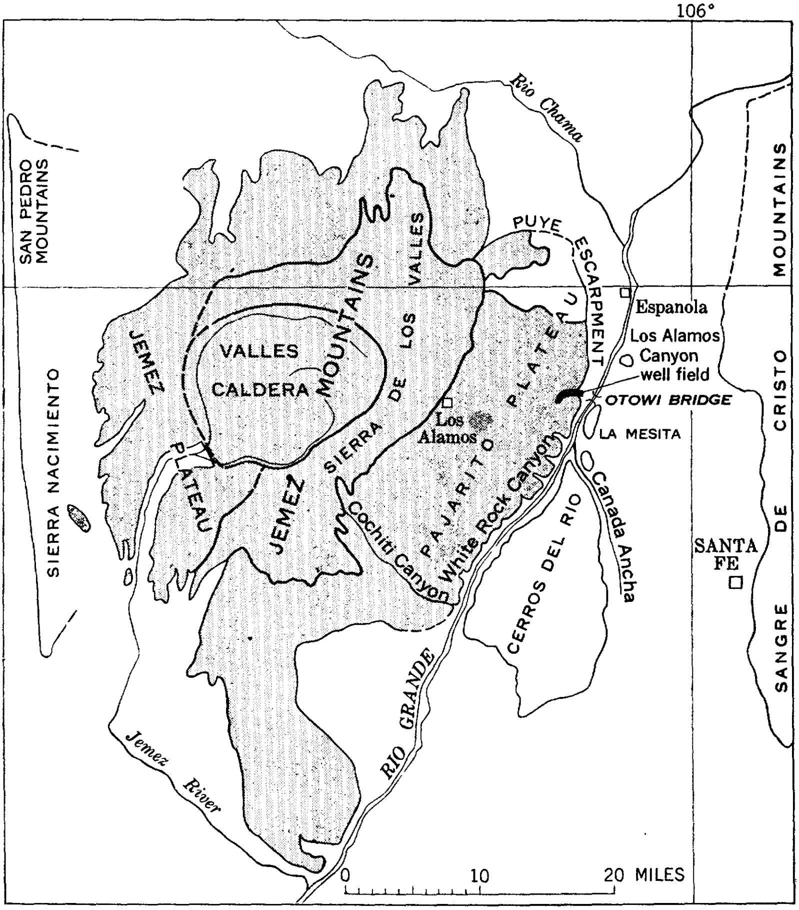
INTRODUCTION

When the town of Los Alamos, N. Mex., was founded in 1943, its water supply was obtained from the small flows of water in the upper reaches of major canyons west of the town. These surface sources supplied water in quantities sufficient for only the early needs of the town. The water requirements of the new town soon outgrew the available surface-water supply, and prospecting for ground water became necessary. The first explorations for ground water were made early in 1946 in alluvium of Recent age in the lowlands near the Rio Grande, but these were abandoned when test drilling indicated that wells yielding several hundreds of gallons per minute could be obtained in Los Alamos Canyon more than a mile west of the Rio Grande, and thus closer to the town. The first supply well in the Los Alamos Canyon well field was placed in operation on November 7, 1946. Additional wells were drilled as needed, and by December 1948 six wells were in operation.

The consulting-engineering firm of Black and Veatch of Kansas City, Mo., made a study of the water supply in September 1948 and concluded that the surface-water supply and that from the six wells in Los Alamos Canyon would be inadequate to meet the town's water demand by 1950. As the quick development of the ground-water supply in 1946–48 had permitted no adequate study of the permanence of the supply, the Atomic Energy Commission called upon the U.S. Geological Survey to make a study of the adequacy of the Los Alamos Canyon source and to report on possible future sources of water from the Santa Fe group of the Rio Grande trough. Additional wells probably will be located in nearby Guaje Canyon. This report gives the results of pumping tests made in the Los Alamos Canyon well field in April and May 1950.

LOCATION AND SETTING

Los Alamos is in north-central New Mexico, about 25 miles northwest of Santa Fe, the State capital. (See fig. 1.) The town is on the eastern slope of the Jemez Mountains at an altitude of 7,330 feet. Immediately west of the town, the mountain slopes rise abruptly to form the Sierra de los Valles, whose peaks reach an altitude of about 10,500 feet. The land slopes gently eastward from the base of the Sierra de los Valles and forms the Pajarito Plateau, which is dissected



Base from Geologic Map of New Mexico, 1928; scale 1:500,000

Prepared by R. L. Griggs

Figure 1.—Map of north-central New Mexico showing geographic and physiographic features in the vicinity of the Los Alamos Canyon well field.

by deep canyons trending east-southeastward. About 9 to 10 miles east of Los Alamos, the plateau terminates at the Puye escarpment, and the land surface drops 300 to 400 feet to the floor of the Rio Grande valley. The Rio Grande, the master stream of the region, flows southward about a mile east of the escarpment and is at an altitude of about 5,500 feet at Otowi Bridge. About 9 miles southeast of Los Alamos, the Rio Grande enters a deep gorge (White Rock Canyon), which cuts south-southwestward through a part of the Pajarito Plateau and isolates a part of the plateau, the Cerros del Rio, from the main plateau.

Los Alamos Canyon, in which the well field of that name is located, is one of the major east-southeastward-trending canyons incised in the plateau. The mouth of this canyon at the Rio Grande is about 3 miles upstream from White Rock Canyon. The easternmost supply well of the Los Alamos Canyon well field is about a mile above the mouth of the canyon at an altitude of 5,624 feet; the westernmost well is about 2.4 miles up the canyon from the easternmost well at an altitude of 5,975 feet. The other 4 wells are spaced between these 2 wells, as shown in plate 1.

WELL-NUMBERING SYSTEM

Location numbers based on the common system of subdivision of public lands are used in this report to identify the wells. The location number consists of four segments. 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 the subdivisions of the section. The section is considered as being divided into four quarters, numbered 1, 2, 3, and 4 for the northwest, northeast, southwest, and southeast quarters respectively. The first digit of the fourth segment of the location number refers to the appropriate quarter 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 and are numbered in the same manner as the 160- and 40-acre tracts. Thus location number 19.7.14.312 identifies a location in the NE¼NW¼SE¼ sec. 14, T. 19 N., R. 7 E.

A zero or zeros may be used in the fourth segment of the location number to indicate that the location of the point is known only to the accuracy of the preceding digit. The fourth segment of the location is stated even if all three of its digits are zeros.

In the event that more than one well is listed within a 10-acre tract, lowercase letters, a, b, c, are added to the fourth segment to identify the second and succeeding points in that tract.

Wells referred to specifically in the text are numbered on maps in this report by using only the numerals of the fourth segment of the complete location number. Township, range, and section numbers appear elsewhere on the maps to aid the reader in identifying a location when the complete location number is mentioned in the text.

All wells mentioned in this report are within T. 19 N., and R. 7 E.; therefore, the first and second segments of each well number have been omitted in the text for simplicity.

The supply wells of the Los Alamos Canyon well field are known to Los Alamos water-supply officials by the following numbering system: Los Alamos (L1), Los Alamos (L2)—Los Alamos (L6). These numbers, enclosed by parentheses and following the location number, are included on maps, diagrams, tables, and in the text of this report.

GENERAL DISCUSSION OF GROUND WATER

All ground water of quantitative importance is moving from a point of recharge to a point of discharge. Because virtually no water can be added to or subtracted from the system underground before development by wells, the recharge and discharge over a period of years are equal, and the water body is in a state of approximate dynamic equilibrium. Discharge by wells is, therefore, a new discharge superimposed on a previously stable system, and the amount of water discharged by wells must be balanced by an increase in recharge, a decrease in natural discharge, a loss of storage in the aquifer or some combination of these. Withdrawal from a well is thus a diversion for the natural circulation of ground water.

Withdrawal of water creates a cone of depression in the water table or piezometric surface. The cone of depression reflects the hydraulic gradient in the aquifer that is required to move the water to the pumped well. The shape of the cone is governed by the ease with which the aquifer transmits water and the amount of water the aquifer releases from storage. The water released from storage in the aquifer is related to the amount withdrawn from storage in a unit column of the aquifer when the head is lowered a unit distance, and is denoted as the coefficient of storage. The ease with which the aquifer transmits water is related to the volume of water that will move through a specified width of aquifer during a specified period of time under a specified hydraulic gradient, and, quantitatively, it is denoted by a coefficient of transmissibility. In this report, the coefficient of transmissibility is expressed as the number of gallons of water per day, at the prevailing temperature, that will flow through a mile width of aquifer under a hydraulic gradient of 1 foot per mile. The cone of depression expands by withdrawal of water from storage. It expands slowly if a large amount of water is available from storage, as is the case in a water body having a free surface, or water table, in a porous material; and more rapidly in a confined water body, where all the stored water available is that derived from compaction of the sediments and expansion of the water as the internal pressure in the aquifer declines. In leaky artesian aquifers, the shape of the cone is modified by the water that is induced to enter the aquifer through confining beds when the head in the aquifer is reduced.

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A new state of dynamic equilibrium may be reached when the cone expands until it reaches the areas of recharge or discharge. The new equilibrium will be reached when the sum of the amounts by which the recharge is increased and the natural discharge is decreased is equal to the amount pumped by the well. If the recharge is to be increased by the lowering of water level in the recharge area, water must previously have been rejected by the aquifer and there should be evidence in the recharge area of this water in the form of seeps or springs, or areas of water-loving vegetation, at least through some seasons of the year. If water is not rejected by the aquifer, then a new equilibrium can be reached only by a decrease in natural discharge in the amount yielded by the well. It thus follows that water levels must lower with pumping until consequent changes in natural recharge and (or) discharge are effected. In other words, the discharge from a well cannot be balanced by interception of precipitation over the areal extent of the cone of depression.

AQUIFERS IN THE SANTA FE GROUP

Wells in Los Alamos Canyon draw water from the Santa Fe group of middle(?) Miocene to Pleistocene(?) age, an unconsolidated or partially consolidated deposit of silt, sand, and gravel that was laid down in a long, wide downfaulted trough along the Rio Grande. The Rio Grande and its tributaries were the agents of deposition. In general, the deposits grade from coarse near the mountains to fine beneath the old flood plain near the center of the trough. However, coarse channel deposits laid down by the old river also are a part of the old flood-plain deposits.

Few of the water-bearing beds in the Santa Fe group contain well-sorted material, and, therefore, most of these beds have low permeability. Hydrologically, the formation consists of a few beds of moderate to high permeability, alternating with many beds of low to very low permeability; the transmissibility (the permeability of the whole deposit) is therefore considerably greater parallel to the bedding than it is across the bedding.

After, and perhaps during, the deposition of the Santa Fe group, these strata were faulted and tilted in the area. Deformation of these rocks is plainly visible along the road between Santa Fe and Espanola. In the vicinity of the Los Alamos Canyon well field, however, there is little evidence of deformation in the exposed rocks. One fault on the north side of the road between wells 13.114(L1) and 14.222(L2), with a displacement of about 12 feet, has been noted by R. L. Griggs (written communication, 1952). Such a small displacement ordinarily would not be expected to interrupt the continuity of the more permeable beds across the fault zone in a formation. It is possible, however, that some of the beds at depth have been faulted or tilted without corresponding deformation in the younger beds. Hydrologically, this means that beds forming the lower aquifers tapped by the wells in Los Alamos Canyon may be at or near the surface not far from the well field.

If the beds are nearly horizontal, the lower aquifers do not crop out in the general vicinity of the wells. In this case the natural circulation of water in them must be sustained by recharge by downward percolation through the overlying semiconfining beds in areas near the mountains and discharge by upward percolation through these beds in areas near the river. Wells 13.114(L1), 14.221(L3), and 14.222(L2) originally flowed, showing an upward hydraulic gradient in their vicinity; wells 14.312(L6), 15.434(L5), and 22.114(L4) are deeper and appear to have had heads originally higher than those of the three shallower wells.

PUMPING TESTS

DESCRIPTION OF WELLS

The six supply wells of the Los Alamos Canyon field are constructed with a gravel pack around the screens. In wells 13.114(L1), 14.221 (L3), and 14.222(L2), 12-inch blank casing extends from the land surface down to depths of 60 to 105 feet; below the blank casing in each well is an alternating series of 10-inch slotted casing and 10-inch commercial well screens. In wells 14.312(L6) and 15.434(L5), 12-inch blank casing extends from the land surface to a depth of 420 feet; below that depth, 10-inch screens alternate with sections of 10-inch blank casing. Well 22.114(L4) is similarly cased, except that the top of the upper screen is at a depth of 754 feet.

Three test wells—13.124, 13.114a, and 14.221a—are located respectively about one-sixth of a mile east of well 13.114(L1), about 30 feet southeast of well 13.114(L1), and about 50 feet northwest of well 14.221(L3). Test well 13.124 has 2-inch galvanized casing and a sounded depth of 271 feet below the land surface; its initial depth was 475 feet. Test well 13.114a has 4-inch casing and a sounded depth of 305 feet below the land surface; its initial depth was 400 feet. Test well 14.221a is cased with 2-inch galvanized pipe and was sounded to a depth of about 164 feet below the land surface; its initial depth was 315 feet.

Other pertinent data for the 6 wells and the 3 test wells are given in table 1. The nonpumping, or "static", levels at time of completion of the wells are measured with reference to the land surface at that time. The water levels in 1950 refer to arbitrary measuring points.

The original land surface has been obliterated at each well, and the change in water level since the wells were completed cannot be obtained precisely by direct comparison between the original and 1950 depths to water because the difference in altitude of the reference datums is unknown.

The measured depths to water given in table 1 for wells used in the test are the levels observed immediately before the start of pumping, April 17, 1950. The nonpumping level after a period of pumping depends upon the length of time since cessation of pumping and the amount of pumping before its cessation; the longer the period of recovery the higher the water level. The nonpumping levels given, therefore, are not the highest levels to which the water would have risen in the wells had recovery been longer. However, a major part of the recovery of water in a well takes place within a relatively short time—a few hours to a few days, according to circumstances. As the time of recovery given for each well in the table is comparatively long, with the exception of that for well 14.312(L6), it is evident that the major part of the recovery in the wells had taken place, and the measured levels given may be taken as an approximation of the "static" level.

Nonpumping water levels in wells 22.114(L4), 15.434(L5), and 14.312(L6) declined about 37, 50, and 64 feet, respectively, from the time of their completion (table 1) to 1950. Nonpumping water levels in wells 13.114(L1) and 14.221(L3), which originally flowed (as did well 14.222(L2)), declined more than 26 and 42 feet, respectively, from the time of their completion (table 1) to 1950. On an average, water levels were at least 35 feet lower in 1950 than in 1948, when most of the pumping began.

The discharge rates, table 1, were determined by noting over an interval of time the difference in readings of a propeller-type meter installed in the discharge pipe of each pump.

The pumping levels given in the table, with the exception of that for well 14.312(L6), were obtained by adding to the measured nonpumping level the difference between the nonpumping and pumping levels, as given on the air-line recorder. In well 14.312(L6) the recorder was not installed in time to make a direct correlation between its reading and a tape measurement, and the pumping level was computed on the basis of the reported length of air line. The pumping levels, like the nonpumping levels, vary with time—the longer the time since pumping started, the lower the water level in the well. Pumping times in excess of those given in the table would result in slightly lower pumping levels, and equal pumping times a year later also would result in slightly lower pumping levels.

TABLE 1.—*Records of wells in the Los Alamos Canyon well field*

Well location	Date of completion of well	Depth of well (feet)	Diameter of casing at land surface (inches)	Altitude above mean sea level (feet)		Depth to water		Performance, May 1950					
				Land surface at time of completion [1]	Measuring point [2]	At time of completion [1] (feet)	Below measuring point (feet)	Day measured April 1950	Discharge (gpm)	Pumping level (feet)	Specific capacity (gpm per foot)	Time pumped (days)
19.7.13.114(L1)	Nov. 7, 1946	870	12	5,624	5,625.8	(3)	[4] 26.0	17	246	321	0.8	14
13.114a	Mar. 16, 1946	400	4		5,626.8	(3)	[4] 29.4	17				
13.124	Mar. 30, 1946	475	2		5,611.3	(3)	[4] 10.5	17				
14.221(L3)	May 5, 1947	870	12	5,672	5,676.2	(3)	[4] 41.6	17	302	262	1.4	14
14.221a	Mar. 21, 1946	315	2		5,678.2	(3)	[4] 27.8	17				
14.222(L2)	Dec. 12, 1946	870	12	5,651	5,653.2	(3)	[4] 37.5	17	[1] 276			
14.312(L6)	Dec. 1948	1,790	12	5,770	5,780.3	5±	58.8	3	625	150	6.9	34
15.434(L5)	Sept. 4, 1948	1,750	12	5,840	5,852.0	71	121.5	28	552	285	3.2	8
22.114(L4)	July 14, 1948	1,965	12	5,975	5,970.9	189	226	21	650	329	6.3	1.5

[1] Reported by Black and Veatch with reference to land-surface datum.
[2] Measuring point during pumping test.
[3] Flowing.
[4] Water level immediately before well 19.7.14.221(L3) started pumping.

The specific capacity in gallons per minute per foot of drawdown is obtained by dividing the discharge rate of each well by the amount of drawdown in the respective well at the end of the period of pumping given in table 1. The specific capacities ranged from 0.8 to 6.9 gpm per foot of drawdown. Specific capacity varies with the length of the pumping period. Longer pumping times would give smaller values of specific capacity, as the drawdowns would increase and the discharge rates decrease. Specific capacities of several wells are not truly comparable unless they are computed from tests made on about the same date and of equal pumping-time duration.

DESCRIPTION OF TESTS

In order to eliminate from the test data as much as possible the effects on water levels caused by irregular pumping of the wells, pumping tests were made during April and early May, at which time the demand upon the wells was expected to be at a minimum. At this season the supply of surface water to Los Alamos is normally at a maximum as a result of spring runoff.

Well 14.221(L3) was selected as the well to be pumped for the principal pumping test because of the comparable nearness of supply wells 13.114(L1) and 14.222(L2) and the three test wells, 13.124, 14.114a, and 14.221a, in which observations of water level could be made during the test. A brief pumping test was made on well 15.434(L5).

Each production well was equipped with a recording pressure gage attached to an air line for determining depths to water. These gages were alike and each had a pressure-scale range from 0 to 250 pounds per square inch, graduated to 5 pounds per square inch, and a 24-hour time scale, graduated to 15 minutes. Because of the large pressure range of these instruments, readings of changes of water level of less than 3 feet were uncertain. Measurements of the water level were made with a steel tape whenever possible.

The test, as planned, called for no pumping from any well for 2 weeks, except that from well 14.312(L6) as necessary to make up deficiencies of water supply for Los Alamos. At the end of this 2 weeks, well 14.221(L3) would be pumped for 2 weeks at a constant rate of discharge. In this way, it was hoped to determine the water-level fluctuations caused by the pumping of one well. However, because of the comparatively small amount of surface water available in April and May 1950, well 14.312(L6) was pumped almost continuously during the entire period of the test, and wells 15.434(L5) and 22.114(L4) were pumped occasionally. Measurements of water level were restricted to supply wells 13.114(L1), 14.221(L3), and

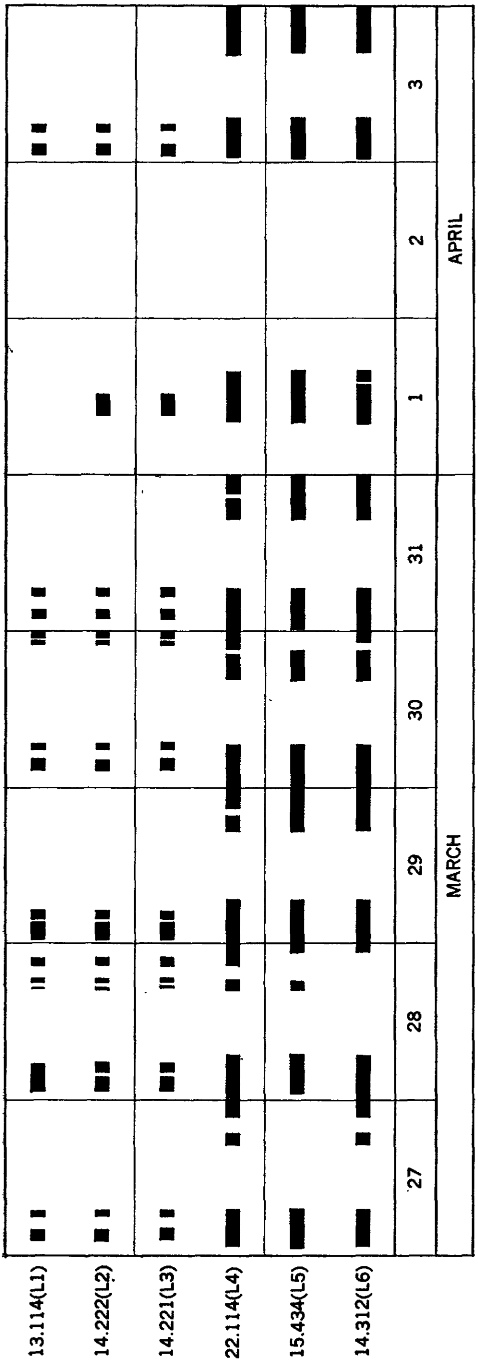

FIGURE 2.—Graph showing times of pumping, March 27 to April 3, 1950, Los Alamos Canyon well field, near Los Alamos, N. Mex.

14.222(L2) and the nearby three test wells. The times of pumping before regular measurements of water levels were begun on April 4 are given in figure 2. The times of pumping of each supply well during the test are given on plate 2.

Supply wells 13.114(L1), 14.221(L3), and 14.222(L2) were shut off after a short period of pumping on April 3, and measurements were made of the recovery of water level. During the 2 weeks before the start of pumping from well 14.221(L3), the water levels in the 3 supply wells and the 3 test wells rose at a continually diminishing rate, as is normal upon cessation of pumping from a well. The rate of rise in each well, other things being equal, is related in general to the amount of pumping in the past in the vicinity of the well. At no time did the water levels reach a "static" level, as they were still rising, although slowly, when pumping from well 14.221(L3) was started. From noon of April 4 to the start of pumping of well 14.221(L3) on April 17, the water level rose 14.3 feet in wells 13.114(L1) and 13.114a, 19.6 feet in well 14.222(L2), 22.5 feet in well 14.221(L3), 8.9 feet in well 14.221a, and 1.0 foot in well 13.124.

During this period of recovery there were some slight variations in the rate of rise of water level in the wells that might have been the result of the irregular periods of pumping from supply wells 14.312(L6), 15.434(L5), and 22.114(L4). Even though the effects of pumping from these supply wells were not definitely discernible by variations in the rate of rise of the water level in the test observation wells, the overall rate of rise may have been somewhat less than it would have been had those supply wells not been pumped.

Pumping from well 14.221(L3) started at 11:42 a.m. on April 17 and stopped at 9:15 a.m. on May 1. The well was pumped continuously during this period except for 7 minutes (7:55 p.m. to 8:02 p.m.) on April 19, but the gradual decline in pumping level in the well was accompanied by a gradual decline in discharge of the pump from about 460 gpm at the start to about 300 gpm on the last day of pumping. (See pl. 3.) The average discharge during the period of pumping was 334 gpm.

The effect of pumping well 14.221(L3) upon the water levels in wells 13.114(L1), 13.114a, and 14.222(L2) is shown on plate 2.

A few minutes after pumping of well 13.221(L3) began, the water level in well 14.222(L2) virtually ceased to rise. The water level remained nearly constant for about 8 hours. At about 9:00 p.m. it began to decline and continued to decline at a gradually diminishing rate until the end of the pumping period, at which time it was declining about 0.6 foot a day.

The effect of pumping well 14.221(L3) was not as definite in wells 13.114(L1) and 13.114a as in well 14.222(L2). The water levels in wells 13.114(L1) and 13.114a continued to rise, at the prepumping rate, for 3 to 4 hours after the start of pumping from well 14.221(L3). From about 4:00 p.m. on April 17 to about 4:00 a.m. on April 18, the rate of rise decreased, after which time the water levels resumed approximately the rate of rise established before pumping began. By the time pumping from well 14.222(L3) was stopped, the water levels in wells 13.114(L1) and 13.114a were rising at a rate of about 0.1 foot a day. Had pumping continued, the water levels in these wells probably would have started declining in a few days.

When pumping from well 14.221(L3) was stopped, the decline of water level in well 14.222(L2) slackened almost immediately, and the water level began rising in 5 or 6 hours. The water levels in wells 13.114(L1) and 13.114a began rising at an accelerated rate 3 to 4 hours after pumping from well 14.221(L3) stopped. Six days thereafter, the water levels in wells 13.114(L1) and 13.114a were rising about 0.3 foot a day, as compared with about 0.1 foot a day immediately before pumping stopped.

The water level in well 14.221a (pl. 3) began declining immediately after pumping began in well 14.221(L3). When the water level declined below about 77 feet, water sprayed into the well through holes in the casing above the water level, and water-level measurements could not be made with an unprotected measuring tape. Readings of water level below 77 feet were made either with the measuring tape protected by a rubber tube or with an electrical contact device. The irregularities in the measurements were not the result of poor measurements because the readings were consistent. Rises in water level were noticed at four different times, April 19, 23, 24, and 25. After each rise, a slight change in the rate of decline was noticed. The most pronounced rise (about 2 feet) occurred on April 19, between 4 and 8 p.m. The pump on well 14.221(L3) stopped from 7:55 to 8:02 p.m., and the subsequent change in water level probably is mainly the result of the interruption in pumping.

The small erratic rises in water level in well 14.221a probably were caused by water breaking through holes corroded in the casing at points above the water level in the well. The rise in water level on April 23 was accompanied by noise in the well such as would be caused by water pouring into the well. Meager information indicates that only the lower 10 feet or so of the casing was perforated when the well was completed.

Water levels in well 14.221(L3) below about 105 feet, during and after pumping, were obtained from the air-line recorder. As the recorder is not accurate to changes of less than about 3 feet, small variations of water level are not apparent, and the slight scattering of points on plate 2 for levels below 105 feet may be disregarded. The water level in well 14.221 (L3) at the end of the 2 weeks of pumping was declining about 0.5 foot a day. Part of the gradual decrease in the rate of decline of the water level was a result of the decrease in the discharge from the well. The drawdown of water level in this well before the pump was stopped was 219 feet, as based upon the difference between the pumping level and the projected curve of recovery of water level before the pump was started. (See pl. 3.) The specific capacity at the end of 14 days of pumping, based on the final discharge rate of 295 gpm, was about 1.4 gpm per foot of drawdown.

INTERPRETATION OF TESTS

Most of the formulas applied in analyzing pumping tests are based on the assumption that all the water discharged from the well, up to the time the pumping increases recharge and (or) decreases natural discharge of the aquifer, is being taken from storage in the aquifer. This assumption represents the hydraulic condition in most aquifers, and the applicability of the assumption has been repeatedly demonstrated in many localities in the last decade. Although the tests on the wells in Los Alamos Canyon indicate by their inconsistencies that the aquifer does not conform strictly to this basic assumption, the treatment of the pumping-test data according to the usual methods (Theis, 1935) probably will give an approximation of the effects of future pumping on water levels in the well field.

The drawdown of a well pumping from storage in an ideal homogeneous and broadly extended aquifer is given by the equation

$$s=\frac{114.6Q}{T}\left[-0.577-\ln u+u-\frac{u^2}{2\,.\,2!}+\frac{u^3}{3\,.\,3!}-\ .\ .\ .\ .\right]$$

in which

s=drawdown, in feet

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

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

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

r=distance, in feet, from discharging well to point of observation

S=coefficient of storage, expressed as a decimal fraction

t=time, in days, well has been pumped

In most aquifers, after the time of pumping has exceeded a few days, the quantity u is so small that all but the first two terms in brackets in the equation above can be neglected and the equation written in terms of common logs is

$$s=\frac{264Q}{T}\left(-0.251+\log\frac{Tt}{1.87r^2S}\right)$$

This in turn, may be expressed as

$$s=\frac{264Q}{T}\left(-0.522+\log t+\log\frac{T}{r^2S}\right)$$

This equation indicates that the rate of lowering of water level in a well after a short time will depend only on the transmissibility of the aquifer and the rate of pumping, and the plot of water level against the logarithm of the time since pumping started should be a straight line.

The semilogarithmic plots of the various drawdowns and recoveries of water level are shown in figures 4 to 6, and the computations

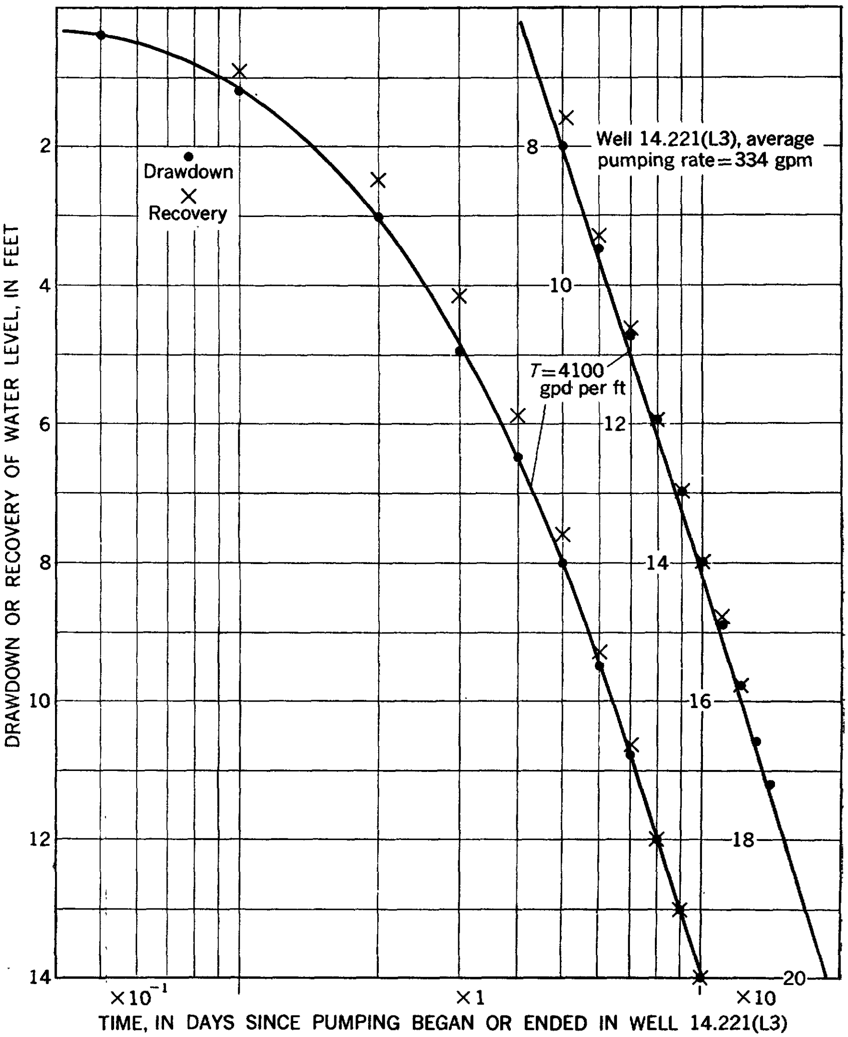

FIGURE 3.—Graph showing drawdown and recovery of water level with respect to time in well 14.222(L2) caused by pumping well 14.221(L3), Los Alamos Canyon well field near Los Alamos, N. Mex.

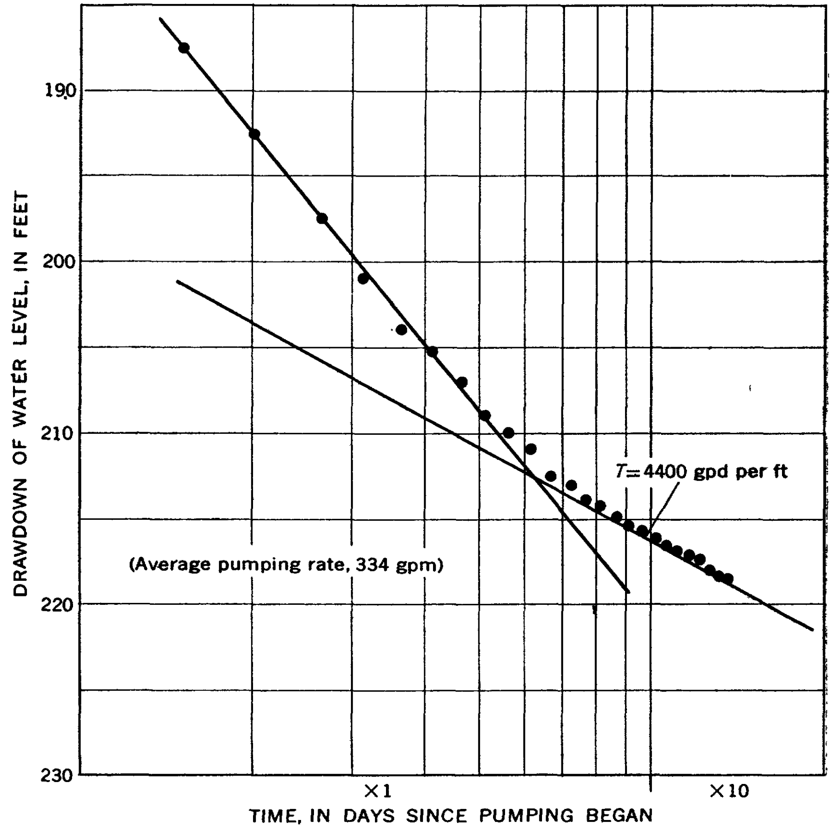

FIGURE 4.—Graph showing drawdown of water level with respect to time in well 14.221 (L3) while well was pumping, Los Alamos Canyon well field near Los Alamos, N. Mex.

of coefficients of transmissibility and storage are shown in table 2. The results for the coefficient of transmissibility range from about 1,400 gpd per foot, as computed from the rate of recovery of well 14.221(L3), to 4,100 gpd per foot, as computed from the drawdown and recovery of well 14.222(L2). The coefficient of transmissibility,

TABLE 2.—*Computed Coefficients of transmissibility and storage*

Pumped well	Data source	Coefficient of transmissibility (gpd per foot)	Coefficient of storage
19.7.14.221(L3)	Drawdown in well 14.222(L2)	4,100	0.0033
14.221(L3)	Recovery in well 14.222(L2)	4,100	.0033
14.221(L3)	Recovery in well 14.221(L3)	1,400	----------
14.221(L3)	Recovery in well 14.221a	2,900	----------
14.221(L3)	Drawdowns in wells 14.221(L3) and 14.222(L2)	2,600	.0035
15.434(L5)	Drawdown in well during step-discharge test	6,500	----------

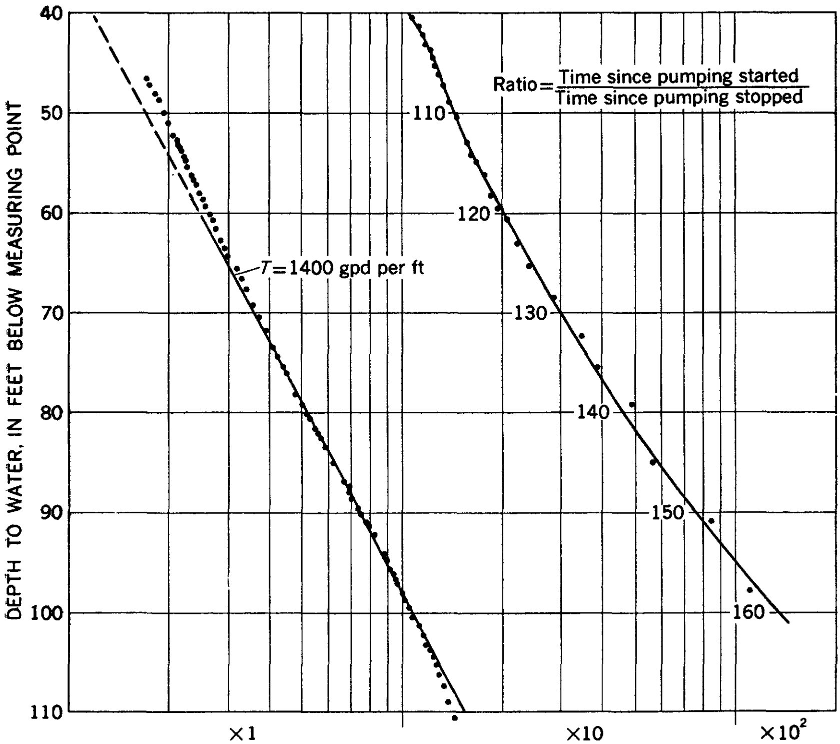

FIGURE 5.—Graph showing recovery of water level with respect to a pumping-nonpumping time ratio in well 14.221 (L3) after 14 days of continuous pumping, Los Alamos Canyon well field near Los Alamos, N. Mex.

as indicated by the final drawdowns in these two wells, is about 2,600 gpd per foot. The approximate coefficient of transmissibility indicated by the specific capacity of well 14.221 (L3) (1.4 gpm per foot of drawdown after 14 days pumping) is about 2,400 (Theis and others, 1954).

The results from the drawdown and recovery of well 14.222 (L2) at a distance from the pumped well probably are too high, inasmuch as drawdown at a distance from a pumped well in a leaky aquifer is slower than that in a nonleaky one. The characteristics of the recovery curve in a leaky aquifer have not been determined, but the result obtained from the recovery in well 14.221 (L3) probably is too low; the transmissibility of the part of the aquifer tapped by that well—approximately the upper 1,000 feet—probably is about 2,500 gpd per foot.

Probably the cone of depression of any one of the supply wells extends to various distances in the permeable beds of the aquifer.

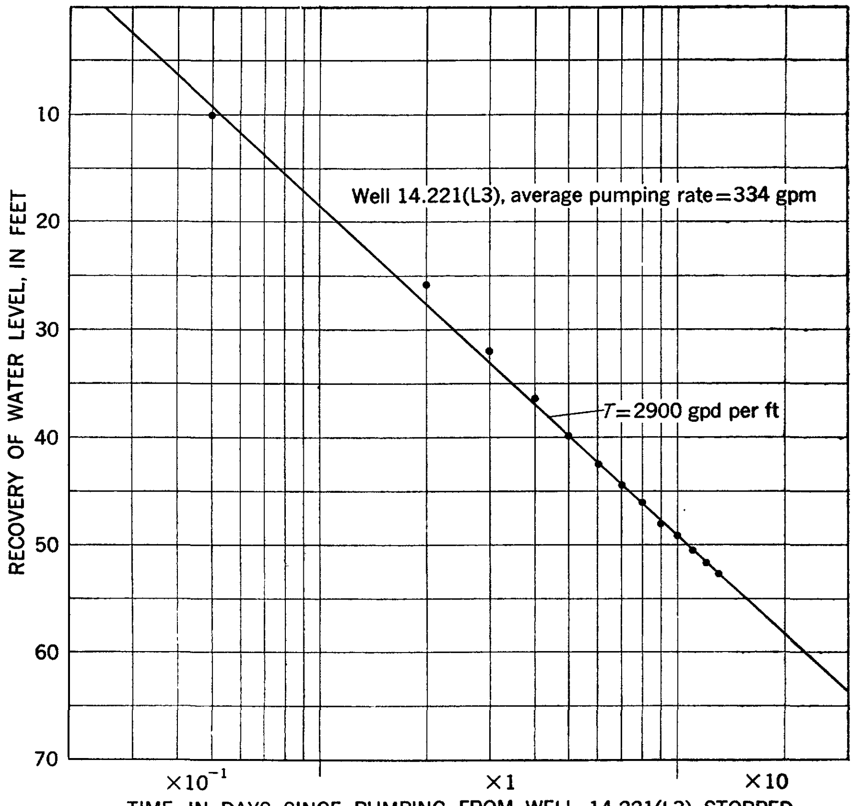

FIGURE 6.—Graph showing recovery of water level with respect to time in well 14.221a after 14 days of continuous pumping from well 14.221(L3), Los Alamos Canyon well field near Los Alamos, N. Mex.

Pumping of a well thus causes differences in head at different depths under the same map point and thereby causes some changes in the vertical movement of water. At some places water in the lower beds that would normally percolate upward is diverted to the pumped well, and at other places the vertical flow probably is reversed. Water pours down the casing in most of the supply wells when they are pumped, indicating that the upper aquifers have a higher head during pumping, at least near the well. When well 14.221(L3) was pumped, the water level in well 13.114(L1) declined slightly below its position as extrapolated from its previous rise within a few hours after the beginning of pumping, but declined no further during the next several days. This action apparently indicates that a cone of depression reaching from well 14.221(L3) to well 13.114(L1) was formed very quickly in some confined or semiconfined bed and did not spread farther because it was fed by some source of water outside this particular bed. This apparent vertical percolation between the beds makes the interpretation of the pumping test difficult, as the simpler pumping-test formulas are not entirely applicable.

A step drawdown test (stepped pumping rates, Rorabaugh, 1953) of well 15.434(L5) made on April 30 and May 1, 1950, indicated a coefficient of transmissibility of about 6,500 gpd per foot. As this well has a specific capacity only about half that of either well 14.312(L6) or well 22.114(L4), well 15.434(L5) probably does not tap any of the more permeable beds or parts of them; therefore, the average coefficient of transmissibility of the deeper part of the aquifer is probably higher than that indicated by the test on well 15.434(L5). These three wells tap the aquifer from about 800 to 1,800 feet. A small part of the total screen length in these wells is set at depths corresponding to those at which screen is set in wells 13.114(L1), 14.221(L3), and 14.222(L2) but most of the screen is at greater depths. Wells 14.312 (L6), 15.434(L5), and 22.114(L4) are at altitudes about 100 to 300 feet higher than wells 13.114(L1), 14.221(L3), and 14.222(L2). The altitude of the beds within the Santa Fe group is unknown, and it is uncertain whether or not the two groups of wells draw water from different beds. When the wells can be pumped on a fixed schedule, it may be possible to determine approximately from the interference effects of one group of wells upon the other the extent that their pumping affects the same beds. The beds tapped by the two sets of wells probably are separate, and, therefore, the transmissibilities determined from pumping tests on the two groups of wells should be added rather than averaged. Adding the figures determined for the two groups of wells would give a coefficient of transmissibility of about 9,000 gpd per foot, for all the beds tapped by the wells. The actual transmissibility probably is considerably larger because of the probable larger transmissibility in the lower aquifers than that indicated by the test on well 15.434(L5).

Determination of a correct figure for the coefficient of transmissibility is important because the computation of the rate and ultimate drawdown of water level in the well field is largely dependent on that figure.

PREDICTION OF WATER-LEVEL TRENDS IN THE WELL FIELD

Figure 7, which shows the additional drawdown to be expected in the Los Alamos Canyon well field, is based on the equations given on pages I-14 and I-15. It is assumed that the water will be withdrawn from storage in the aquifer, that the boundaries of the aquifer will

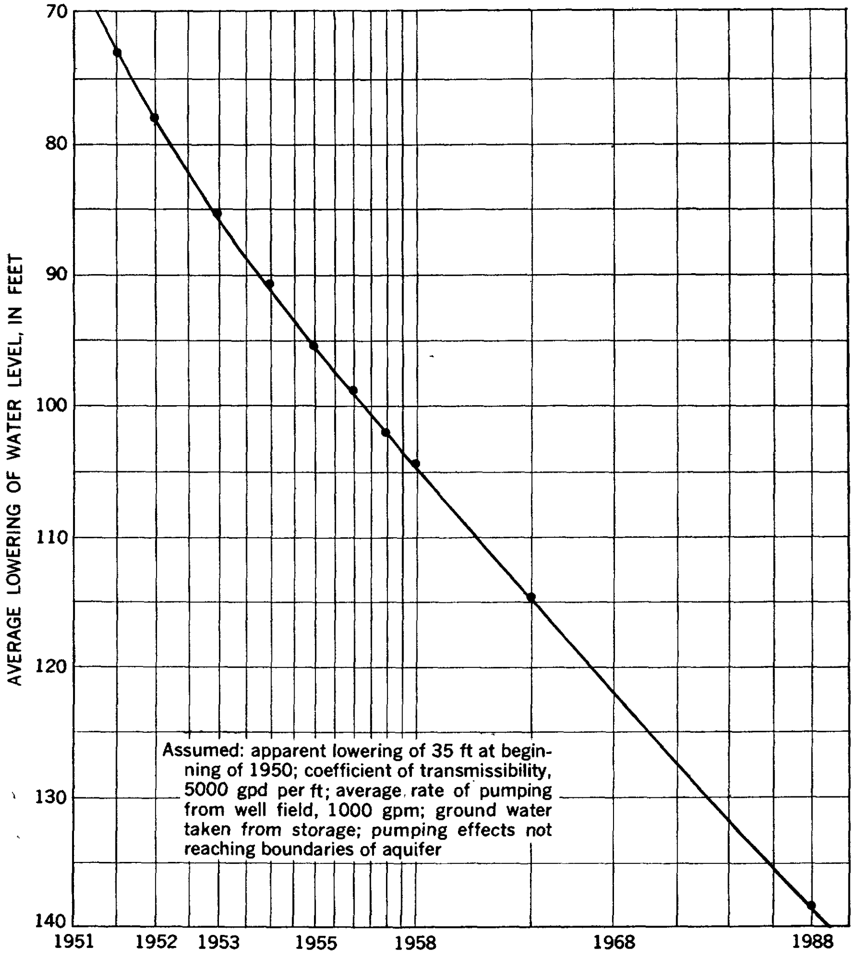

FIGURE 7.—Graph showing expected average decline of water level in Los Alamos Canyon well field in period 1951–88.

not significantly affect the water level within the time considered, and that the coefficient of transmissibility is 5,000 gpd per foot. This coefficient probably is conservative; it may be more than 9,000 gpd per foot. If the coefficient is larger than 5,000 gpd per foot, the rate of drawdown will be less than that indicated on figure 7. From the data available the general decline of water levels in the well field appears to be about 35 feet from the beginning of pumping to 1950 and the average rate of pumping from the field during 1948 and 1949 was about 500 gpm, or about three-quarters of a million gallons per day. In 1950 and in future years, the average rate of pumping is assumed to be 1,000 gpm, or a little more than half a billion gallons per year. If the wells had been pumped at this rate in the past, the general lowering would have been about 70 feet, or twice as large as it was. As indicated by the formula, the drawdown varies as the log of time, other things being constant, and therefore, the plot of expected decline on semilog paper should be a straight line. The curve in figure 7 is based on the assumption of constant discharges of 500 and 1,000 gpm, beginning in 1948 and 1950, respectively.

The graph indicates that in 1988 the general water level in the well field may be about 140 feet below its original position, or nearly 100 feet below its 1950 position. The prospective supply wells in Guaje Canyon would increase the lowering of the water level in the Los Alamos Canyon well field, but the amount is not easily estimated until the wells have been drilled and put into operation and the characteristics of the aquifer near Guaje Canyon evaluated. The total lowering probably would not be as much as twice that indicated on the graph; and, because the coefficient of transmissibility probably is higher than that assumed in constructing the graph, might be no more than indicated by the graph. The pumping level in any well will be below the level indicated on the graph roughly by an amount, in feet, equal to the pumping rate, in gallons per minute, divided by the specific capacity of the well, as determined after pumping a day or so.

EFFECTS OF A LEAKY AQUIFER

An independent approach to predicting the future decline in water level involves the theory of a leaky aquifer. Under this theory, the discharge of the well is considered to be balanced by water drawn through a semipermeable bed overlying the aquifer from a reservoir constantly replenished from above. The theory would be the same if the water were rising under artesian pressure from a reservoir below. This appears to be the case in the Los Alamos Canyon well field. The theory requires only one aquifer and one semipermeable confining bed, whereas the Los Alamos Canyon field has several of each. However, the idealized condition will give at least an approximate figure for the drawdown to be expected.

This theory, as developed by Steggewentz and Van Nes (1939) and Jacob (1946), gives rise to the equation

$$s=\frac{229Q}{T}K_0\left(r\sqrt{\frac{K'}{TD}}\right)$$

in which K_0 represents a modified Bessel function of the second kind of zero order of the quantity following in parentheses

K'=the permeability of the confining bed, in gallons per day per square foot
D=thickness of the confining bed, in feet

The other terms have definitions and dimensions as previously given.

The quantities K' and D cannot be determined for the aquifer designated in this report, however, an equivalent expression probably can be derived from the physical aspects of the hydraulic system.

The quantity of water moving downgradient through the Santa Fe group toward the Rio Grande in gallons per day is

$$F = Tgw$$

in which

g=hydraulic gradient
w=width of section considered, in feet.

This must be equal to the quantity discharged by upward percolation which if idealized as percolation through one confining bed would be

$$F = \frac{K'hwl}{D}$$

in which

h=difference in head, in feet, driving the water through the semipermeable confining beds
l=length of strip through which water is rising, in feet.

Equating

$$Tgw = \frac{K'hwl}{D}$$

$$\frac{K'}{D} = \frac{Tgw}{hwl} = \frac{Tg}{hl}$$

Introducing this in the previous equation,

$$s = \frac{229Q}{T} K_0\left(r\sqrt{\frac{Tg}{Thl}}\right)$$

$$= \frac{229Q}{T} K_0\left(r\sqrt{\frac{g}{hl}}\right)$$

None of the factors g, h, and l are known definitely but they can be approximated, and it will be found that the value of the function does not change even with considerable errors in the argument. It seems probable that the hydraulic gradient is of the order of 30 feet per mile, or 0.006; that h is about 100 feet, based on the fact that wells 13.114(L1), 14.221(L3), and 14.222(L2) originally flowed and that the deeper wells seemed to have an even higher head; and that l can be taken as about 3 miles, or roughly 1.5×10^4 feet. The quantity $\sqrt{\frac{g}{hl}}$ with these figures becomes

$$\sqrt{\frac{6 \times 10^{-3}}{10^2 \times 1.5 \times 10^4}} = \sqrt{40 \times 10^{-10}} = 6.3 \times 10^{-5}$$

As K_0 is a function that is close to the logarithm for small values, a large error in this factor would change the value of the function only a small amount for small values of r.

If it is assumed that each of the wells 14.312(L6), 15.434(L5), and 22.114(L4) will be pumped at an average rate of 333 gpm in the future, the drawdown in the middle well 15.434(L5) would be as follows:

Owing to pumping well 15.434(L5) (radius assumed as 1 foot)

$$s_5=\frac{229\times 333}{5000}K_0\ (6.3\times 10^{-5})=15.25\times 9.80=150 \text{ feet.}$$

Owing to pumping well 22.114(L4)

$$s_4=15.25\ K_0\ (2690\times 6.3\times 10^{-5})=15.25\times 1.9=29 \text{ feet.}$$

Owing to pumping well 14.312(L6)

$$s_6=15.25\ K_0\ (4020\times 6.3\times 10^{-5})=15.25\times 1.5=23 \text{ feet.}$$

The total is 202 feet.

The above-computed figure of 202 feet is that for an average rate of pumping of 333 gpm, and includes the pumping drawdown of the well. The decline indicated on figure 7 does not include this effect but shows the general decline of the water level in the well field. If we add to the general decline after 40 years, shown in figure 7, the drawdown of the well when pumping 333 gpm, which is about 100 feet at well 15.434(L5) or about 50 feet at well 14.312(L6) or 22.114(L4), the totals are 240 and 190 feet, respectively. Owing to the leaky-aquifer effect, the water level in the aquifer probably will approach an equilibrium position in a few decades.

Neither of these methods of predicting future water levels can be considered to be rigorously correct, and the nature of the aquifer probably prohibits any rigorous solution. The correspondence of the figures obtained under different assumptions gives some assurance that a general decline of the water level in the well field of about 150 feet in 50 years may be assumed for engineering purposes.

POSSIBILITY OF WASTE CONTAMINATION REACHING THE WELL FIELD

Contaminating wastes have been discharged in the vicinity of Los Alamos up the hydraulic gradient from the well fields in Los Alamos and Guaje Canyons. A consideration of the probable rate of movement of water, carrying wastes, will be instructive, even though not all the possible conditions of movement can now be evaluated.

The average velocity of ground water through an aquifer is

$$V = \frac{Tg}{7.48\,mp}$$

in which

$V=$ velocity, in feet per day
$T=$ coefficient of transmissibility, in gallons per day per foot
$g=$ gradient of piezometric surface
$m=$ thickness of aquifer, in feet
$p=$ porosity.

In order to be conservative, and thus to indicate as rapid a movement as seems possible under the conditions known or surmised to exist at Los Alamos, T may be estimated at 10,000 gpd per foot (twice the transmissibility assumed to compute the lowering of water levels); g may be taken as about 60 feet per mile (twice that used for computations of a leaky aquifer) or 0.011; m may be taken as 300 feet, it being assumed that the greater part of the thickness of the Santa Fe is too nearly impermeable to transmit water readily, and p may be taken as 5 percent, indicating an aquifer of very poorly sorted material. Substituting these values in the equation gives a velocity of 0.98 foot per day, or about 1 foot per day. To traverse the distance of about 5 miles from sites of possible contamination to the well fields would take about 26,000 days, or more than 70 years.

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