GROUND-WATER CONDITIONS IN THE NEOSHO RIVER VALLEY IN THE VICINITY OF PARSONS, KANSAS

By

CHARLES C. WILLIAMS

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GROUND-WATER CONDITIONS IN THE NEOSHO RIVER VALLEY IN THE VICINITY OF PARSONS, KANSAS

By Charles C. Williams[1]

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By CHARLES C. WILLIAMS

ABSTRACT

This report presents the results of an investigation of the ground-water conditions in the Neosho river valley near Parsons, Kansas, which was made with special reference to the possibility of developing a supply of water for the Kansas Ordnance Plant. A geological reconnaissance of a part of the valley was supplemented by test drilling and by a pumping test.

It was found that the physical characteristics and thickness of the water-bearing materials comprising the alluvium are quite variable. In general the alluvium is about 35 feet thick. The upper 10 to 30 feet consists of silt and clay and the lower part, ranging in thickness from a few inches to 15 feet, consists of poorly sorted sand and gravel.

Neosho river receives water from the ground-water reservoir which in turn receives recharge from precipitation. Some recharge is supplied to the alluvium by Neosho river in times of flood. In 1942 the water table was less than 10 feet below land surface in most parts of the valley.

A pumping test was made, and from the data obtained it was computed that the alluvium has a coefficient of permeability of about 420 and a specific yield of about 20 percent. It is concluded that during periods of normal precipitation a supply of about 200,000 gallons of water daily can be developed in the Neosho valley from several wells properly distributed within an area of about 1 square mile. It is believed that the pumping rate of each well should not exceed 50 gallons a minute.

The ground water in the alluvium is very hard and contains a considerable amount of iron but it is low in chloride. The hardness is almost all carbonate hardness, so that both hardness and iron can be removed by relatively simple and inexpensive treatment.

INTRODUCTION

The area described in this report includes about 10 square miles bordering Neosho river in northeastern Labette county, Kansas (fig. 1), adjacent to the Kansas Ordnance Plant reservation.

On January 13, 1942, Mr. L. C. Childs, of the firm of Consoer, Townsend, and Quinlan, and Battey and Childs, architect-engineers for the Kansas Ordnance Plant, requested the cooperation of the Federal Geological Survey and the State Geological Survey of Kansas in making test borings at proposed dam sites and in prospecting for a possible source of water supply in the Neosho river valley in the vicinity of the Kansas Ordnance Plant, near Parsons, Kansas. In view of the importance of this project for the prosecution of the war, the investigation was undertaken immediately under the direction of S. W. Lohman, Federal geologist in charge of ground-water investigations in Kansas, and Raymond C. Moore, state geologist and director of the State Geological Survey. The firm of architect-engineers furnished subsistence to members of the drilling crew and supplied men to assist with the routine labor necessary to the investigation. The Kansas State Board of Health made the analyses of the water samples collected. The results of the analyses are included in this report through the courtesy of the State Board of Health and the architect-engineers.

The field work was done mainly during the period from January 15 to February 9, 1942. Using the portable hydraulic-rotary drilling machine owned by the State and Federal Geological Surveys, Ellis D. Gordon, driller, James B. Cooper, sampler, and LeRoy Fugitt, assistant driller, drilled and cored 8 test holes to determine subsurface conditions at proposed dam sites along Neosho river and drilled 21 test holes in the alluvium of the Neosho river valley. During October, 1942, 18 holes were bored in the alluvium by hand auger to obtain additional data for construction of a water-table

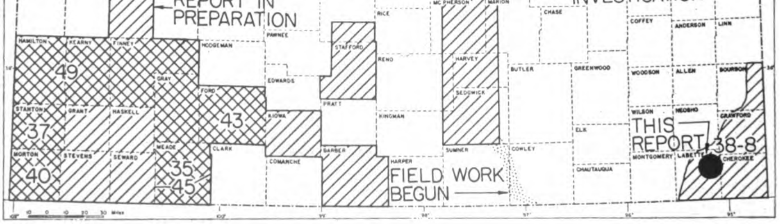

Figure 1. Index map of Kansas showing areas for which cooperative ground-water reports have been published or are in preparation. Bulletin numbers of ground-water reports published by State Geological Survey of Kansas are indicated. Arrow points to area described in this report.

contour map. Levels were run to the auger holes and to the water surface of several creeks and ponds by Silas C. Brown and Richard Tripp, of the State Geological Survey of Kansas. Levels were run to the test holes by the architect-engineers. The locations of the test holes and auger holes are shown in figure 2. Four wells were selected in June, 1943, for periodic measurement, and these measurements will be continued for an indefinite length of time.

The pumping test described herein was conducted by the Layne-Western Company for the Kansas Ordnance Plant, and the results of the test and elevations of the pumped well and observation wells were supplied by John A. Fulkman, of the architect-engineers. V. C. Fishel, physicist for the Federal Geological Survey, assisted in interpreting the pumping test data for field determinations of permeability and offered many valuable suggestions which have been incorporated in this report. John C. Frye and G. E. Abernathy of the Kansas Geological Survey assisted in a reconnaissance of the valley. S. W. Lohman visited the area of investigation several times and assisted in planning the field work and the form of the report.

This report was reviewed critically by O. E. Meinzer, S. W. Lohman, L. K. Wenzel, V. C. Fishel, and W. D. Collins of the Federal Geological Survey; John C. Frye, assistant director, State Geological Survey of Kansas; George S. Knapp, chief engineer, Division of Water Resources, Kansas State Board of Agriculture; and Ogden S. Jones, geologist, Division of Sanitation, Kansas State Board of Health.

GEOLOGY IN RELATION TO GROUND WATER

Pennsylvanian Rocks

The bedrock underlying the part of the Neosho river valley studied consists of the upper part of the Cherokee shale and the Fort Scott limestone. The Fort Scott limestone forms the escarpments bordering the Neosho valley in this area.

The base of the Fort Scott limestone (which is also the top of the Cherokee shale) is placed by definition at the base of the lower of two limestones at the type locality of the Fort Scott (Moore, 1936, p. 58). Beds of sandstone and sandy limestone (pl. 1A) encountered in test hole 17 and certain other test holes are in the uppermost part of the Cherokee shale and may be equivalent to the Breezy Hill limestone member (Pierce and Courtier, 1937, p. 33).) The Fort Scott-Cherokee formational contact is shown in figure 3. A few domestic wells have been dug to the base of the Fort Scott limestone and are reported to yield small quantities of water in seasons of normal precipitation. Water is obtainable in small quantities in seasons of normal precipitation from the porous soil cover above the Cherokee shale (Moore, 1940, p. 50). The unweathered part of the Cherokee shale has very low permeability and yields little or no water to wells. The beds of sandstone that were encountered in test holes in this area are very fine grained and tightly cemented; hence they probably would yield little or no water to wells.

Quaternary Deposits

TERRACE DEPOSITS

Terrace deposits of clay, sand, and gravel occur in patches along a belt about 2.5 miles wide just west of Neosho river, from about 840 to 850 feet above sea level, or about 30 feet above normal river level. Such deposits have been removed from much of the west side of the valley and cannot be found on the east side in this part of the valley. Where present, the terrace gravels range in thickness from a few inches to about 20 feet. The pebbles making up the gravel are composed mostly of brown subangular chert. The gravel and associated sand and clay are exploited for road material at a pit in the SE¼ NW¼ sec. 17, T. 31 S., R. 21 E. The thickness of the material at the gravel pit is about 20 feet (pl. 1B.)

According to Pierce and Courtier (1937, p. 51)

> The Quaternary [terrace] gravels in Labette county contain brown chert, which, in conjunction with their regional location, suggests that they were derived from the chert in the limestones of Pennsylvanian age which now lie to the northwest.

The present investigation resulted in no additional evidence bearing on the age of the terrace deposits. Therefore, Pierce and Courtier's conclusion that these deposits are of Quaternary age is accepted for this report.

The bedding and sorting of the deposits, together with the degree of rounding of the pebbles, indicate fluviatile deposition. The pebbles in the terrace gravels are very similar to those in the alluvium which indicates that they were a source of part of the alluvium. The terrace gravels were deposited before the river had excavated its present valley, and, when mapped in detail over a

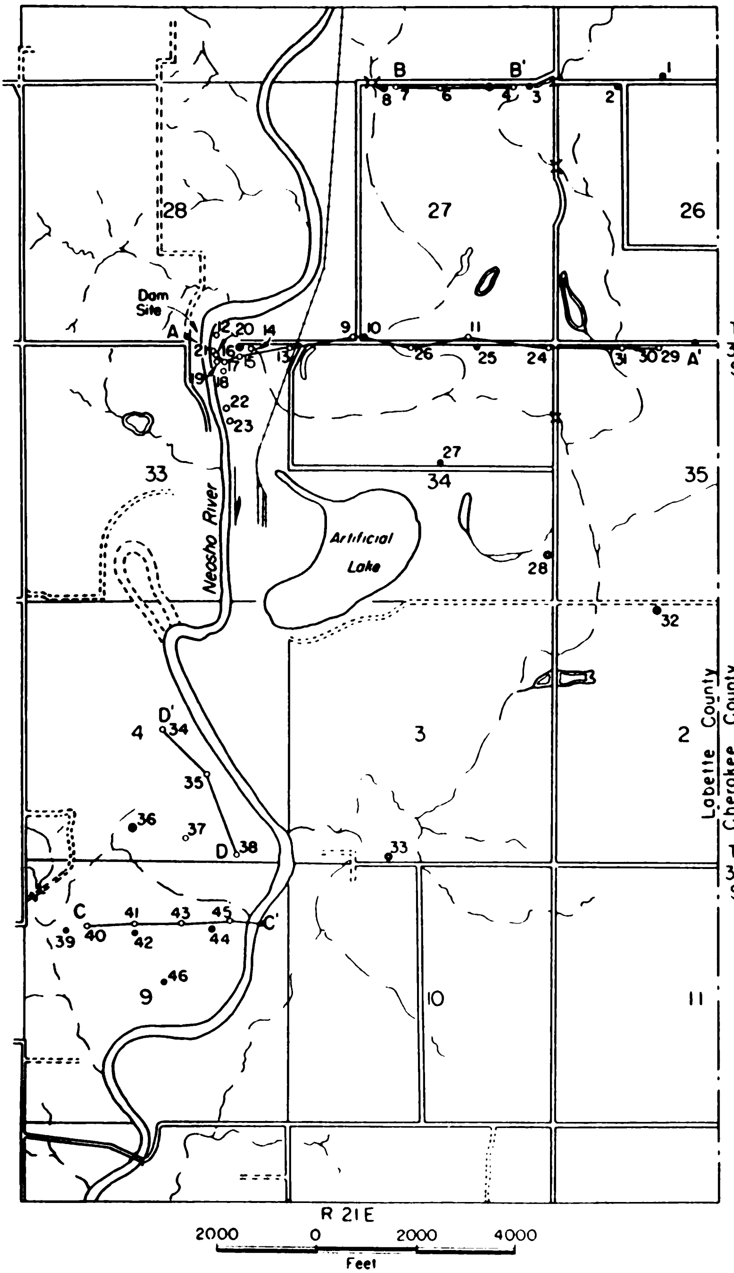

Fig. 2. Map of a part of Neosho river valley showing locations of test holes, auger holes, and wells. Open circle designates rotary test hole, closed circle designates hand auger hole, and double circle designates a well.

large area, drainage lines of an ancestral Neosho river probably will be revealed.

The terrace deposits are not a source of ground water in this area because they are discontinuous and limited in extent, and owing to their high topographic position any water that seeps into them drains out rapidly.

ALLUVIUM

General considerations.—The alluvium of the Neosho river valley yields water to many domestic and stock wells in the valley, but very little was known concerning the quality and quantity of water available for industrial or municipal use. In order to determine the thickness, character, and extent of the alluvium, the locations of any deep channels that might have been excavated into bedrock, and the quality of the water, 21 test holes (in addition to the 8 drilled at dam sites) were drilled at the locations indicated in figure 2.

The test holes were drilled through the alluvium and from 6 inches to 37 feet into bedrock by the hydraulic-rotary method (pl. 3). Samples of the material drilled were collected at regular intervals or whenever any change in the character of the alluvium was noted, and these samples were studied microscopically in the laboratory. After the completion of each test hole that encountered water-bearing gravel, a sample of water was obtained in the following manner. A 5-foot screened well point was attached to the drill stem and lowered nearly to the bottom of the hole. Water was pumped using the mud pump on the well rig for a period of time sufficient to obtain a reasonably clear sample of water for analysis (pl. 3A).

Character of material.—The alluvium in the Neosho river valley consists of silt, clay, sand, and gravel. In general it is about 35 feet thick. The upper 10 to 30 feet is composed generally of silt and clay in varying proportions and locally contains some very fine sand. In most places this material contains flakes and concretions of limonite. Poorly sorted sand and gravel, ranging in thickness from a few inches to 15 feet, generally underlies the silt and clay. Some of the gravel closely resembles the terrace gravel described above and is probably derived in part from terrace deposits. The sand and gravel in the alluvium ranges greatly in thickness, as shown in plate 2 and as indicated in the logs given at the end of this report.

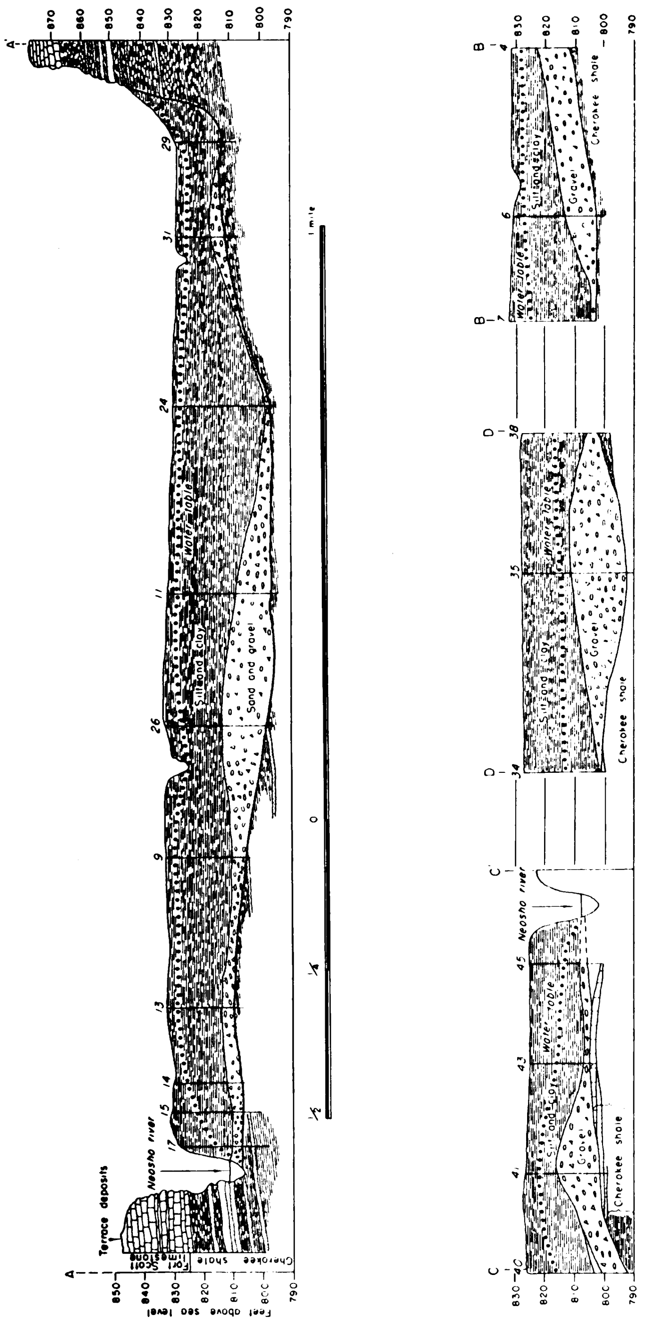

Fig. 3. Geologic profiles in Neosho river valley showing character of alluvium and its relation to bedrock. A-A[1], East-west profile across the valley; B-B[1], East-west profile across a portion of Neosho valley; C-C[1], Profile paralleling a section of Neosho river; D-D[1], East-west profile across a portion of the valley (fig. 2).

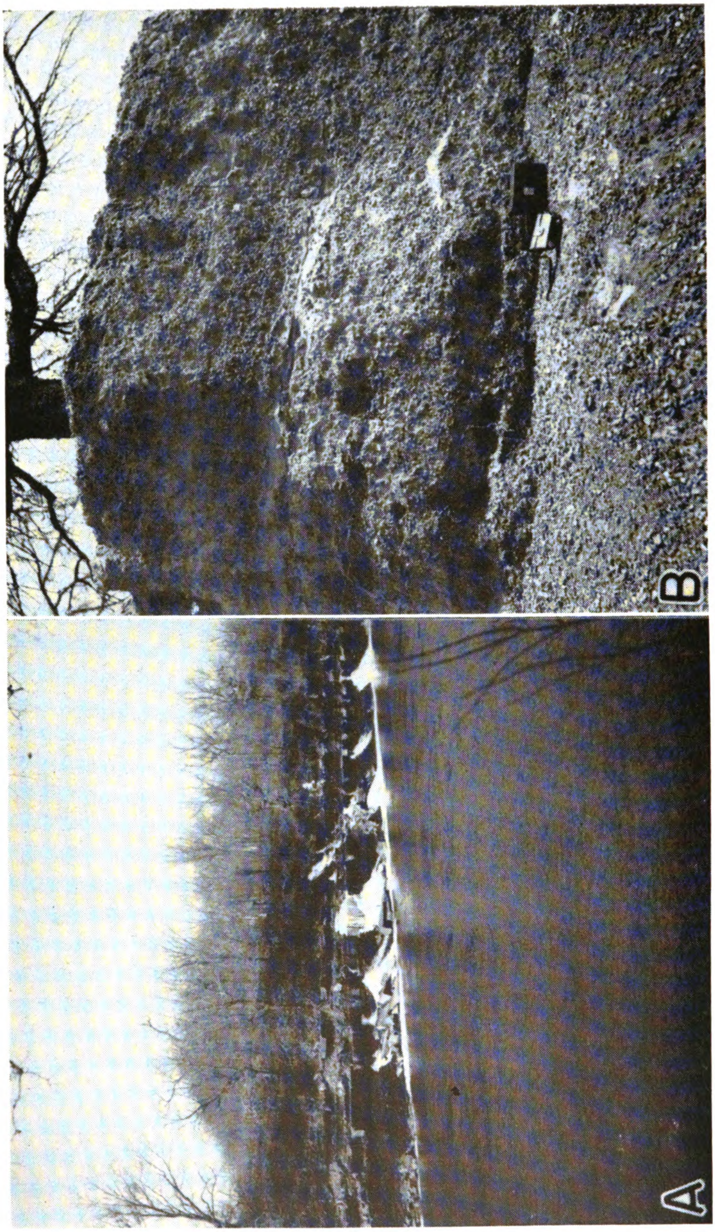

PLATE 1. *A.* Outcrop of sandstone in the upper Cherokee shale, SW¼ NW¼ sec. 33, T. 31 S., R. 21 E. *B.* Terrace gravel deposit, SE¼ NW¼ sec. 17, T. 31 S., R. 21 E.

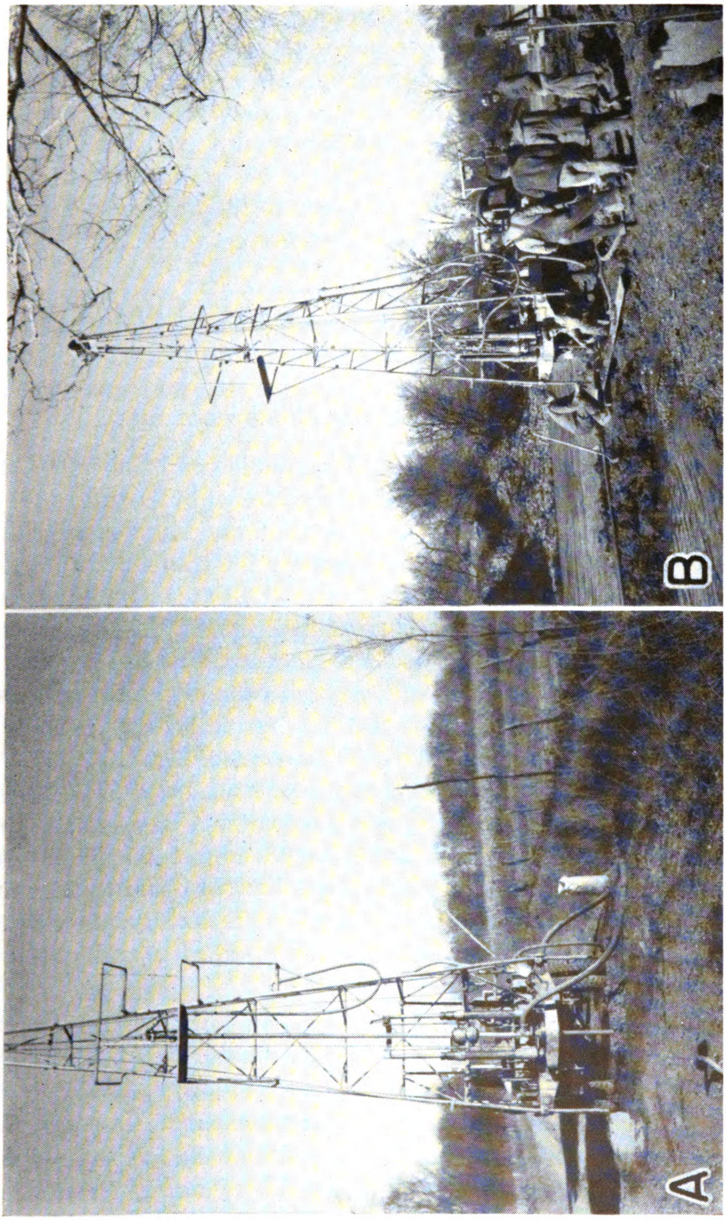

PLATE 3. *A.* Pumping water from test hole 6 with the drilling rig.
B. Core drilling at a prospective dam site at Neosho river's edge.

Water supply.—The gravel in the alluvium supplies sufficient water for domestic and stock use in most parts of the Neosho valley. Most of these supplies are obtained from driven wells that generally are about 10 to 20 feet deep. These wells are reported not to have failed during the droughts that occurred between 1930 and 1940. As indicated elsewhere in this report, yields of about 50 gallons a minute may be expected from properly constructed wells in areas of the valley where the alluvium contains beds of saturated gravel that are 5 or more feet thick.

PHYSICAL PROPERTIES OF WATER-BEARING MATERIALS

Definitions and General Considerations

The rate of movement of ground water is conditioned by the size and shape of the interstices in the rocks and the difference in hydraulic gradient from one point to another. The permeability of a water-bearing material is its capacity for transmitting water under pressure. The coefficient of permeability may be expressed as the number of gallons of water a day, at 60° F., that is conducted laterally through each mile of the water-bearing bed under investigation (measured at right angles to the direction of flow), for each foot of thickness of the bed, and for each foot per mile of hydraulic gradient (Meinzer's coefficient; see Stearns, 1927, p. 148). The coefficient of transmissibility (Theis, 1935, p. 520) may be defined as the number of gallons of water a day, at the prevailing temperature, that is transmitted through each mile of the water-bearing bed under a hydraulic gradient of 1 foot to the mile; hence it is the average coefficient of permeability, as defined above, multiplied by the thickness of the aquifer and adjusted for temperature.

The specific yield of a water-bearing formation is defined as the ratio of (1) the volume of water which a saturated aquifer will yield by gravity to (2) its own volume (Meinzer, 1923, p. 28). The quantity of water that may be removed from storage in a saturated material depends upon the specific yield of the material. Permeability, transmissibility, and specific yield were determined for the alluvium of Neosho valley by methods based on pumping tests.

Behavior of the Water Level Near a Pumped Well

The following discussion has been adapted for use in this report from similar discussions by L. K. Wenzel and other members of the Federal Geological Survey.

As soon as a pump begins discharging water from a well under water-table conditions, the water table in the vicinity of the well is lowered, thus establishing an hydraulic gradient toward it. The water table soon assumes a form comparable to that of an inverted cone, the well being at the apex. For a short time most of the water that is pumped from a well is derived by unwatering materials close to it. As pumping is continued, more of the formation is gradually unwatered and a gradient is established which transmits to the well approximately the amount of water that is being pumped, most of the water being derived from ever increasing distances from the well. Thus, the cone of depression continues to expand and the water table within the cone continues to decline gradually. The development of the cone of depression may be halted if water is added to the formation by natural or artificial recharge.

After the discharge of a well is stopped, water continues to percolate toward the well for a time because the hydraulic gradient is still in that direction, but instead of being discharged at the surface the water refills the well and the adjacent material that was unwatered by the pumping. As the formation near the well is gradually refilled, the hydraulic gradient is gradually decreased and the recovery of the water level in the well becomes progressively slower. At a considerable distance from the well, the water level may continue to lower for a time after pumping has been stopped because water continues to move toward the well. In time there is a general equalization of water levels over the entire area affected, and the water table tends to assume its original form, although it may remain temporarily or permanently somewhat lower than before water was withdrawn.

Pumping Test

A test well, 30.4 feet deep, was constructed in February, 1942, by the Layne-Western Company at the site of test hole 36, in the NE¼ SE¼ SW¼ sec. 4, T. 32 S., R. 21 E. This location for the pumping test was chosen by Mr. J. A. Fulkman, of the architect-engineers. The well was gravel-packed to a diameter of 38 inches and the 10-inch casing was perforated throughout the lower 10 feet. The pump used was a Layne turbine. Seven observation wells were drilled nearby so that measurements of the depth to water could be obtained at different distances and in different directions from the pumped well before, during, and after the pumping test. The location of the observation wells and other pertinent data are given in table 1.

TABLE 1.—*Location, diameter, depth, and altitude of wells used in the pumping test*

Well number	Diameter (inches)	Depth of well below measuring point (feet)	Height of measuring point above land surface (feet)	Altitude of measuring point (feet above sea level)	Altitude of static water level (feet above sea level)	Distance and direction from pumped well 1 (feet)
1	38.0	31.7	1.3	825.2	818.03	0
1S	1.25	30.5	.5	825.8	818.05	50 south
1N	1.25	29.5	.5	822.4	817.82	50 north
1E	1.25	31.5	.5	826.9	819.45	100 east
1W	1.25	27.5	.5	820.2	817.45	100 west
2S	1.25	32.5	.5	826.4	818.15	150 south
2N	1.25	25.5	.5	819.7	817.7	150 north
3S	1.25	25.5	.5	824.6	817.6	350 south

The well was pumped continuously for 98 hours at an average rate of 90 gallons a minute. The average pumping rate for the last 12 hours was 80 gallons a minute; at the end of the test the specific capacity (gallons a minute per foot of draw-down) was found to be 3.9. The water levels as measured in the pumped well and in the observation wells, and the pumping rates are given in table 2. Draw-down and recovery curves for the observation wells are shown in figure 4. The recovery curve for the pumped well is shown in figure 5. The shape of the water table near the pumped well at the end of the pumping test is shown in figure 6. The measurements of water levels were made by the wetted-tape method. The lower foot of a steel tape was coated with blue carpenter's chalk, so that the depth of immersion of the tape into the water could be seen plainly.

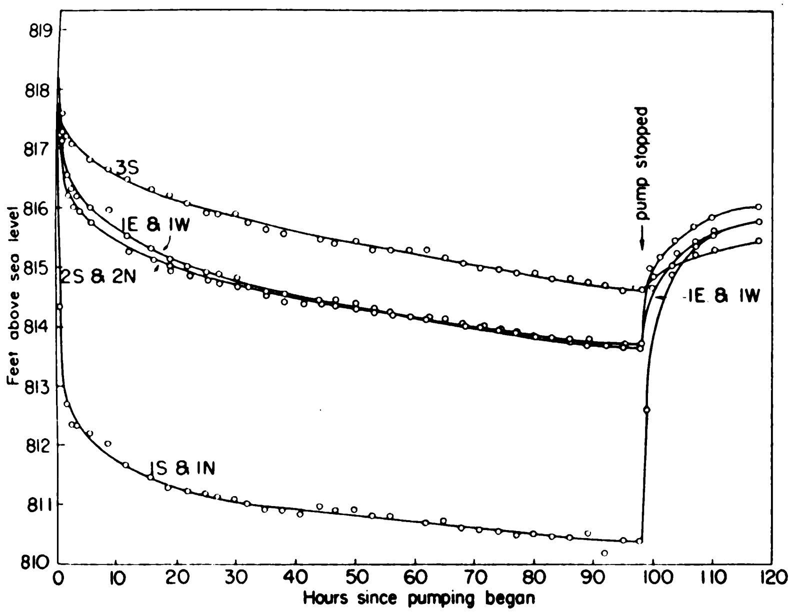

FIG. 4. Draw-down and recovery curves for the observation wells near the pumped well.

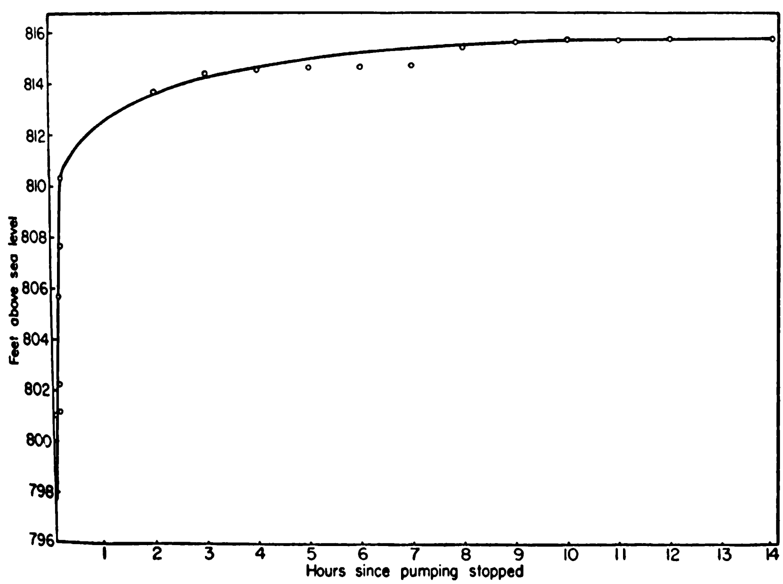

FIG. 5. Recovery curve for the pumped well.

Determination of Permeability

The coefficient of permeability and the specific yield of water-bearing materials were determined in the field by methods described below. An attempt was made to determine in the laboratory the permeability of samples of gravel from the Neosho river valley, but the results obtained are believed to be in error, hence they are not included in this report. The samples collected from the test holes put down by the hydraulic-rotary method were washed in the field to free them of drilling mud, and no doubt much of the finer material also was washed away. Furthermore, some of the pebbles were too large to be used in the laboratory apparatus.

The data obtained from the pumping test (tables 1 and 2) were used in making determinations of the coefficient of permeability by the following methods.

EQUILIBRIUM METHOD

Thiem formula.—The application of the Thiem formula for determining the permeability of water-bearing materials has been described fully by L. K. Wenzel (1936, pp. 1-26; 1942, p. 81). The method on which this formula is based consists of pumping a well that penetrates water-bearing material, the permeability of which is to be determined, and observing the decline of the water table or piezometric surface at several points around the pumped well. This formula is based on the assumption that the nonpumping water table is horizontal. Although this condition seldom exists, a horizontal water table may be assumed or a sloping water table may be corrected for and considered horizontal. The Thiem formula also involves the assumption that after approximate equilibrium is established around a pumped well, equal quantities of water move toward it in a given unit of time through successive concentric cylindrical cross sections around the well. Because the areas of the large cylinders through which the water percolates are greater than the areas of the smaller cylinders, the velocity of the ground water moving through them is proportionately smaller.

According to Darcy's law (Darcy, 1856), the discharge through any concentric cylindrical section of water-bearing material, Q, is equal to the permeability of the material, P, multiplied by the hydraulic gradient, I, multiplied by the cross-sectional area, A.

Hence, P = Q/IA. The hydraulic gradient at a given distance from the pumped well can be determined from the slope of the water table. For water-table conditions the area A is equal to 2 π x (m-s); x being the distance from the pumped well; m the thickness of the saturated part of the water-bearing material; and s the draw-down at the distance x from the pumped well. The permea-

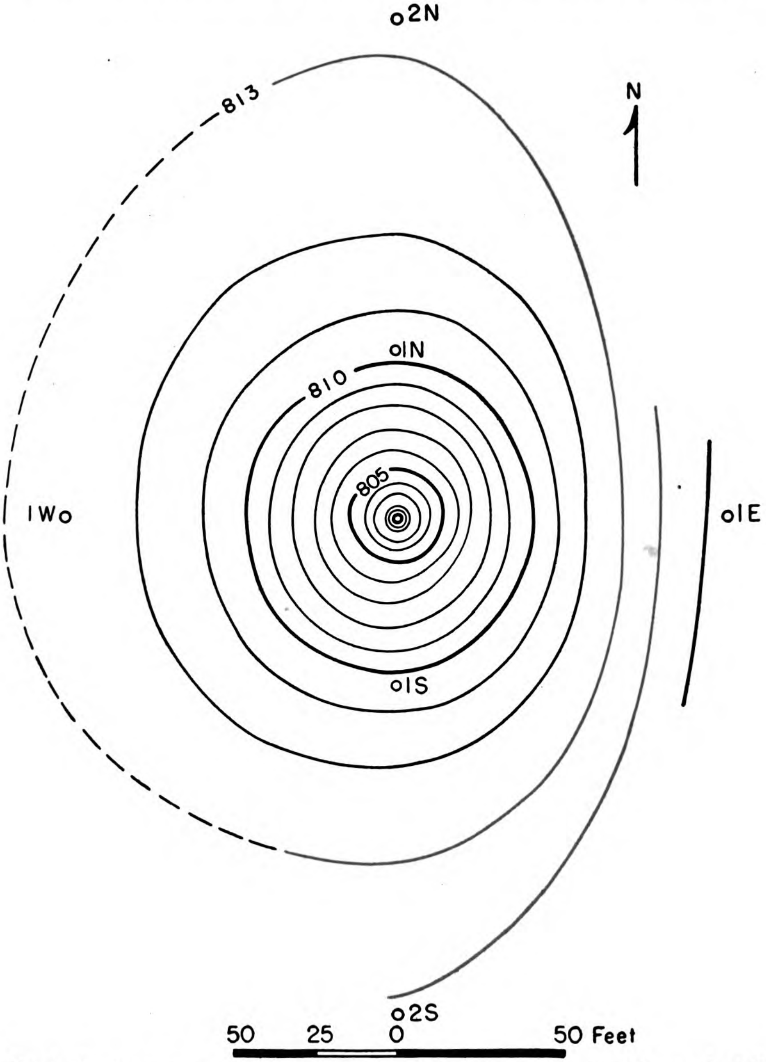

FIG. 6. Contour map of the water table at the pumped well at the end of the pumping period. Contour interval 1 foot.

TABLE 2.—*Pumping-test data for the pumped well and nearby observation wells.*

		Pumped Well 1			Well 1S		Well 1N			Well 1E	
Date, 1942	Time	Water level (feet above sea level)	Draw-down (feet)	Pumping rate (gallons a minute)	Water level (feet above sea level)	Draw-down (feet)	Water level (feet above sea level)	Draw-down (feet)	Average of columns 7 and 9 (feet)	Water level (feet above sea level)	Draw-down (feet)
1	2	3	4	5	6	7	8	9	10	11	12
2-8	2:00P	818.03			818.05		817.82			819.45	
	3:00P										
	4:00P	806.2	11.83	104	814.88	3.17	813.65	4.17	3.67	818.15	1.30
	5:00P			106	812.88	5.17	812.4	5.42	5.29	817.57	1.88
	6:00P			104	812.4	5.65	812.23	5.59	5.62	817.32	2.13
	7:00P			104	812.43	5.62	812.19	5.63	5.63	817.22	2.23
	9:00P			104	812.09	5.96	812.19	5.63	5.79	817.04	2.41
	12:00M			104	812.09	5.96	811.9	5.92	5.94	817.03	2.42
2-9	3:00A			108	811.72	6.33	811.54	6.28	6.30	816.57	2.88
	7:00A			104	811.38	6.67	811.48	6.34	6.50	816.32	3.13
	10:00A	801.2	16.83	102	811.26	6.79	811.32	6.50	6.65	816.19	3.26
	1:00P	798.6	19.43	100	811.18	6.87	811.23	6.59	6.73	816.07	3.38
	4:00P	799.05	18.08	100	811.09	6.96	811.19	6.63	6.79	815.94	3.51
	6:00P	799.74	18.66	100	811.05	7.00	811.15	6.67	6.84	815.90	3.55
	9:00P			100	810.97	7.08	811.11	6.71	6.89	815.86	3.59
	11:00P			100	810.97	7.08	811.07	6.75	6.92	815.65	3.80
2-10	2:00A			100	810.88	7.17	810.98	6.84	7.01	815.61	3.84
	5:00A			100	810.88	7.17	810.94	6.88	7.03	815.57	3.88
	8:00A				810.80	7.25	810.90	6.92	7.09	815.53	3.92
	8:25A			84							
	9:00A	800.0	18.03								
	11:00A	799.2	18.83	84	810.97	7.08	810.94	6.88	6.98	815.48	3.97
	1:30P	799.2	18.83	84	810.94	7.11	810.90	6.92	7.01	815.48	3.97
	5:00P	799.2	18.83	84	810.88	7.17	810.90	6.92	7.04	815.44	4.01
	8:00P	798.87	19.16	84	810.76	7.29	810.82	7.00	7.15	815.36	4.09
	11:00P	798.78	19.25	84	810.76	7.29	810.78	7.04	7.17	815.32	4.13
2-11	2:00A	798.62	19.41	84	810.72	7.33	810.73	7.09	7.21	815.23	4.22
	5:00A	798.62	19.41	84	810.76	7.29	810.69	7.13	7.21	815.19	4.26
	8:00A	798.53	19.50	82	810.76	7.29	810.69	7.13	7.21	815.15	4.30
	11:00A	797.45	20.58	82	810.63	7.42	810.61	7.21	7.32	815.11	4.34
	2:00P	797.45	20.58	82	810.59	7.46	810.57	7.25	7.35	815.07	4.38
	5:00P	797.45	20.58	82	810.55	7.50	810.53	7.29	7.40	815.03	4.42
	8:00P	797.41	20.62	82	810.47	7.58	810.48	7.34	7.46	814.99	4.46
	11:00P	797.37	20.66	82	810.47	7.58	810.48	7.34	7.46	814.95	4.50
2-12	2:00A	797.33	20.70	82	810.47	7.58	810.44	7.38	7.48	814.88	4.57
	5:00A	797.33	20.70	82	810.43	7.62	810.40	7.42	7.52	814.82	4.63
	8:00A	....	19.33	78	....	......	....	......	......	814.82	4.63
	11:00A	797.95	20.09	80	....	......	810.36	7.46	......	814.78	4.67
	2:00P	797.78	20.25	80	810.43	7.62	810.36	7.46	7.54	814.73	4.72
	4:59P	797.7	20.33	80	810.43	7.62	810.32	7.50	7.56	814.73	4.72
	5:00P										
	5:02P	806.53	11.50								
	5:04P	808.2	9.83								
	5:06P	808.28	9.75								
	5:08P	808.83	9.20								
	5:10P	810.53	7.50								
	5:13P	811.55	6.48								
	5:16P	812.87	5.16								
	5:45P				813.30	4.75	811.90	5.92	5.33	815.15	4.30
	6:30P				813.63	4.42	812.23	5.59	5.00	815.40	4.05
	7:00P	814.53	3.50								
	8:00P	814.87	3.16		814.01	4.04	813.73	4.09	4.06	815.65	3.80
	9:00P	814.95	3.08								
	10:00P	814.99	3.04								
	11:00P	815.16	2.87		815.30	2.75	814.76	3.06	2.90	815.9	3.55
	12:00M	815.28	2.87								
2-13	1:00A	815.37	2.66								
	2:00A	815.53	2.50		815.63	2.42	815.07	2.75	2.58	816.15	3.30
	3:00A	815.62	2.42								
	4:00A	815.62	2.42								
	5:00A	815.67	2.36		815.72	2.33	815.32	2.50	2.41	816.28	3.17
	7:00A	815.67	2.36								
	12:40P				815.97	2.08	815.57	2.25	2.16	816.44	3.01

Well 1W			Well 2S		Well 2N			Well 3S		
Water level (feet above sea level)	Draw-down (feet)	Average of columns 12 and 14 (feet)	Water level feet above sea level)	Draw-down (feet)	Water level (feet above sea level)	Draw-down (feet)	Average of columns 17 and 19 (feet)	Water level (feet above sea level)	Draw-down (feet)	Remarks
13	14	15	16	17	18	19	20	21	22	23
817.45			818.15		817.70			817.60		Static water level Pump started
816.29	1.16	1.23	817.82	0.33	816.37	1.33	0.83	817.52	0.08	Temp. 60° F.
815.47	1.98	1.93	817.15	1.00	815.20	2.50	1.25	817.18	.42	Do
815.20	2.25	2.19	816.90	1.25	815.12	2.58	1.91	817.02	.58	Do
815.08	2.37	2.30	816.82	1.33	815.02	2.68	2.00	....	......	
814.83	2.62	2.51	816.57	1.58	814.87	2.83	2.20	816.76	.84	
814.82	2.63	2.52	816.44	1.71	814.70	3:00	2.30	816.6	1.0	
814.37	3.08	2.98	816.07	2.08	814.45	3.25	2.66	816.43	1.17	
814.2	3.25	3.19	815.86	2.29	814.37	3.33	2.81	816.27	1.33	
814.03	3.42	3.34	815.65	2.50	814.20	3.50	3.00	816.18	1.42	Do
813.91	3.54	3.46	815.57	2.58	814.12	3.58	3.08	816.02	1.58	
813.83	3.62	3.57	815.48	2.67	814.03	3.67	3.17	815.89	1.71	
813.78	3.67	3.61	815.44	2.71	813.99	3.71	3.21	815.89	1.71	Do
813.70	3.75	3.67	815.40	2.75	813.95	3.75	3.25	815.85	1.75	
813.62	3.83	3.81	815.40	2.75	813.95	3.75	3.25	815.74	1.86	
813.53	3.92	3.88	815.23	2.92	813.78	3.92	3.42	815.60	2.00	
813.45	4.00	3.94	815.07	3.08	813.74	3.96	3.52	815.52	2.08	
813.37	4.08	3.99	815.07	3.08	813.70	4.00	3.54	815.52	2.08	
										Pumping rate changed
813.37	4.08	4.03	815.03	3.12	813.70	4.00	3.56	815.43	2.17	
813.34	4.11	4.04	814.98	3.17	813.70	4.00	3.58	815.39	2.21	
813.24	4.21	4.10	814.94	3.21	813.62	4.08	3.64	815.39	2.21	
813.18	4.27	4.18	814.87	3.28	813.58	4.12	3.70	815.27	2.33	
813.12	4.33	4.23	814.82	3.33	813.53	4.17	3.75	815.23	2.37	
813.08	4.37	4.30	814.82	3.33	813.49	4.21	3.77	815.23	2.37	
813.03	4.42	4.35	814.82	3.33	813.45	4.25	3.79	815.23	2.37	
812.99	4.46	4.38	814.69	3.46	813.45	4.25	3.85	815.10	2.50	Temp. 59° F.
812.95	4.50	4.42	814.61	3.54	813.37	4.33	3.93	815.02	2.58	
812.91	4.54	4.46	814.57	3.58	813.37	4.33	3.95	814.98	2.62	
812.83	4.62	4.52	814.56	3.59	813.28	4.42	4.00	814.93	2.67	
812.78	4.67	4.57	814.48	3.67	813.24	4.46	4.06	814.85	2.75	
812.74	4.71	4.61	814.40	3.75	813.20	4.50	4.12	814.81	2.79	
812.74	4.71	4.64	814.36	3.79	813.16	4.54	4.16	814.77	2.83	
812.70	4.75	4.69	814.32	3.83	813.12	4.58	4.20	814.73	2.87	
812.66	4.79	4.71	814.32	3.83	813.16	4.54	4.18	814.68	2.92	Temp. 59° F.
812.62	4.83	4.75	814.23	3.92	813.12	4.58	4.25	814.64	2.96	
812.58	4.87	4.80	814.23	3.92	813.12	4.58	4.25	814.60	3.00	
812.58	4.87	4.80	814.23	3.92	813.08	4.62	4.27	814.60	3.00	Temp. 61° F. Pump stopped Recovery meas.
813.83	4.62	4.46	814.73	3.42	814.28	3.42	3.42	814.6	3.00	
813.91	3.54	3.79	815.07	3.08	814.87	2.83	2.95	814.77	2.83	
814.20	3.25	3.52	815.2	2.95	815.08	2.62	2.78	814.89	2.71	
814.45	3.00	3.27	815.65	2.50	815.28	2.42	2.46	815.02	2.58	
814.62	2.83	3.06	815.94	2.21	815.45	2.25	2.23	815.14	2.46	
814.87	2.58	2.87	816.03	2.12	815.70	2.00	2.06	815.27	2.33	
815.03	2.42	2.71	816.19	1.96	815.87	1.83	1.89	815.43	2.17	

bility of the water-bearing formation can be computed by substituting these values in the equation P = Q/IA. The method was first used by G. Thiem (1906), who developed a formula for computing permeability by using the draw-down as measured in two observation wells and the discharge of the pumped well rather than determining the flow through concentric cylindrical sections directly by Darcy's equation. Thiem's formula, modified for convenient use in the United States (Wenzel, 1936, p. 10), is

$$P = \frac{527.7q \log_{10} \frac{a_1}{a}}{m\ (s\text{-}s_1)}$$

in which P = the coefficient of permeability as defined above

q = rate of pumping in gallons a minute.

a and a_1 = respective distances of two observation wells from the pumped well, in feet.

m (for water-table conditions) = average thickness (at a and a_1) of the saturated part of the water-bearing bed, in feet.

s and s_1 = draw-downs at the two observation wells, in feet.

From the data in table 2 and from distances indicated in figures 7 and 8, calculation of permeability by the Thiem method using wells located 50 and 150 feet from the pumped well follows:

q = 80 gallons a minute (average pumping rate for the last 12 hours of the test)

a = 50 feet (distance from well 1 to either 1N or 1S)

a_1 = 150 feet (distance from well 1 to either 2N or 2S)

m = (dn + fo + jq + lr)/4 = 17.9 feet

s = (ef + ij)/2 = 7.6 feet

s_1 = (cd + kl)/2 = 4.3 feet

$$P = \frac{527.7 \times 80 \times \log_{10} \frac{150}{50}}{17.9 \times 3.3} = 341$$

Table 3 gives the permeabilities obtained by using all combinations of observation wells along the north-south line (fig. 7). Wells 1E and 1W were not used in obtaining an average coefficient of permeability (fig. 8) because there was no other pair of wells located on the east-west line.

TABLE 3.—*Coefficients of permeability computed by the Thiem method* (Pumping rate 80 g.p.m.)

Distance from pumped well (feet)		Average thickness of saturated part of water-bearing bed at a_1 and a (feet) (m)	Average difference in draw-down at a and a_1 (feet) ($s-s_1$)	Coefficient of Permeability (P)
Distant well (a_1)	Near well (a)			
150	50	17.9	3.29	341
350	50	18.4	4.56	421
350	150	19.8	1.62	484
Average	- - -	- - -	- - -	415

As indicated in table 3, the values for the coefficient of permeability are increasingly greater when the draw-down in the more distant observation wells are used in the computations. The water-level measurements given in table 2 indicate that during the last 12 hours of pumping the rate of draw-down in the well 350 feet from the pumped well (3S) was greater than in the wells 50 feet distant (1N and 1S). These facts indicate that the cone of depression had not reached equilibrium form at distances 350 feet from the pumped well and that the value of 341 for the coefficient of permeability may be more nearly correct than the other values given in table 3.

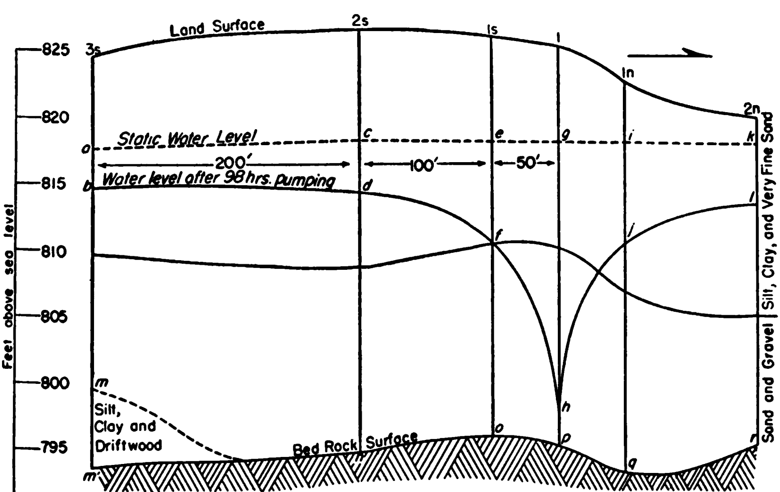

FIG. 7. Cross section at the site of the pumping test showing location of observation wells, static water level, and cone of depression after 98 hours pumping.

NON-EQUILIBRIUM METHOD

Theis recovery formula.—C. V. Theis (1935) has shown that, under certain conditions, Darcy's law concerning the motion of ground water under natural conditions and under the artificial conditions set up by pumping is analogous to the flow of heat by conduction; hydraulic pressure being analogous to temperature, hydraulic gradient to thermal gradient, permeability to thermal conductivity, and specific yield to specific heat. From his final equation expressing the relation between the draw-down and the rate and duration of discharge of a well, Theis developed the following special formula for determining the transmissibility of an aquifer (as defined above):

$$T = \frac{264q}{s} \log_{10} \frac{t}{t_1}$$

in which T = coefficient of transmissibility

q = pumping rate, in gallons a minute

t = time since pumping began, in minutes

t_1 = time since pumping stopped, in minutes

s = residual draw-down at the pumped well, in feet, at time t_1

The Theis formula does not assume equilibrium conditions, as does the Thiem formula, and time is included as a factor. Residual draw-down (s) is computed by subtracting the static water-level measurement from appropriate depth to water-level measurements taken from the recovery curve (fig. 5). The proper ratio

$\dfrac{\log_{10} \frac{t}{t_1}}{s}$ is determined graphically by plotting $\log_{10} \dfrac{t}{t_1}$

against corresponding values of s (fig. 9). Use of semi-logarithmic paper simplifies this procedure. For any convenient value for $\log_{10} \dfrac{t}{t_1}$ the corresponding value for s may be found by inspection.

When values for s and t/t, and q (80 gallons a minute) are substituted in the Theis recovery formula, the coefficient of transmissibility of the aquifer at the pumped well is computed to be 9,820. Dividing the coefficient of transmissibility by 23.1 feet, which is the average thickness of the saturated water-bearing material in the vicinity of the well, the coefficient of permeability is found to be 425[1], as compared with an average value of 415 computed by the Thiem method. As mentioned above, however, the minimum value for the coefficient of permeability (341) may be more nearly correct than the average value (415). On the other hand, the

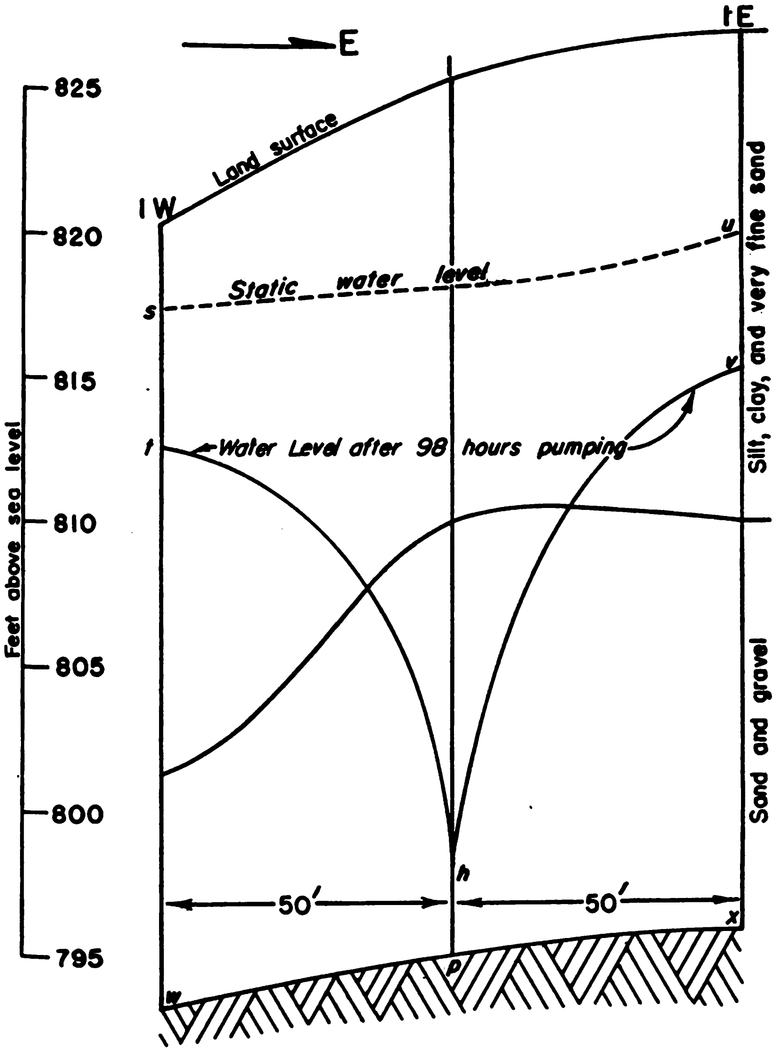

Fig. 8. Section at right angles to the section shown in figure 7.

[1] As indicated in table 2, the temperature of the water during the pumping test ranged from 59° to 61° F., and averaged 60° F., hence no correction for temperature is needed.

value of 425 obtained by using the Theis formula is in close agreement with the average value obtained by the Thiem method. The average of these two values, 420, is chosen as probably being the correct value. In other words, about 420 gallons of water a day are conducted laterally through each section of the aquifer 1 mile wide and 1 foot thick under an hydraulic gradient of 1 foot per mile.

Determination of Specific Yield

As Wenzel has shown (1936, pp. 53-57), the specific yield of a water-bearing formation can be determined by the pumping test method. When pumping begins in a well under water-table conditions, ground water is removed from storage in the vicinity of the well until eventually an hydraulic gradient that is essentially an equilibrium gradient is established and the quantity of water moving toward the well is equal to the rate of discharge of the well. Until conditions approaching equilibrium are reached, the quantities of water moving toward the well through successive concentric cylindrical sections of different diameter will not be the same as required by Darcy's law, but will differ by the differences in the quantities of water being removed from storage along each cylinder.

The specific yield may be determined by ascertaining the difference in the quantities of water that percolate through any two cylindrical sections in a given time, and may be expressed by the equation

$$y = \frac{100\,(Y_1 - Y)}{V}$$

where y is the specific yield; Y_1 is the quantity of ground water, in cubic feet, that percolates through the smaller cylinder; Y is the quantity of ground water, in cubic feet, that percolates through the larger cylinder; and V is the volume of water-bearing material, in cubic feet, that is unwatered between the two cylinders.

The volume of water-bearing material that is unwatered between concentric cylindrical sections around the pumped well may be computed by the formula

$$V = \pi\,(a^2 - a_1^2)\,\frac{s + s_1}{2}$$

in which V is the volume of unwatered material, in cubic feet; a is the radius of the large cylinder, in feet; a_1 is the radius of the small cylinder, in feet; and s and s_1 are the depths that the water table is lowered during the period, in feet, at the distances a and a_1, respectively, from the pumped well.

The quantity of water that percolates through each cylinder may be computed by the formula

$$Y = \frac{2 \quad Piaht}{7.48 \times 24}$$

in which Y is the quantity of ground water, in cubic feet; P is the coefficient of permeability; i is the average hydraulic gradient, in

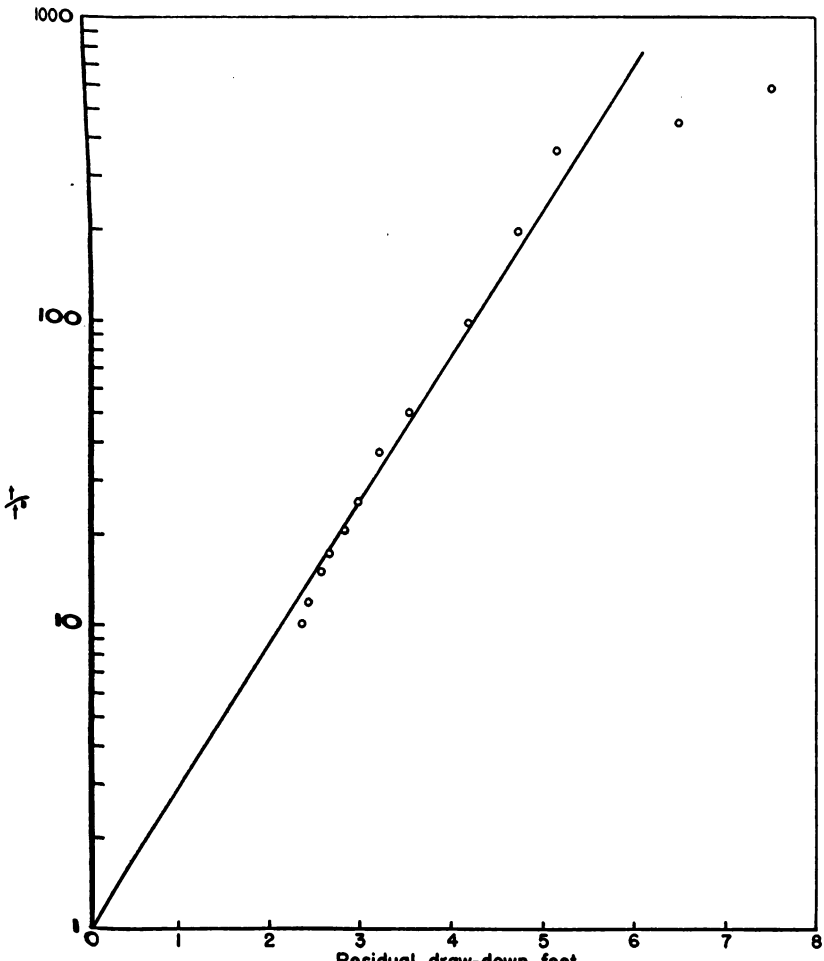

FIG. 9. Curve for pumping test obtained by plotting s against t/t_1.

feet per foot, at the distance a from the pumped well; h is the average thickness, in feet, of the saturated water-bearing material at the distance a; and t is the period of pumping, in hours. Values of the specific yield determined by this method for several periods of pumping are given in the following table.

TABLE 4.—*Values of specific yield (expressed as percentage) computed for cylindrical sections 100 and 300 feet in diameter for several different periods of pumping*

Time	6 hrs	12 hrs.	24 hrs.	36 hrs.	48 hrs.	72 hrs.	96 hrs.
Specific Yield	1.2	3.7	5.4	7.7	10.3	16.7	19.5

As indicated in the above table, the computed value of the specific yield becomes larger as the period of pumping increases, because considerable time is required to drain the unwatered material completely. Plotting the computed values against pumping time suggests that the true specific yield of the material around the well is about 20 percent. In other words, each cubic foot of material that is completely drained yields about 0.20 cubic foot of water.

SHAPE OF THE WATER TABLE AND MOVEMENT OF WATER

The approximate shape of the water table in the part of the Neosho river valley here considered is shown by the water-table contours in plate 2. As a basis for constructing this map, the altitude of the water table was determined instrumentally at some of the 29 test holes and at 18 hand-auger holes and wells. The locations and altitudes of the drill holes, auger holes, and wells are given in table 5. The water surface of Neosho river and its local tributaries was determined in part instrumentally and in part from maps of the Neosho river valley prepared by the Engineer Corps of the U.S. Army.

The water table intersects the land surface in some parts of the valley, as indicated by the ponds and small streams shown in plate 2. In other parts of the valley the water table ranges from less than 1 foot to 13 feet below the land surface (table 5). In most parts of the valley the water table is less than 10 feet below land surface, but it is somewhat deeper than 10 feet in those parts of the area immediately adjacent to Neosho river.

TABLE 5.—*Locations, altitudes, and water levels in wells and test holes*

No. on fig. 2	Location	Source of data [1]	Surface altitude (feet)	Depth to water level (feet)
	T. 31 S., R. 21 E.			
1	SE SE SW sec. 23	A	837.1	2.3
2	NE NW NW sec. 26	A	831.9	1.0
3	NE NE sec. 27	A	831.7	2.3
4	NW corner NE NE sec. 27	R	832.1	2.7
5	do	W	831.6	2.2
6	NW corner NE sec. 27	R	830.6	2.7
7	NE NW sec. 27	R	832.1	
8	do	W	833.4	7.8
9	SE corner SW SW sec. 27	R	831.9	
10	SW SE SW sec. 27	A	832.0	3.4
11	SW corner SE sec. 27	R	830.8	2.2
12	SE sec. 28	R	827.2	
13	NE corner sec. 33	R	831.5	
14	NE sec. 33	R	829.6	
15	do	R	830.4	
16	do	W	832.0	8.3
17	do	R	828.1	
18	do	R	829.7	
19	NE sec. 33	R	814.8	
20	do	R	813.9	
21	do	R	818.0	
22	do	R		
23	do	R		
24	NE corner sec. 34	R	829.1	
25	NE NW NE sec. 34	A	830.7	2.1
26	NE corner NW sec. 34	R	832.1	6.2
27	SW corner NE sec. 34	A	827.1	2.9
28	NW SE SE sec. 34	W	827.9	2.9
29	NE NW sec. 35	R	828.4	
30	do	A	828.0	4.7
31	do	R	828.0	
	T. 32 S., R. 21 E.			
32	NE corner NW sec. 2	W	826.4	1.7
33	SE SE SW sec. 3	W	827.9	9.1
34	NW NW SE sec. 4	R	826.9	
35	SE NW SE sec. 4	R	827.7	12.7
36	NE SE SW sec. 4	R	823.9	5.5
37	SW SE sec. 4	R	826.5	
38	SW SE SE sec. 4	R	828.0	11.2
39	SE NW sec. 4	A	826.1	9.6
40	SW NW sec. 9	R	826.0	10.3
41	NE NW sec. 9	R	826.2	4.9
42	do	A	825.0	2.9
43	NW NE sec. 9	R	825.0	
44	NE corner SW NE sec. 9	A	825.3	5.8
45	NW corner SE NE sec. 9	R	825.6	
46	SW corner NE sec. 9	A	825.5	3.7

[1] A, test hole drilled by hand auger; R, test hole drilled by hydraulic-rotary method; W, water well.

The water-table contours roughly parallel the river and its tributaries and intersect the river at an acute angle upstream, indicating that the gradient of the water table is toward Neosho river in this area and that ground water eventually flows into it. The route may be indirect and circuitous, as in the northeastern part of the area, or direct, as near test hole 35. At times of high stage, however, the river probably returns some water to the underground reservoir near the course of the stream.

In some places the water table stands as much as 18 feet above river level. The average slope of the water table ranges from about 10 to about 20 feet to the mile. The gradient becomes progressively greater near the river and is small in some parts of the valley, as near test hole 20. These facts, together with the moderately low permeability of the aquifer, indicate that the movement of ground water under the natural conditions prevailing here is relatively slow. The several small ponds and meandering tributaries and the swampy conditions existing in parts of the valley also suggest slow movement of ground water, both laterally and vertically.

In the area contoured on the west side of the river in the southwestern part of the area, the ground water moves radially from high points on the water table near test holes 41 and 37 toward small tributary streams and Neosho river.

QUANTITY OF GROUND WATER

Yield of Wells

At present there are no wells in this part of the Neosho valley that yield large quantities of water. There are many small domestic and stock wells, the yields of which are sufficient to supply the small quantities required by the farmers and their families and by a few head of livestock at each farm. These wells supply as much water as is required of them but the quantity is not an index of the potential yield of the alluvium. Some residents of the area reported that their farm wells did not fail during the droughts that occurred between 1930 and 1940.

The test well, which is discussed at length above, was pumped at an average rate of 80 gallons a minute for the last 60 hours of the pumping test, during which time the water level in the pumped well declined 2.3 feet. The water level had not reached an equilibrium condition at the end of the 98-hour pumping test. These data are in part the basis for the conclusion that 50 gallons a minute is near the maximum rate at which a single well in the valley should be pumped continuously. Quantities greater than 50 gallons a minute, perhaps 100 gallons a minute, could be pumped from a single well only for short periods of time.

Quantity Available from Recharge

According to the U. S. Weather Bureau, the mean annual precipitation at Parsons is 40.63 inches; however, in 1941 the total precipitation was 53.92 inches, or 13.29 inches above normal. Neosho river overflowed its banks in June, August, September, and October, 1941. In October, 1941, the river was over its banks at Oswego for 21 consecutive days. A line marking the limit of overflow as mapped by the Engineer Corps, U. S. Army, is shown in plate 2 and that line approximately delimits the area underlain by alluvium. The sources of water available for recharge in this area are the precipitation that falls in the valley and flood waters of Neosho river derived from precipitation in the drainage basin.

The amount of water available for recharge from flood waters is difficult to determine and varies greatly from year to year. The percentage of the annual precipitation that percolates downward to the water table and recharges the ground-water reservoir is dependent on several factors. Some of these factors are the amount of annual rainfall, the physical character and the composition of the soil and subsoil, the proximity of the water table to the land surface, the condition of the soil before rainfall (i. e., moisture content, cultivation), and the number and depth of roots, animal burrows, and so forth.

The alluvial soils in the Neosho river valley have been classified as silty clay loam, silty clay, and clay (Drake, 1904, pp. 15-17; Knobel, von Treba and Higbee, 1926, pp. 14-16). These soils contain 15 to 45 percent clay, 40 to 65 percent silt, 5 to 15 percent very fine sand, and 2 to 5 percent fine sand. Constituents larger than fine sand (0.25 mm) are negligible. Descriptions of the surficial materials encountered in test drilling (see well logs) indicate that the soil is mostly silt and clay. The water table is close to the land surface and intersects it in places. The soils are of such composition that water percolates very slowly through them, but the proximity of the water table to the land surface tends to increase the amount of recharge, although in seasons of high precipitation some water may be rejected from an already full reservoir.

Many borings of the type made by some fresh-water crustaceans were observed in parts of the river valley both in March and in October, 1942. A pebble dropped into one of these holes can be heard to splash as it strikes the shallow water table. A great deal of water must reach the water table through openings of this kind, conceivably more than seeps through the clayey soil and subsoil.

In Kansas as a whole, the percentage of the annual precipitation that reaches the water table seems to range widely from probably less than 1 percent in parts of the High Plains to more than 25 percent in some areas (Lohman, S. W., 1941, p. 45). Although detailed study covering a year or more is necessary to determine the percentage of the annual precipitation that reaches the water table, it is probably safe to assume that at least 5 percent of the precipitation that falls in the Neosho valley recharges the underground reservoir. This assumed amount of recharge would amount to about 35,000,000 gallons on each square mile annually, or an average of about 100,000 gallons daily.

Quantity in Storage

The specific yield of the water-bearing materials, as computed in another section of this report, is about 20 percent. If this figure is taken as a fair average of the specific yield of the alluvium in the Neosho valley, the available quantity of water in storage at the time of this investigation amounted to about 40,000,000 gallons for each foot of thickness and for each square mile. Assuming that the average thickness of water-bearing material in the alluvium was 17 feet, the total quantity of water in storage amounted to about 680,000,000 gallons in each square mile. Part of the quantity of ground water held in storage would be available for pumping during dry seasons provided that conditions were favorable for its replenishment during succeeding seasons of normal or above normal precipitation.

Quantity of Movement

By applying the available data to the fundamental formula, $Q=PIA$, discussed above, the amount of water moving across a given contour line toward Neosho river may be estimated.

For this purpose, the 818-foot contour line (pl. 2) may be taken as a reference line from the point near the sharp bend in Neosho river near the southwestern corner of the artificial lake across the valley to the outcrop of the bedrock. The length of this line is approximately 1 mile. Although no test holes were drilled along this contour line, the average thickness of saturated material in the test holes shown on figure 3 is 17 feet, and it is assumed that about the same average thickness of saturated material would be found along the contour line. The average hydraulic gradient determined from the water-table contour map is about 20 feet to the mile. The average coefficient of permeability of the water-bearing material, as determined by the pumping test, is about 420, and it is assumed that this value is applicable for the portion of the Neosho valley along the contour line here considered. According to these assumptions the quantity of water that crosses the reference line under the static conditions prevailing at the time of the investigaion was as follows: 420 (average coefficient of permeability) $\times$ 17 (average saturated thickness of the aquifer, in feet) $\times$ 20 (average hydraulic gradient, in feet per mile) $\times$ 1 (length of reference line in miles) = 134,400 gallons a day. Using the minimum value of 341 (table 3) for the coefficient of permeability, a similar computation indicates that the quantity of water crossing the reference line is 116,000 gallons a day.

Discharge

Discharge of water from the zone of saturation may take place in several ways, including evaporation and transpiration, effluent seepage into streams or lakes, discharge of springs, and pumpage from wells.

The quantity of ground water currently pumped from wells in the Neosho river valley is negligible in comparison with the total amount available. No springs were observed and if springs are present their discharge is probably small. The many small ponds and streams tributary to Neosho river attest the effluent seepage of ground water. Neosho river is a perennial stream except in prolonged periods of drought, and receives part of its flow by seepage from the alluvium. The quantity of water discharged by effluent seepage is difficult to determine, but because the permeability of the water-bearing materials is low the quantity of water discharged in this manner probably is correspondingly small.

Although no studies of the use of ground water by plants have been made in this area, it is believed that most of the ground-water discharge occurs as transpiration. Direct evaporation of ground water also occurs, principally in the vicinity of the small ponds. If large quantities of ground water were to be pumped from wells in the valley, however, the lowered water table in the vicinity of the wells would lessen the amount of discharge by transpiration and evaporation and by seepage into Neosho river.

OBSERVATION WELLS

In June, 1943, four wells (numbers 5, 16, 28, and 33 in table 5) were selected for periodic measurement of water levels. These wells have been measured biweekly since June 2, 1943, and it is planned to continue measurements for a period of time sufficient to gain knowledge of water-table fluctuations in this area during several wet and dry seasons. The records of the measurements of the water level in these observation wells will be published in a U. S. Geological Survey Water-Supply Paper "Water levels and artesian pressure in the United States in 1943," and in subsequent Water Supply Papers of this series as long as measurements continue.

The water levels in the four wells listed above were assigned a stage of 10 feet above an arbitrary datum on October 12, 1942, a date on which all wells were measured, and subsequent measurements were referred to this datum. The highest observed stage of the four wells to date was 12.62 feet on July 1, 1943, and the lowest observed average stage was 3.70 feet on October 2, 1943. The difference between the highest and lowest stage is 8.92 feet. Most of the decline in water level occurred in July and August, 1943, during which time precipitation at Parsons, Kansas, was 5.16 inches below normal.

The magnitude of this observed decline in water level indicates (1) that considerable fluctuation in water level may be expected in this area between wet and dry periods, and (2) that the season during which this investigation was made was one when ground-water levels were at a relatively high stage.

QUALITY OF WATER

The chemical character of the ground water in the alluvium of that part of the Neosho river valley here considered is shown by the analyses of samples of water collected from six of the test holes and the partial analyses of samples from test holes 26 and 11 given in table 6. The analyses were made by Howard Stoltenberg in the Water and Sewage Laboratory of the Kansas State Board of Health. The constituents were determined by the methods used by the U. S. Geologcial Survey.

CHEMICAL CONSTITUENTS IN RELATION TO USE

The following discussion of the chemical constituents of ground water has been adapted from publications of the U. S. Geological Survey.

Total dissolved solids.—The residue left after a natural water has evaporated consists of rock materials, with which may be included some organic material and a small amount of water of crystallization. Water containing less than 500 parts per million of dissolved solids generally is entirely satisfactory for domestic use except for the difficulties resulting from its hardness and, in some areas, because of excessive corrosiveness. Water having more than 1,000 parts per million of dissolved solids is likely to contain enough of certain constituents to produce a noticeable taste or to make the water unsuitable in some other respects.

The content of total dissolved solids in the samples collected from the alluvium ranges from 365 to 801 parts per million, the average being about 500. Water of this concentration is suitable for most ordinary purposes.

Hardness.—The hardness of water, which is the property that generally receives the most attention, is commonly recognized by its effects when soap is used with the water in washing. Calcium and magnesium cause almost all the hardness of ordinary waters. These constituents are also the active agents in the formation of the greater part of all the scale formed in steam boilers and in other vessels in which water is heated or evaporated.

In addition to the total hardness, the table of analyses shows the carbonate hardness and the noncarbonate hardness. The carbonate hardness is that due to the presence of calcium and magnesium bicarbonates. The noncarbonate hardness is due to the presence of sulphates or chlorides of calcium and magnesium. In general, the noncarbonate hardness forms harder scale in steam boilers.

Water having a hardness of less than 50 parts per million is generally rated as soft, and its treatment for removal of hardness under ordinary circumstances is not necessary. Hardness between 50 and 150 parts per million does not seriously interfere with the use of water for most purposes. It does slightly increase the consumption of soap, and its removal by a softening process is profitable for laundries and other industries using large quantities of soap. Waters in the upper part of this range of hardness will cause considerable scale in steam boilers. Hardness exceeding 150 parts per million can be noticed by anyone, and if the hardness is 200 or 300 parts per million it is common practice to soften water for household use or to install a cistern to collect soft rain water. Where municipal water supplies are softened, an attempt is generally made to reduce the hardness to 60 or 80 parts per million.

The samples of water from the Neosho river valley ranged in hardness from 146 to 800 parts per million. Most of the hardness, however, is in the form of carbonate hardness, and only two of the samples had appreciable amounts of noncarbonate hardness.

Iron.—Next to hardness, iron is the constituent of natural waters that generally receives the most attention. The quantity of iron in ground waters may differ greatly from place to place, even though the waters are from the same formation. If a water contains much more than 0.2 or 0.3 part per million of iron the excess may separate out and settle as a reddish sediment. Iron, which may be present in sufficient quantity to give a disagreeable taste and to stain cooking utensils, may be removed from most water by simple aeration and filtration, but a few waters require the addition of lime or some other substance.

As indicated in the table, all of the waters contained iron in amounts sufficient to produce a reddish sediment on exposure to air, the range being from 8.4 to 36 parts per million.

Chloride.—Chloride (Cl) is an abundant constituent of sea water and is dissolved in small quantities from rock materials or in some localities comes from sewage. However, there are many sources of chloride and therefore its presence in large quantities cannot be taken as a definite indication of pollution. Chloride has

TABLE 6.—*Analyses of water from test holes in Neosho river valley, Labette county, Kansas*

(Analyzed by Howard Stoltenberg. Dissolved constituents given in parts per million[1]; reacting values are given in italics[2])

Test hole no. figure 2	Location	Date of collection 1942	Temperature (F°)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium[3] (Na + K)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids	Hardness (Calculated as $CaCO_3$) Total	Carbonate	Noncarbonate
	T. 31 S., R. 21 E.															
4	NW corner NE NE sec. 27	Jan. 22	55	12	45 *2.25*	9.2 *.76*	8.1 *.35*	120 *1.97*	58 *1.21*	4 *.11*	0.1 *.01*	0.88 *.01*	381	150	98	52
11	SW corner SE sec. 27	Jan. 19	55	36	....	....	....	....	....	540	....	....	....	800	448	352
26	NW corner sec. 34	Jan. 18	54	12	....	....	....	....	....	27	....	....	....	384	385[5]	0
	T. 32 S., R. 21 E.															
36	NE SE SW sec. 4	Jan. 24	55	20	100 *4.99*	16 *1.32*	6.9 *.30*	381 *6.25*	11 *.23*	4 *.11*	.1 *.01*	.88 *.01*	735	316	312	4
36	do[4]	Feb. 9	59	18	97 *4.84*	16 *1.32*	20 *.87*	388 *6.36*	23 *.48*	6 *.17*	.1 *.01*	.62 *.01*	365	308	308[6]	0
35	SE NW SE sec. 4	Jan. 25	56	28	97 *4.84*	16 *1.32*	11 *.47*	384 *6.30*	6.6 *.14*	6 *.17*	0 *0*	1 *0.2*	584	308	308[7]	0
38	SW SE SE sec. 4	Jan. 24	55	18	84 *4.19*	18 *1.48*	18 *.77*	320 *5.25*	51 *1.06*	4 *.11*	.1 *.01*	.84 *.01*	630	284	262	22
41	NE NW sec. 9	Jan. 23	55	8.4	100 *5.49*	20 *1.64*	15 *.64*	315 *5.17*	105 *2.18*	14 *.39*	.2 *.01*	1.2 *.02*	801	356	258	98
40	SW NW sec. 9	Jan. 23	55	19	85 *4.24*	14 *1.15*	18 *.80*	364 *5.97*	6.4 *.13*	3 *.08*	0 *0*	.62 *.01*	406	270	270[8]	0

1 One part per million is equivalent to 1 pound of substance per million pounds of water, or 8.33 pounds per million gallons of water.
2 Equivalents per million.
3 Calculated.
4 Collected after 19.5 hours pumping.
5 Total alkalinity, 422 parts per million; excess alkalinity, 38 parts per million.
6 Total alkalinity, 318 parts per million; excess alkalinity, 10 parts per million.
7 Total alkalinity, 315 parts per million; excess alkalinity, 7 parts per million.
8 Total alkalinity, 298 parts per million; excess alkalinity, 28 parts per million.

little effect on the suitability of water for ordinary use unless there is enough to impart a salty taste. Waters high in chloride may be corrosive if used in steam boilers.

All the samples had a low content of chloride except the one collected from test hole 11. The chloride content of that sample is much higher than the others and is difficult to explain. Mr. Fulkman, of the architect-engineers, suggested that the slow flowing stream passing close to test hole 11 may have carried water high in chloride derived from some cinder dumps. There is no known abandoned oil well nearby. The chloride content is believed not to result from contamination.

Summary

Because of its hardness and high content of iron, ground water in this part of the Neosho river valley would require treatment for municipal use and for industrial purposes. Because most of the hardness is of the carbonate type, however, the treatment required for reduction of hardness and removal of iron would be relatively simple. The chloride content is generally low, and the one known occurrence of water containing considerable chloride is believed to be of only local extent.

CONCLUSIONS CONCERNING WATER SUPPLY

Test drilling indicated that the water-bearing material in the Neosho river valley near Parsons, Kansas, has a considerable range in thickness and physical character. In general, it is about 35 feet thick. The most permeable beds of gravel are in the basal part of the alluvium and range from a few inches to 15 feet in thickness. These gravels are sinuous in areal extent and are thickest in old channels once occupied by Neosho river.

The ground water in the alluvium moves toward Neosho river. The water table was as much as 18 feet above normal river level during the period of this investigation, and in some places in the valley it intersected the land surface, causing small ponds and swamps. The depth to the water table was less than 10 feet below land surface in most parts of the valley in 1942. During the same period the gradient of the water table ranged from about 10 to 20 feet per mile. In 1941 the precipitation was 132 percent of normal and in 1942 it was 111 percent. Owing to this fact the water table probably was at a higher stage in 1942 than in years of normal precipitation. No direct evidence is available concerning the stage of the water table in years of drought, but the observation-well program begun in June, 1943, and continuing at present indicates that considerable fluctuation in water level may be expected, especially during the summer. Farm wells in the alluvium in this area are reported not to have failed during the droughts that occurred between 1930 and 1940. There are in the area many live cottonwood trees as large as 3 feet in diameter whose root systems probably tap the saturated part of the alluvium. The fact that they are still alive seems to indicate that the alluvium was not completely unwatered during earlier years of drought.

Data obtained from the pumping test indicate that, in the vicinity of the pumped well, the coefficient of permeability of the saturated part of the aquifer is approximately 420 and the specific yield is about 20 percent. The specific capacity of the test well was about 3.9 gallons a minute per foot of draw-down.

Recharge to the ground-water reservoir comes largely from precipitation, but some recharge occurs from seasonal flood waters. The amount of recharge from precipitation was not determined but is probably at least 5 percent of the average annual precipitation, or about 35,000,000 gallons to the square mile annually.

Pumping from wells will result in a decrease in the amount of water discharged naturally into Neosho river and its tributaries and through evaporation and the transpiration by plants, and, at least temporarily, a decrease in the amount of water stored in the underground reservoir. Pumping may result also in increased recharge in parts of the valley where the water table is very close to or intersects the land surface. In some years or seasons potential recharge may be rejected under natural conditions, whereas it might be admitted to the zone of saturation if the water table were lowered by pumping.

The quantity of water passing a line 1 mile long at right angles to the slope of the water table, as computed above, is approximately 135,000 gallons a day. Although the slope of the water table and the thickness of the more permeable parts of the acquifer are variable, this quantity of water is probably a close approximation of the underflow across comparable reference lines in most parts of the valley.

The average amount of free ground water in storage in each square mile was about 680,000,000 gallons at the time of this investigation. Part of this water would be available to wells in seasons of low precipitation and would be replenished in seasons of above-normal precipitation.

The quantity of water that can be recovered by wells depends in part upon the area over which it is practicable to spread the wells. The above computations and assumptions indicate that during years of normal precipitation and temperature about 200,000 gallons of water daily could be obtained from several wells properly distributed within an area of not less than 1 square mile in a part of the valley in which the total saturated thickness of the alluvium and the thickness of the basal gravel are near average. There is no direct evidence concerning the quantity of water available to wells in years of drought, but the available quantity of water probably would be less. Observation of water levels in 1943 indicates that considerable decline may be expected in dry periods. There is indirect evidence that the alluvium has not been completely unwatered in recent dry years, but such complete unwatering could conceivably occur if severe drought conditions were sufficiently prolonged.

The permeability of the aquifer and the shape of the cone of depression developed during the pumping test (fig. 6) indicate that wells should be spaced 1,000 to 2,000 feet apart in order to avoid serious mutual interference. Development of a water supply from an aquifer of this type should be preceded by test drilling to determine the proper location of the wells.

The quality of the ground water occurring in the alluvium is indicated by the analyses given in table 6. The carbonate hardness and the iron content are high and the removal of iron and reduction of hardness would be necessary for municipal and most industrial uses. Such treatment, however, would not be difficult.

WELL LOGS

Logs describing the materials encountered in test drilling in the Neosho valley are listed in the following pages. All of the test holes were drilled in January, 1942, by the portable hydraulic-rotary drilling machine owned and operated by the State and Federal Geological Surveys. Field descriptions of the samples were made by James Cooper, sampler for the drilling crew. These descriptions were amplified by the author after examining the samples microscopically in the laboratory.

4. Log of test hole 4, NW corner NE¼ NE¼ sec. 27, T. 31 S., R. 21 E. on south edge of road. Surface altitude, 832.1 feet. Water sample collected, point set from 16 to 21 feet, temperature of water 55°. Static water level, 2.7 feet below land surface, January 23, 1942.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, silt, and very fine sand, brown. Root cavities filled with limonite	6.5	6.5
Silt and sand, very fine, gray to tan, slightly calcareous, containing much limonite	3.4	9.9
Sand, very fine to fine, tan, and silt, gray to tan, slightly calcareous. Contains much limonite.	6.1	16
Gravel, coarse to fine, and sand, coarse to very fine, poorly sorted. Gravel more nearly uniform than most samples in this area. Sand contains some grains of limonite.	2	18
Gravel, coarse to fine, and sand, coarse to fine, angular, poorly sorted, contains many pebbles of shale	3	21
Cherokee shale		
Shale, gray, soft, and black, fissile	2	23

6. Log of test hole 6, NW corner NE¼ sec. 27, T. 31 S., R. 21 E., on south edge of road. Surface altitude, 830.6 feet. Water sample collected, point set from 22 to 28 feet, temperature of water 55°. Static water level, 2.7 feet below land surface.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, silt, and clay, brown to tan, some very fine sand. Root cavities filled with limonite	11	11
Silt, tan, clay, gray, and very fine sand. Streaks of limonite	5	16
Gravel, fine to coarse, and sand, coarse to fine. Contains much clay and silt and small concretions of limonite	2	18
Gravel, coarse to fine, tan, chert, angular, poorly sorted	4	22
Gravel, coarse to fine, angular, poorly sorted, mostly chert, but containing some pebbles of black shale	5	27
Gravel, coarse to fine, and sand, coarse to fine. Poorly sorted.	1.5	28.5
Cherokee shale		
Shale, sandy, micaceous, gray ,soft.	1.5	30

7. Log of test hole 7, NE¼ NW¼ sec. 27, T. 31 S., R. 21 E., on south edge of road. Surface altitude, 832.1 feet.

	Thickness, feet	Depth, feet
Alluvium		
Soil, dark brown, clay, black, and silt, tan. Contains concretions and streaks of limonite	10	10
Silt, light brown, and sand, very fine. Slightly calcareous, contains streaks of limonite	10	20
Clay, chocolate-brown, containing some silt and very fine sand.	7	27
Clay, silt, gravel, and sand. All sizes of gravel and sand mixed with clay and silt. Contains streaks of limonite.	2	29
Cherokee shale		
Shale, sandy, micaceous, gray, soft.	1	30

9. Log of test hole 9, SE corner SW¼ SW¼ sec. 27, T. 31 S., R. 21 E., west edge of one-quarter mile road. Surface altitude, 831.9 feet.

	Thickness, feet	Depth, feet
Alluvium		
Soil, clay, and silt, dark brown to tan.	10	10
Silt, tan, and clay, chocolate-brown.	12	22
Gravel, coarse to fine, poorly sorted, containing much blue and brown clay.	5	27
Cherokee shale		
Sandstone, very fine grained, micaceous, gray.	1	28

11. Log of test hole 11, SW corner SE¼ sec. 27, T. 31 S., R. 21 E., north edge of road. Surface altitude, 830.8 feet. Water sample collected, point set from 28 to 33 feet, temperature of water 55° F. Static water level, 2.2 feet below land surface, January 20, 1942.

	Thickness, feet	Depth, feet
Alluvium		
Road material.	2.5	2.5
Silt and clay, tan to brown.	7.5	10
Clay, tan, and silt, with streaks of limonite	13	23
Gravel, coarse to fine, tan, and some coarse sand. Irregular, poorly sorted, mostly chert, contains some pebbles of black shale.	7	30
Gravel, mostly coarse, some medium and fine. Chert, with a few pebbles of shale.	4	34
Cherokee shale		
Shale, micaceous, gray, alternately soft and fissile	2	36

12. Log of test hole 12 at dam site, SE¼ sec. 28, T. 31 S., R. 21 E., 60 feet north of section line on east bank of Neosho river. Surface altitude, 827.2 feet. Core from 21 to 25 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, silt, and clay, brown to tan.	15	15
Gravel, coarse to fine, mostly irregular chert, much clay and silt.	2	17
Gravel, coarse to fine, mostly irregular chert. Sample contains some pebbles of limestone and shale.	3	20
Gravel, coarse, irregular chert, contains some pebbles of limestone and sandstone. Better sorted than above sample.	1	21
Cherokee shale		
Sandstone, very fine grained, calcareous, gray.	1.3	22.3
Shale, blue-gray to black, soft, some carbonaceous material.	2.7	25

13. Log of test hole 13, NE corner sec. 33, T. 31 S., R. 21 E., 100 feet west of railway crossing. Surface altitude, 831.5 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Silt and clay, tan to brown.	10	10
Silt and sand, very fine, gray to tan, containing small concretions of limonite.	8	18
Gravel, coarse to fine, and sand, medium to coarse. Poorly sorted, angular, mostly tan chert, and some small pebbles of limestone	4	22
Cherokee shale		
Shale, slightly calcareous, gray, soft.	2	24
Sandstone, fine grained, calcareous, light gray, hard	0.5	24.5
Shale, light gray, soft.	0.5	25

14. Log of test hole 14, NE¼ sec. 33, T. 31 S., R. 21 E., 0.2 mile east of test hole 15. Surface altitude, 829.6 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, black, and silt, brown.	10	10
Silt, tan, and sand, very fine.	8	18
Gravel, coarse to fine, and sand, coarse to medium. Gravel angular, poorly sorted, mostly brown chert with some pebbles of shale.	4.5	22.5
Cherokee shale		
Sandstone, very fine grained, micaceous	0.5	23

15. Log of test hole 15 near dam site, NE¼ sec. 33, T. 31 S., R. 21 E., 300 feet east of hole 17. Surface altitude, 830.4 feet. Core from 25 to 30 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, silt, and clay, brown to tan, and some fine sand. Contains streaks of limonite.	10	10
Silt and clay, tan, and some fine sand.	10	20
Gravel, coarse to fine, some coarse sand. Sample poorly sorted, mostly irregular chert gravel, containing some pebbles of limestone, sandstone, and shale.	4	24
Cherokee shale		
Sandstone, fine grained, calcareous, gray, very hard.	1	25
Shale, sandy, micaceous, gray to blue-gray, platy	1	26
Limestone, sandy, gray.	1	27
Shale, very sandy, calcareous, soft.	3	30

17. Log of test hole 17 at dam site, NE¼ sec. 33, T. 31 S., R. 21 E., 115 feet south of section line on east bank of Neosho river. Surface altitude, 828.1 feet. Core from 21 to 30 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Silt, brown to tan, clay, and sand, very fine, some fragments of charcoal.	10	10
Silt, tan, and sand, very fine.	8	18
Gravel, coarse to fine chert, sand, coarse to fine, some clay and pellets of limonite.	2	20
Gravel, coarse to fine, some sand, mostly chert pebbles, but contains some pieces of limestone.	1	21
Cherokee shale		
Sandstone, fine grained, very calcareous, gray, hard.	0.5	21.5
Shale, soft, micaceous, slightly calcareous, gray to black, soft.	1.5	23
Sandstone, micaceous, gray, alternately soft and hard.	2	25
Shale, dark gray to black, soft.	5	30

18. Log of test hole 18 at dam site, NE¼ sec. 33, T. 31 S., R. 21 E., 215 feet south of section line on east bank of Neosho river. Surface altitude, 829.7 feet. Core from 25 to 35 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil and silt, dark brown, contains some clay.	8	8
Silt and clay, brown.	11	19
Gravel, coarse to fine, brown, and clay, silt, and sand, fine.	4	23
Cherokee shale		
Shale, sandy, calcareous, gray, soft.	2	25
Sandstone, limy, gray, very hard.	2	27
Shale, dark gray to black.	23	50

19. Log of test hole 19 at dam site on gravel bar at river's edge, NE¼ sec. 33, T. 31 S., R. 21 E., 45 feet west of test hole 17. Surface altitude, 814.8 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Gravel, coarse to fine, and sand, coarse, poorly sorted, mostly chert with some fragments of black shale and limestone.	8	8
Cherokee shale		
Sandstone, very fine grained, calcareous, gray, very hard.	1	9
Shale, sandy to silty, gray, fissile.	1	10

20. Log of test hole 13 at dam site on gravel bar at river's edge, NE¼ sec. 33, T. 31 S., R. 21 E., 75 feet west of test hole 17. Surface altitude, 813.9 feet. No core recovered.

	Thickness, feet	*Depth, feet*
Alluvium		
Gravel, coarse to fine, and sand, coarse, poorly sorted. Mostly chert with some pebbles of black shale and limestone.	8	8
Cherokee shale		
Sandstone, very fine grained, calcareous, gray, very hard.	1	9
Shale, sandy to silty, gray, fissile	1	10

21. Log of test hole 15 at dam site on gravel bar at river's edge, NE¼ sec. 33, T. 31 S., R. 21 E., 100 feet north of test hole 20. Surface altitude, 818.0 feet. Core from 12.5 to 14 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Road material.	3	3
Gravel, coarse to fine, and sand, coarse to fine, poorly sorted, angular, mostly chert, but contains some black shale and pebbles of limestone.	9.3	12.3
Cherokee shale		
Sandstone, very fine grained, calcareous, gray, very hard.	1.2	13.5
Shale, sandy streaks, black, fissile, and some soft gray shale.	0.5	14

22. Log of test hole 22 at dam site, NE¼ sec. 33, T. 31 S., R. 21 E., near north line of Kansas Power Company on east bank of Neosho river. Core from 24 to 28 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, silt, and clay, brown.	10	10
Silt, clay, and fine sand, tan, some streaks of limonite. Medium gravel near base.	10	20
Gravel, coarse to fine, angular, poorly sorted. Mostly chert, but contains some pebbles of limestone and shale.	4	24
Cherokee shale		
Shale, light gray, soft.	4	28

23. Log of test hole 23 at dam site, NE¼ sec. 33, T. 31 S., R. 21 E., on property of Kansas Power Company, east bank of Neosho river. Core from 24 to 30 feet.

	Thickness, feet	Depth, feet
Alluvium		
Soil, silt, and clay, some very fine sand, dark to light brown.	10	10
Clay, dark brown, and silt, tan.	9	19
Gravel, coarse to fine, angular, poorly sorted, mostly chert, and some blue clay.	1	20
Gravel, coarse to fine, angular, poorly sorted, mostly chert, some pebbles of limestone and shale.	4	24
Cherokee shale		
Shale, black, clayey to fissile.	6	30

24. Log of test hole 24, NE corner sec. 34, T. 31 S., R. 21 E., south edge of road. Surface altitude, 829.1 feet.

	Thickness, feet	Depth, feet
Alluvium		
Road material.	2.5	2.5
Clay, chocolate-colored, and silt, tan, contains some streaks of limonite.	7.5	10
Clay, dark gray to blue, and some silt, slightly calcareous, containing some small concretions of limonite.	16	26
Clay, dark gray to blue, and some silt, tan, slightly calcareous.	4.5	30.5
Sand, coarse to fine, and gravel, fine to coarse, many grains and pebbles of shale, much blue clay interbedded.	1	31.5
Cherokee shale		
Shale, gray, alternately soft and fissile.	1.5	33

26. Log of test hole 26, NE corner NW¼ sec. 34, T. 31 S., R. 21 E., south edge of road. Surface altitude, 832.1 feet. Water sample collected, point set from 26 to 31 feet, temperature of water 54° F. Static water level, 6.2 feet below land surface, January 19, 1942.

	Thickness, feet	Depth, feet
Alluvium		
Soil, silt, brown, and sand, very fine.	2	2
Silt, tan, and sand, very fine.	8	10
Clay and silt, brown, containing streaks of limonite.	8.5	18.5
Gravel, coarse to fine, and sand, coarse to medium, mostly chert, irregular, poorly sorted.	11.5	30
Gravel, coarse to fine, chert, some jasperoid, angular, poorly sorted.	4.5	34.5
Cherokee shale		
Sandstone, fine grained, micaceous, gray, and shale, sandy, black, soft.	1.5	36

29. Log of test hole 29, NE¼ NW¼ sec. 35, T. 31 S., R. 21 E., 0.15 mile east of test hole 31, south edge of road. Surface altitude, 828.4 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil and clay, dark gray, calcareous, and some fine sand containing streaks of limonite near the base.	10	10
Silt, light brown, and sand, very fine, calcareous, contains streaks of limonite.	6	16
Cherokee shale		
Shale, micaceous, sandy, gray, alternately soft and hard.	4	20

31. Log of test hole 31, NE¼ NW¼ sec. 35, T. 31 S., R. 21 E., south edge of road. Surface altitude, 828.0 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, dark gray, clay, chocolate-brown, and silt, gray, with streaks of limonite.	8	8
Silt, light brown, and sand, very fine. Sample contains much limonite. Turned drilling mud yellow.	3	11
Gravel, coarse to fine, and some coarse sand. Angular to subangular pebbles of chert, poorly sorted.	5	16
Cherokee shale		
Shale, sandy, micaceous, slightly calcareous, gray, soft.	4	20

34. Log of test hole 34, NW¼ NW¼ SE¼ sec. 4, T. 32 S., R. 21 E. Surface altitude, 826.9 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Silt, brown, some clay, and spots of iron.	10	10
Silt, brown, some clay and very fine sand.	5	15
Silt, brown, and very fine sand. Some streaks of limonite.	5	20
Clay, brown to black, calcareous, gravel, chert and partly decomposed limestone.	5	25
Gravel, coarse to fine, clay and silt, brown, calcareous, and some fine sand.	1	26
Cherokee shale		
Limestone, gray to light brown, crystalline, with fragments of residual chert.	0.5	26.5

35. Log of test hole 35, SE¼ NW¼ SE¼ sec. 4, T. 32 S., R. 21 E. Surface altitude, 827.7 feet. Water sample collected, point set from 18 to 23 feet. Temperature of water 56° F. Static water level, 12.7 feet below land surface, January 25, 1942.

	Thickness, feet	*Depth, feet*
Alluvium		
Silt, brown, and sand, very fine.	10	10
Silt and clay, tan to brown, contains some sand, very fine.	7	17
Gravel, coarse to fine, mostly medium, sand coarse to fine, and clay, brown. Very poorly sorted. Gravel angular, mostly chert, and some pebbles of shale.	3	20
Gravel, coarse to fine, mostly coarse. Angular, chert, not well sorted, but much better than above sample.	10	30
Gravel, coarse to fine, and sand, coarse, poorly sorted, not as coarse as above. Mostly chert, contains some pebbles of limestone.	4.5	34.5
Cherokee shale		
Shale, black, hard, fissile.	1.5	36
Shale, gray, soft, clayey.	0.5	36.5

36. Log of test hole 36, NE¼ SE¼ SW¼ sec. 4, T. 32 S., R. 21 E. Surface altitude, 823.9 feet. Water sample collected, point set from 15 to 20 feet, temperature of water 55° F. Static water level, 5.5 below land surface, January 25, 1942.

	Thickness, feet	*Depth, feet*
Alluvium		
Silt, buff to dark brown, and sand, very fine to fine.	15	15
Gravel, coarse to fine, angular, poorly sorted, dark gray to black, contains some pebbles of black shale. Samples contain some dark-gray clay.	5	20
Gravel, coarse to fine. Dark-gray to brown angular chert. Sorted much better than above sample.	10	30
Cherokee shale		
Limestone, light gray, containing fragments of silicified fossils.	1	31

37. Log of test hole 37, SW¼ SE¼ sec. 4, T. 32 S., R. 21 E. Surface altitude, 826.5 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, silt, brown, clay, chocolate-colored, and very fine sand.	10	10
Sand, very fine, and silt, buff to brown, contains limonite.	8	18
Silt and clay, buff, and some fine sand. Contains much limonite and some carbonaceous material.	3	21
Gravel, coarse to fine, angular, poorly sorted, mostly chert. Contains some pebbles of limestone and silicified coral.	2	23
Cherokee shale		
Limestone, gray, crystalline, containing some chert.	1	24

38. Log of test hole 38, SW¼ SE¼ SE¼ sec. 4, T. 32 S., R. 21 E. Surface altitude, 828.0 feet. Water sample collected, point set from 21 to 26 feet. Temperature of water 55° F. Static water level, 11.2 feet below land surface, January 25, 1942.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, silt, and sand, very fine, slightly calcareous	7	7
Silt, clay, and sand, very fine, buff to brown. Contains limonite.	3	10
Silt and sand, very fine, some clay and limonite	11	21
Gravel, coarse to fine, and some sand, coarse. Mostly chert, angular, poorly sorted. Contains some pebbles of shale.	5.5	26.5
Cherokee shale		
Shale, light gray, very soft.	3.5	30

40. Log of test hole 40, SW¼ NW¼ sec. 9, T. 32 S., R. 21 E. Surface altitude, 826.0 feet. Water sample collected, point set from 23 to 28 feet, temperature of water 55° F. Static water level 10.3 feet below land surface, January 24, 1942.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, clay, chocolate-colored, and silt, tan, some very fine sand.	10	10
Silt, light brown, and sand, very fine.	13	23
Sand, very fine to medium, containing much brown clay and silt.	2	25
Gravel, coarse to fine, angular, very poorly sorted. Many pebbles of shale. Sample contains a considerable amount of clay and silt.	5	30
Gravel, coarse to fine, angular, mostly chert, contains some pebbles of black shale and a few pebbles of limestone. Coarser and better sorted than above.	4.5	34.5
Cherokee shale		
Shale, micaceous, sandy, gray, soft.	1.5	36

41. Log of test hole 41, NE¼ NW¼ sec. 9, T. 32 S., R. 21 E. Surface altitude, 826.2 feet. Water sample collected, point set from 15 to 20 feet, temperature of water 55° F. Static water level, 4.9 feet below land surface, January 24, 1942.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, black, clay and silt, gray to brown.	8	8
Clay and silt, gray to brown, containing sand, very fine to coarse, and gravel, coarse.	2	10
Gravel, coarse to medium, angular, poorly sorted, mostly chert, but contains a few pebbles of limestone and shale.	10	20
Gravel, mostly coarse, some medium, angular, poorly sorted, mostly chert. Coarser than above sample.	5	25
Cherokee shale		
Sandstone, micaceous, gray, loosely cemented with calcium carbonate, soft.	1.5	26.5
Sandstone, micaceous, gray, calcareous, hard	0.5	27

43. Log of test hole 43, NW¼ NE¼ sec. 9, T. 32 S., R. 21 E. Surface altitude, 825.0 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, silt, and clay, light brown, and some very fine sand. Contains carbonaceous material and limonite.	5.5	5.5
Silt and very fine sand, tan to buff, contains limonite.	12.5	18
Gravel, coarse to fine, and some silt and clay. Poorly sorted, angular chert, and some fragments of black shale.	2	20
Gravel, coarse to fine, containing much clay and many fragments of limestone. Seems to be from a weathered erosion surface.	1.5	21.5
Cherokee shale		
Limestone, gray to tan, much tan chert, and many fragments of silicified coral.	1.5	23
Sandstone, fine grained, white quartz grains loosely cemented.	0.5	23.5

45. Log of test hole 45, NW corner SE¼ NE¼ sec. 9, T. 32 S., R. 21 E. Surface altitude, 825.6 feet.

	Thickness, feet	*Depth, feet*
Alluvium		
Soil, clay, silt, and very fine sand. Contains limonite.	6	6
Clay and silt, buff, contains some carbonaceous material.	4	10
Silt and sand, very fine to fine, contains some limonite.	7	17
Gravel, coarse to fine, and some very fine sand. Mostly angular quartz gravel and some pebbles of shale.	3	20
Clay, and many fragments of chert and limestone and pieces of silicified corals. Seems to be a weathered erosion surface.	3.5	23.5
Cherokee shale		
Limestone, gray, containing chert and fragments of silicified fossils.	0.5	24

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Showing Geology and Water-table Contours. Geology Adapted With Minor Revision From Pierce and Courtier, 1937, Plate I

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