UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Federal Center, Denver 25, Colorado

In reply refer to:

Technical Letter
Dribble-32
April 5, 1963

Mr. James E. Reeves, Manager
Nevada Operations Office
U.S. Atomic Energy Commission
P. O. Box 1676
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TECHNICAL LETTER: Dribble-32

RESULTS OF AQUIFER TESTS AT
HYDROLOGIC TEST SITES 1 AND 2, TATUM DOME,
LAMAR COUNTY, MISSISSIPPI

By

F. C. Koopman, A. I. Johnson
C. A. Armstrong, and R. E. Taylor

USGS-474-289

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William E. Hale
for

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CONTENTS

	Page
Introduction -----	1
Purpose and scope -----	1
Methods of investigation -----	2
Construction and development of test wells -----	2
Aquifer tests -----	7
Hydrologic properties -----	8
Analysis of aquifer test data -----	10
Conditions affecting results -----	10
Results and comments -----	12
References -----	16

ILLUSTRATIONS

Figure 1. Location of Hydrologic Test Wells 1 and 2, Tatum Dome, Lamar County, Miss. -----	3
2. Semilogarithmic graph of water-level recovery for Aquifer 1, Hydrologic Test Well 1, May 29, 1961 ---	17
3. Semilogarithmic graph of water-level recovery for Aquifer 1, Hydrologic Test Well 2, June 7, 1961 ---	18
4. Semilogarithmic graph of water-level recovery for Aquifer 2, Hydrologic Test Well 1, May 16, 1961 ---	19
5. Logarithmic graph of water-level recovery for Aquifer 2, Observation Well 1 (HT-1a) after pumping from Hydrologic Test Well 1 was dis- continued, May 16, 1961 -----	20
6. Logarithmic graph of water-level recovery for Aquifer 2, Observation Well 3 (HT-2a) after pumping from Hydrologic Test Well 2 was dis- continued, May 29, 1961 -----	21
7. Logarithmic graph of water-level drawdown for Aquifer 2, Observation Well 3 (HT-2a) during pumping from Hydrologic Test Well 2, May 30, 1961 -----	22
8. Logarithmic graph of water-level recovery for Aquifer 2, Observation Well 3 (HT-2a) after pumping from Hydrologic Test Well 2 was discontinued, May 30, 1961 -----	23

ILLUSTRATIONS--Continued

	Page
Figure 9. Logarithmic graph of water-level recovery for Aquifer 2, Observation Well 4 (HT-2b) after pumping from Hydrologic Test Well 2 was discontinued, May 29-30, 1961 -----	24
10. Semilogarithmic graph of water-level recovery for Aquifer 2, Hydrologic Test Well 2, May 29, 1961 -----	25
11. Semilogarithmic graph of water-level recovery for Aquifer 3, Hydrologic Test Well 1, May 9, 1961 -----	26
12. Semilogarithmic graph of water-level recovery for Aquifer 3, Hydrologic Test Well 2, May 28, 1961 -----	27
13. Semilogarithmic graph of water-level recovery for Aquifer 4, Hydrologic Test Well 1, April 28, 1961 ----	28
14. Semilogarithmic graph of water-level recovery for Aquifer 4, Hydrologic Test Well 2, May 18, 1961 -----	29
15. Lithologic and electrical log of hydrologic test wells, showing aquifers and perforated intervals for HT1 -----	30
16. Lithologic and electrical log of hydrologic test wells, showing aquifers and perforated intervals for HT2 -----	31

TABLES

Table 1. Depth of aquifers developed and tested in hydrologic test wells and observation wells -----	5
2. Hydrologic properties of aquifers at Tatum Salt Dome, Lamar County, Miss. -----	13

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By

F. C. Koopman, A. I. Johnson, C. V. Armstrong, and R. E. Taylor

INTRODUCTION

Purpose and Scope

The purpose of the U.S. Geological Survey's hydrologic investigation near Tatum Dome, Lamar County, Miss., is to evaluate for the Atomic Energy Commission the ground-water conditions prior to and after nuclear testing in the area. This objective requires, among other information, a knowledge of the physical and hydrologic characteristics of aquifers.

The basic data for determining the physical and hydrologic characteristics of aquifers are being obtained in the laboratory by analysis of samples and in the field by aquifer tests. Aquifer tests were made by pumping from one well while measuring the effect on the water level in the pumped and nearby wells, either during the pumping (drawdown) period, or during the recovery period following the pumping period. The amount of water that can be withdrawn from or put into storage in the aquifer on some unit basis and the capacity of the aquifer to transmit water are then computed from the relation of pumping rate to the time-water level effects. The aquifer tests

are summarized in this report. The laboratory analyses are to be presented in a Technical Letter entitled "Hydrologic and Physical Properties of Cores from Hydrologic Test Sites 1 and 2, Tatum Dome, Lamar County, Mississippi" by A. I. Johnson and A. H. Ludwig.

The investigation is under the general supervision of O. M. Hackett, chief of the Ground Water Branch of the U.S. Geological Survey, and the direct supervision of J. W. Lang, district geologist for Mississippi. The field phases of the project were under the supervision of C. A. Armstrong, geologist, from January 1961 to June 1962. The laboratory phases of the project are supervised by A. I. Johnson, chief, Hydrologic Laboratory.

Methods of Investigation

Preliminary information on the project area was collected primarily by study of records from oil and gas test holes. During the period April through June 1961, 2 multiple-test wells and 4 observation wells were drilled at 2 sites near Tatum Dome (fig. 1). Lithologic and geophysical logs were made for each of these wells to determine the most suitable depths for testing of water-bearing beds. The hydrologic properties of the principal aquifers in the project area were determined by making aquifer tests in 5 zones at the 2 hydrologic test sites.

CONSTRUCTION AND DEVELOPMENT OF TEST WELLS

Preliminary data showed that there were at least five principal aquifers that should be tested in connection with the Atomic Energy

Figure 1.--Location of Hydrologic Test Wells 1 and 2,
Tatum Dome, Lamar County, Miss.

Commission's safety program. It was concluded that the most economical method for obtaining all of the necessary data would be to drill two multiple-test wells (Hydrologic Test Wells 1 and 2 at sites 1 and 2 respectively, fig. 1) in which lithologic and geophysical logs could be made, sidewall cores could be taken at specified depths as determined from the geophysical logs, and aquifer tests could be made of the water-bearing zones.

Hydrologic Test Well 1 (HT-1) and Observation Wells 1 and 2 (HT-1a and HT-1b) were drilled approximately 0.5 mile northeast of Tatum Dome, and Hydrologic Test Well 2 (HT-2) and Observation Wells 3 and 4 (HT-2a and HT-2b) were drilled approximately 0.6 mile southwest of the dome (fig. 1). The observation wells were drilled parallel to the strike of the formations, with Wells 1 and 3 at 300 feet and Wells 2 and 4 at 900 feet from the hydrologic test wells. Detailed data on Hydrologic Test Wells 1 and 2 are reported in Technical Letters Dribble 6 and 7, respectively. (Also see figs. 15 and 16 at end of this report.)

Construction of Hydrologic Test Wells 1 and 2, which are the multiple-test wells, was accomplished by drilling the hole, setting the casing, and squeeze-cementing an outer casing seal from the bottom of the well to the surface. Each aquifer above and including Aquifer 4 was then tested in turn by gun-perforating the casing (four 3/8-inch perforations per ft) and isolating the aquifer with packers during the well development and pumping tests. Aquifer 5 was opened, isolated with a packer and tested after the testing of the first four aquifers was completed. Table 1 presents data on the depths of the aquifer and of the zones of perforated casing in the test wells.

Table 1.--Depth of aquifers developed and tested in hydrologic test wells
and observation wells

Aquifer number	Assigned aquifer interval (depth in feet)	Perforated casing interval (depth in feet)	Remarks
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Hydrologic Test Well 1

Reference datum--rotary table, elevation 321 feet

1	578 - 782	634 - 655 735 - 782	Aquifer contains clay beds. Chunk of casing 3" x 5" recovered from well.
2	853 - 1,140	925 - 955 1,060 - 1,130	Sands finer than in HT-2. Contains clay beds in middle part of aquifer.
3	1,215 - 1,310	1,230 - 1,310	Sand over perforations by end of aquifer test.
3A	1,373 - 1,525	1,375 - 1,403 1,418 - 1,460 1,475 - 1,525	Aquifer 3A did not produce water during an attempted aquifer test.
4	1,680 - 1,902	1,742 - 1,880	Perforated <u>only</u> in lime- stone zone of aquifer.
5.	2,240 - 2,390	2,240 - 2,420	Open-hole.

Hydrologic Test Well 2

Reference datum--rotary table, elevation 302.4 feet

1	600 - 842	670 - 700 800 - 820	Aquifer contains clay beds. Sand over perforations at end of aquifer test.
2	870 - 1,232	920 - 1,000	Perforated <u>only</u> in upper zone of aquifer. Sands and gravels coarser than in HT-1.
3	1,260 - 1,470	1,270 - 1,400	Sands finer than in HT-1.
4	1,815 - 2,067	1,817 - 1,959	Perforated in sand <u>and</u> limestone zones of aquifer
5	2,414 - 2,618	2,435 - 2, 616	Open-hole.

Table 1.--Depth of aquifers developed and tested in hydrologic test wells
and observation wells--Continued

Aquifer number	Assigned aquifer interval (depth in feet)	Perforated casing interval (depth in feet)	Remarks
<u>Observation Well 1 (HT-1a)</u> (Depths in reference to elevation of HT-1)			
2	853 - 1,140	907 - 963 1,067 - 1,128	Perforated in upper <u>and</u> lower zone of aquifer
<u>Observation Well 2 (HT-1b)</u> (Depths in reference to elevation of HT-1)			
2	853 - 1,140	886 - 936	Perforated only in upper zone of aquifer.
<u>Observation Well 3 (HT-2a)</u> (Depths in reference to elevation of HT-2)			
2	870 - 1,232	943 - 1,024	Sanded in to 1,023 ft after aquifer test.
<u>Observation Well 4 (HT-2b)</u> (Depths in reference to elevation of HT-2)			
2	870 - 1,232	935 - 996	Sanded in to 956 ft after aquifer test.

Following completion of the aquifer tests, Hydrologic Test Well 1 and 2 were completed as multiple observation wells with individual pipes opened to Aquifers 3, 4, and 5, and with Aquifers 1 and 2 closed off. Observation Wells 1, 2, 3, and 4 (HT-1a, 1b, 2a, and 2b, respectively) were continued as observation wells for Aquifer 2.

Each aquifer in Hydrologic Test Wells 1 and 2 was developed as follows: The well was jetted with air until the sand content in the water was reduced to approximately 15 ounces of sand per 1,000 gallons of water. Jetting continued for a period of 1 to 2 hours to see if a further reduction of the sand content could be attained and, if not, jetting was stopped and a pump was installed. Pumping then began at a low rate and was increased as fast as practical to approximately the rate shown on the test data plots. The limiting factor was the quantity of sand being pumped.

AQUIFER TESTS

Aquifer tests were completed as follows: (1) a short water-level recovery test was made following the well development; (2) a drawdown test followed after a recovery trend in water levels had been established in the recovery test; and (3) a second recovery test then was made. Periodic measurements of water levels were made in the wells during either the pumping or recovery period or both. The discharge during pumping was measured by use of an orifice meter. It was hoped that the pumping could be held at a nearly constant rate during the

drawdown test to facilitate computation of the aquifer characteristics.

The data were analyzed by the methods described by Wenzel (1942) and Jacob (1950). For the modified nonequilibrium method (Jacob, 1950), the test data were plotted on semilogarithmic paper with the time data plotted on the logarithmic scale and the water level or drawdown data plotted on the arithmetic scale. (See figs. 2 through 4, for example.)

For the Theis nonequilibrium method (Wenzel, 1942) the test data were plotted on logarithmic paper and the data as plotted were then overlaid on type curves. (See figs. 5 through 9, for example.) For recovery tests, the Theis recovery formula is considered to be more accurate than the modified nonequilibrium formula but was not used because of the variable pumpage rates, which were averaged, and the lack of accurate water-level data during the early periods of development when drawdown varied the most.

Hydrologic Properties

The coefficient of storage is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface (Theis, 1938). For an artesian aquifer, the water released from or taken into storage is attributed only to the compressibility of the aquifer material and of the water--there is no actual dewatering or filling of the aquifer.

The coefficient of permeability of material comprising an aquifer is a measure of the material's capacity to transmit water. It is expressed here as the gallons per day that will percolate through a cross section of 1 square foot under a hydraulic gradient of 1 foot per foot at a temperature of 60°F (Wenzel, 1942, p. 7). When corrected to the existing temperature of the water in the aquifer, this coefficient may be expressed in field terms as the gallons of water per day that will percolate through a cross section of aquifer 1 mile wide and 1 foot thick under a hydraulic gradient of 1 foot per mile.

The coefficient of transmissibility is the rate of flow of water (at the prevailing water temperature), in gallons per day, through a vertical strip of the aquifer 1 mile wide extending the full saturated height of the aquifer under a hydraulic gradient of 1 foot per mile. Thus, the coefficient of transmissibility is the product of the field coefficient of permeability and the saturated thickness of the aquifer. (Wenzel, 1942, p. 10). It is usually expressed in gallons per day per foot.

The specific capacity of a well is its rate of yield per unit of drawdown (Meinzer, 1923, p. 62). Specific capacity is related to the transmissibility of an aquifer and to the size and construction of the well. It is computed by dividing the rate of discharge by the drawdown, and is usually expressed in gallons per minute per foot.

Analysis of Aquifer Test Data

Conditions Affecting Results

The wells were drilled and the aquifers isolated as planned, but several difficulties, due principally to incomplete well development, were encountered during the aquifer tests. The hydrologic properties for Aquifer 2, Hydrologic Test Well 2, are thought to be most reliable because of the many confirmation tests and the definitive data. Many of the other test results may not be representative because of (1) excessive discharge of sand, (2) sand filling the casing and thus decreasing the effective perforated interval, (3) cement partially sealing the aquifers--especially the limestone in Aquifer 4, and (4) effects of gases in the water.

Adequate development of the wells usually was impossible because the wells were constructed with perforations too large to prevent movement of the formation sands into the casing. Sand that could not be contained behind the perforated casing also caused considerable variation in discharge rate and probably was the cause of most of the irregularities found in the plotted data. With the exception of Aquifer 2 of Hydrologic Test Well 2, pumping of excessive sand caused such variable discharge rates that the drawdown tests were either discontinued earlier than is generally desirable or the water level measurements were too variable to be of use.

An extreme example of what can happen in a pumping test subject to excessive pumping of sand was encountered in a preliminary bailing test on Observation Well 1. Early test data yielded an apparent

coefficient of transmissibility of 250 gpd per ft (gallons per day per foot) for Aquifer 2. At the completion of the test it was found that sand had entered and filled the casing to a point several feet above the perforations. Test data obtained after Observation Well 1 had been cleaned gave a coefficient of transmissibility of approximately 70,000 gpd per ft, which probably is a reasonable value. The results of a pumping test of Aquifer 2 in Humble Hibernia No. 1 (see fig. 1), which was filled above the perforations with sand, gave an apparent coefficient of transmissibility of 1,000 gpd per ft (data for the latter test are not included in this report). Obviously, the small apparent transmissibilities obtained from such sand-plugged wells do not commonly reflect true aquifer characteristics.

Sand temporarily suspended in the well casing causes erroneous results by covering the perforations as it settles to the bottom. If a significant number of perforations are covered in the process, the apparent transmissibility increases. After discharge is discontinued and the recovery test started the sand causes an apparent low transmissibility as it settles to the bottom; this is because the density of the column of water in the casing decreases as the sand settles and results in a tendency for the water level to rise at a rate greater than would otherwise take place. The plot of the data from Aquifer 1, Hydrologic Test 1 (fig. 2) is believed to be an example showing, first, the early transmissibility affected by an apparent decrease in transmissibility due to settling of sand, (starting at about 30 minutes) and then the apparent increase in

transmissibility due to the covering of the perforations (starting at about 60 minutes).

The results of the recovery tests attempted for Aquifer 5 in both hydrologic test wells are meaningless for recovery calculations because the water levels made a surge upward and then declined until measurements were discontinued about 3 hours after the pumps were turned off; these data have not been included in this report. The upward surge may have been caused in large part by the rise and expansion of gas contained in the water. As the gas slowly escaped, the buoyancy was decreased and the water levels declined. This inference is supported by the fact that traces of gases were detected during a small part of the drilling through Aquifer 5 in Hydrologic Test 2.

The gas escaping from the water may be only part of the cause for the surge upward and the slow decline of water level after pumping has stopped. In addition, the slug of water released from the pump column when the pump is stopped also creates similar effects. The recovery data from all tests for the first 4 to 5 minutes after the pump was turned off were greatly influenced by the return of water from the pump column which resulted in higher than normal water levels. The effect of the returned water gradually diminished after the initial surge and does not appear to affect the data after about 8 to 15 minutes.

Results and Comments

The computations and values for coefficients of transmissibility and storage are shown on figures 2 through 14 (at end of report). These

values, together with specific capacity and coefficient of permeability data for the 5 aquifers also are summarized in table 2.

Table 2.--Hydrologic properties of aquifers at Tatum Salt Dome,
Lamar County, Miss.

Aquifer number	Aquifer thickness (feet)	Coefficient of transmissibility (gpd per ft)	Coefficient of permeability (gpd per sq ft)	Specific capacity (gpm per ft)
Hydrologic Test 1				
Aquifer 1	204	4,500	20	1.8
Aquifer 2 (lower part)	100	^a 70,000	700	3.8
Aquifer 3	95	6,900	70	4.3
Aquifer 4	222	7,000	30	1.5
Aquifer 5	150	^b 1,500	10	---
Hydrologic Test 2				
Aquifer 1	242	^c 5,600	20	4.8
Aquifer 2 (upper part)	150	^a 166,000	1,000+	55.0
Aquifer 3	210	13,800	70	4.8
Aquifer 4	252	8,300	30	2.5
Aquifer 5	204	^b 2,000	10	---

^aCoefficient of storage is 2.9×10^{-4} for HT-1 and 3.0×10^{-4} for HT-2.

^bCalculated from Bureau of Mines data (Riggs, Heath, and Ward, 1962).

^cMay represent upper perforated zone only.

Aquifer 1 contains very coarse to fine sand and clay beds. The effect of the clay beds is evident in that the transmissibility is low at both the hydrologic test sites. The electric logs of the aquifer (see figs. 15, 16) indicate that the aquifer contains more sand at Hydrologic Test Site 2 than at Hydrologic Test Site 1. The transmissibility of the aquifer at Hydrologic Test Well 2 is higher than at Well 1 as might be expected because of the thicker sand section.

Aquifer 2 is composed of all the sizes of sand with a grading upward to the fine sand. The aquifer consists of two parts and is separated by nearly 100 feet of clay. Some difficulty was encountered when testing this aquifer because of its split zones. Observations Wells HT-1a and HT-1b are both completed within Aquifer 2 but at different intervals. The relative effects of tests on these wells suggest that Observation Well HT-1a and Hydrologic Test Well 1 were effectively open only to the lower portion of this aquifer and hence the transmissibility value listed in table 2 probably represents only the lower part of Aquifer 2. Observation Well HT-1b is completed only in the upper portion and there was no effect on it as the result of Pumping Well HT-1a. Only the upper part of Aquifer 2 was tested at Hydrologic Test Site 2. The data indicate that if the total assigned thickness of Aquifer 2 was developed to a well the transmissibility probably would be in excess of 200,000 gallons per day per foot.

Figures 5 through 9 show the test data from Observation Wells 1, 3, and 4, plotted on logarithmic graph paper, for Aquifer 2. Data from Observation Well 2 were omitted because they showed a recovery of

approximately 0.04 foot, which was too small and too irregular to be definitive.

Aquifer 3 contains two predominant lithologies. The lower lithology is limestone or sandy limestone and the upper part is fine to medium sand. The aquifer at Hydrologic Test Site 1 includes more of the lower lithology than at Hydrologic Test Site 2. The greater part of limestone at this site may account for the lower transmissibility as compared to Hydrologic Test Site 2.

Both sand and limestone lithologies are included in Aquifer 4 at Hydrologic Test Sites 1 and 2. Differences in the perforated intervals in the test wells caused the upper sand at Hydrologic Test Site 1 to be tested more fully and the lower limestone to be the greater tested part of the aquifer at Hydrologic Test Site 2. Despite the differences in perforated intervals of the two wells, the transmissibility computed is not indicative of any appreciable difference in hydrologic characteristics.

Data reported by the U.S. Bureau of Mines (Riggs, Heath, and Ward, 1962) have been used to estimate the coefficient of transmissibility for Aquifer 5. The average permeability for this aquifer, as determined by their field and laboratory studies, is approximately 10 gpd per sq ft. The aquifer thickness is 150 feet at Hydrologic Test Well 1 and 204 ft at Hydrologic Test Well 2, providing a coefficient of transmissibility of about 1,500 gpd per ft and 2,000 gpd per ft respectively.

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VELA UNIFORM PROGRAM, OPERATION DRIBBLE, TATUM DOME, MISS.

Figure 2.--Semilogarithmic graph of water-level recovery for Aquifer 1, Hydrologic Test Well 1, May 29, 1961.

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Figure 3.--Semilogarithmic graph of water-level recovery for Aquifer 1, Hydrologic Test Well 2, June 7, 1961.

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Figure 4.--Semilogarithmic graph of water-level recovery for Aquifer 2, Hydrologic Test Well 1, May 16, 1961.

Figure 5.--Logarithmic graph of water-level recovery for Aquifer 2, Observation Well 1 (HT-1a) after pumping from Hydrologic Test Well 1 was discontinued, May 16, 1961.

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Figure 6.--Logarithmic graph of water-level recovery for Aquifer 2, Observation Well 3 (HT-2a) after pumping from Hydrologic Test Well 2 was discontinued, May 29, 1961.

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Figure 7.--Logarithmic graph of water-level drawdown for Aquifer 2, Observation Well 3 (HT-2a) during pumping from Hydrologic Test Well 2, May 30, 1961.

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Figure 8.--Logarithmic graph of water-level recovery for Aquifer 2, Observation Well 3 (HT-2a) after pumping from Hydrologic Test Well 2 was discontinued, May 30, 1961.

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Figure 9.--Logarithmic graph of water-level recovery for Aquifer 2, Observation Well 4 (HT-2b) after pumping from Hydrologic Test Well 2 was discontinued, May 29-30, 1961.

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Figure 10.--Semilogarithmic graph of water-level recovery for Aquifer 2, Hydrologic Test Well 2, May 29, 1961.

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Figure 11.--Semilogarithmic graph of water-level recovery for Aquifer 3, Hydrologic Test Well 1, May 9, 1961.

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Figure 12.--Semilogarithmic graph of water-level recovery for Aquifer 3, Hydrologic Test Well 2, May 28, 1961.

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Figure 13.--Semilogarithmic graph of water-level recovery for Aquifer 4, Hydrologic Test Well 1, April 28, 1961.

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Figure 14.--Semilogarithmic graph of water-level recovery for Aquifer 4, Hydrologic Test Well 2, May 18, 1961.

U.S. Geological Survey
August 1961

Figure 13.- Lithologic and electrical log of Hydrologic Test Well 1, showing aquifers and cored intervals.

Elevation, 295.05 feet above sea level
Datum: rotary table, elevation 302.4 feet
Lithology from binocular microscopic examination
of cuttings and cores.

Figure 16.-Lithologic and electrical log of Hydrologic Test Well 2, showing aquifers and cored intervals.