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# Ground-water Resources of the Arkansas River Flood Plain Near Fort Gibson, Muskogee County, Oklahoma

by

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Prepared in cooperation between the U. S. Geological Survey and the U. S. Bureau of Reclamation

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# GROUND-WATER RESOURCES OF THE ARKANSAS RIVER FLOOD PLAIN NEAR FORT GIBSON, MUSKOGEE COUNTY, OKLAHOMA


By Stuart L. Schoff and Edwin W. Reed


## ABSTRACT


The portion of the Arkansas River flood plain considered in this investigation is an area of 6,465 acres near Fort Gibson in northeastern Muskogee County, Oklahoma, lying south of the Grand (Neosho) River and east and north of the Arkansas River. It could be irrigated by pumping water directly from the Grand (Neosho) River, or by pumping from wells tapping ground water in the alluvium. The purpose of this investigation was to ascertain whether the geologic and hydrologic conditions are favorable for irrigation from wells.

Test holes drilled at 37 locations showed the alluvium to range from 17.5 to 47 feet in thickness, and to average 37.6 feet. In most places it consists of a layer of clay averaging about 16 feet thick, underlain by sand and gravel averaging about 20 feet. Very coarse gravel, with boulders at least 5 inches across, was found in a strip bordering the Grand River, and very fine sand and silt were found in a strip along the east side bordering the bluff. In the rest of the area, sand and fine to medium gravel were found.

Pumping tests were made at three locations, but in the first test the slotted casing used as a well screen became so clogged with coarse sand and fine gravel that the results were unsatisfactory. The tests, which were analyzed by the Thiem formula and the Theis nonequilibrium formula by different methods, indicate an average transmissibility of about 70,000 gallons per day per foot.

An analysis of the probable recharge from precipitation on the area, surface runoff from adjacent uplands, underflow from underlying bedrocks, and underflow from rivers suggests ample annual replenishment to meet the probable demand for irrigation water. Consideration of the natural discharge also suggests that the perennial supply of ground water is adequate for anticipated needs. The volume of water in storage, without recharge, is estimated to be enough for about eight seasons of irrigation. Although very hard, the ground water is of good quality for irrigation use.

Pumping 300 gallons per minute continuously for 33 days—enough to meet the estimated annual water requirement for 40 acres—should produce a drawdown of about 0.48 foot at a distance of 0.25 mile from the pumped well, and 0.01 to 0.08 foot at 0.5 mile.

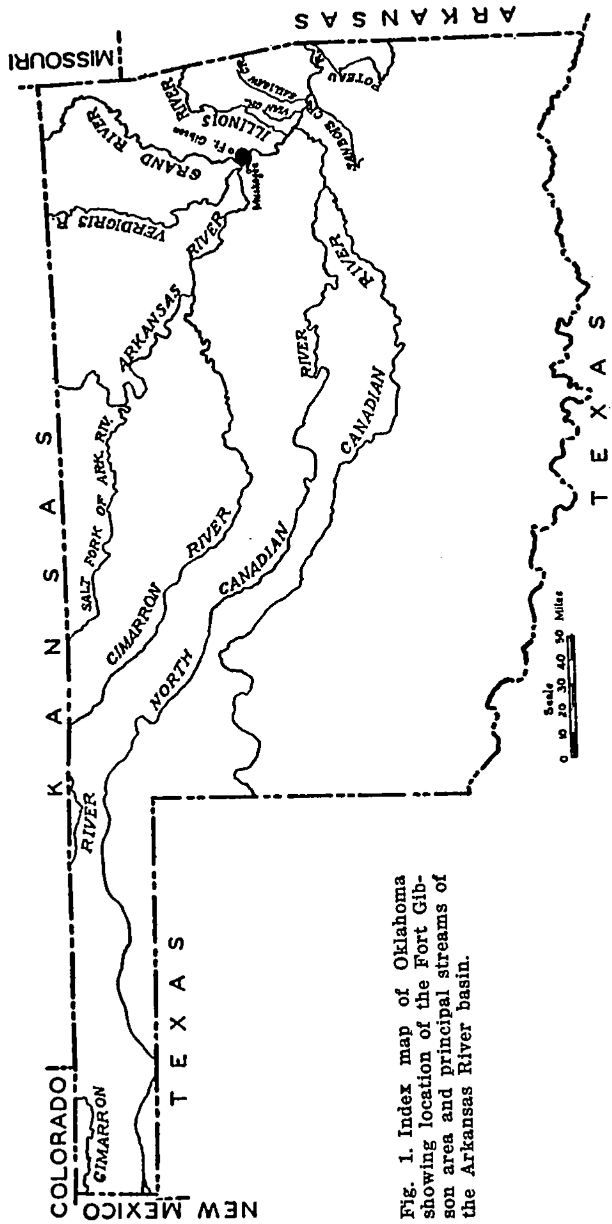



Fig. 1. Index map of Oklahoma showing location of the Fort Gibson area and principal streams of the Arkansas River basin.



*Purpose and scope of investigation.*—This report gives the results of an investigation of the ground water in the alluvium underlying the Arkansas River flood plain near Fort Gibson, Muskogee County, Oklahoma. The investigation was planned and carried out by the writers for the Branch of Project Planning of the Bureau of Reclamation, Oklahoma City, Oklahoma, under the supervision of M. G. Barclay, Area Planning Engineer, and with the active cooperation of several members of the staff of that office. It was also under the general supervision of A. N. Sayre, Geologist in Charge, Ground Water Branch, U. S. Geological Survey.

The purpose of the investigation was to determine whether the ground water in the alluvium is adequate in quantity and satisfactory in quality for irrigation. Enough water is available in the Grand (Neosho) River,[1] which flows along the north side of the area, but the cost of installing and operating pumping equipment and of constructing and maintaining a system to distribute the water over the flood plain is considered not justifiable if most of the area can be irrigated from privately owned wells.

*Location and area.*—The area considered in this investigation is part of the Arkansas River flood plain, or bottom land, immediately below the mouth of the Grand (Neosho) River in northeastern Muskogee County. It lies southwest of Fort Gibson, between that town and the Arkansas River, in the northeastern two-thirds of T. 15 N., R. 19 E., and comprises about 6,465 acres (fig. 1). For convenience in this report, it is called the Fort Gibson flood plain.

The Grand (Neosho) River enters the area from the northeast near the center of sec. 2, and joins the Arkansas River near the middle of sec. 9. From the confluence of the two rivers, the Arkansas flows south to the S¼ cor. sec. 21, southeast to the SE cor. sec. 28, and thence eastward to leave the area near the E¼ cor. sec. 25.

1. The U. S. Board of Geographic Names approves the name Neosho, but the name Grand is more widely used throughout the State.

U. S. Highway 62 enters the area at Fort Gibson and leaves by way of a bridge over the Arkansas River near the middle of the western side. State Highway 10 crosses the area from east to west, the western half coinciding with U. S. Highway 62. The Saint Louis-San Francisco Railway has a line running southwestward from Fort Gibson, crossing the river less than half a mile south of the highway bridge, and the Missouri Pacific Railroad skirts the eastern boundary of the area.

*Ground-water problems.*—Although the maximum area of the Fort Gibson flood plain is about 6,465 acres, a reasonable estimate by the Bureau of Reclamation indicates that the maximum area likely to be under irrigation at one time will not exceed 3,500 acres. As the Bureau estimates that the average annual requirement of irrigation water will be about 1.1 acre-feet for each irrigated acre, the total consumption of water should be about 3,850 acre-feet, or about 1,250,000,000 gallons annually.

A preliminary analysis indicated that, if only 15 to 20 percent of the annual precipitation in the area were to percolate down to the zone of saturation, the annual rate of replenishment of ground water would approximate the maximum requirement for irrigation. This rate of recharge, however, is an assumption, and in the absence of an opportunity to verify it by observing the fluctuations of ground-water levels over a period of years, it was desirable to ascertain whether it might be supplemented by substantial infiltration from the rivers. Accordingly, the investigation included test drilling to show whether the permeable beds in the alluvium might be connected with the rivers, and pumping tests to demonstrate the ability of those beds to transmit the water from the rivers to the places where it is needed.

It was recognized at the outset that the permeable sand and gravel beds might be confined to narrow buried channels flanked on either side by clay or other fine-grained sediments unsuited to the development of irrigation wells. If such were the situation, ground water might be available in too small a part of the Fort Gibson flood plain, and a pumping station on the river bank would be desirable regardless of how freely the gravels in the buried channels might yield water. Hence the test drilling was intended to show also how widely the permeable beds are distributed under the flood plain.



As the mineral content of water used for irrigation may be harmful to the soil and the crops, the investigation included sampling and analysis of ground water from test holes in all parts of the area. Several analyses already were available for waters from farm wells penetrating the zone of saturation for short distances, and so the water samples taken in the investigation came mainly from near the the bottom of the saturated sand and gravel.

To determine whether heavy pumping would cause changes in the character of the water by drawing into the wells water of poorer quality from depth in the aquifer or from distant parts of the aquifer, samples of water were collected at intervals during the pumping tests and were analyzed for chloride and dissolved solids.

Water samples taken during the third pumping test serve also to suggest the quality of the water that may be pumped from wells adjacent to the Arkansas River. The water of the Arkansas River is highly mineralized and rather salty, but that of the Grand is of good quality, although very hard. The Grand enters the Arkansas from the east and its water usually does not become thoroughly mixed with that of the Arkansas for several miles downstream from the Fort Gibson area. The water from the Grand parallels the left bank of the Arkansas, which is the western and southern boundary of the flood plain considered here. Therefore, the water drawn into the alluvium by heavy pumping near the river should at first be more or less like Grand River water. Only after protracted heavy pumping should it resemble the normal Arkansas River water. Hence it is believed that, under the seasonal pumping required for irrigation, little contamination of the underground reservoir is likely to result from infiltration of river water induced by pumping in wells near the river. The infiltration, on the other hand, could be of considerable value in sustaining the supply.

*History of investigations.*—In September 1944, Edwin W. Reed, of the U. S. Geological Survey, made a preliminary reconnaissance of the Fort Gibson area in connection with the availability of ground water for proposed war industries. The analyses of the ground-water samples collected by him then are equally pertinent to this investigation. No further action was taken until June 1946, when Mr. Reed accompanied Norman G. Flaigg of the Bureau of Reclamation to the area for a preliminary investigation that also included the flood plain between the Grand (Neosho) and Verdigris Rivers. Further investigation by the Bureau indicated that a substantial part of the latter area was not very suitable for irrigation because of the character of the soils, and it accordingly was not included in the intensive phase of ground-water study.

At the request of the Bureau, Mr. Reed revisited the area east of the Arkansas and south of the Grand (Neosho) in June 1947 for further information on geologic and hydrologic conditions and to determine whether testing would be feasible. Specifications for an intensive test-drilling and test-pumping program in accord with his findings were prepared by the Bureau of Reclamation, invitations were issued to prospective bidders in April 1948, and drilling was begun in June, continuing with interruptions until August. The drilling of the last few test holes was done while the pumping tests were in progress.

*Methods of this investigation.*—Test drilling with a rotary machine having a rated capacity of 1,000 feet was begun near the W ¼ cor. sec. 11 on June 1, 1948. Drilling proceeded rapidly through silt and clay to a depth of 19.5 feet, but in the underlying gravel the circulation of drilling mud could not be maintained in spite of liberal use of sawdust, bran, and commercial drilling preparations. It was estimated that mud heavy with such materials was being pumped into the gravel at the rate of 50 gallons per minute. The pebbles and cobbles fell back into the hole around the bit and drill stem, so that drilling proceeded at the risk of sticking the bit fast. All progress stopped at a depth of 34 feet, no cuttings being recovered from depths greater than about 28 feet. The drilling machine was moved 1 mile west, to a site near the W ¼ cor. sec. 10, where similar conditions were encountered and no progress could be made below 14 feet. The contractor concluded that the work was excessively costly, and he accordingly



defaulted on the contract. The test holes thus left incomplete are assigned numbers 1 and 2, and the holes later completed successfully at the same sites are designated 1-a and 2-a.

The contract was reawarded to the next higher bidder, Kelley Brothers Contracting Co., who began drilling test hole 1-a on June 28. To make progress in the gravel, this contractor drove 5-inch casing, meanwhile bailing gravel from inside it, but the method proved much too slow and costly. A compressor was then used to introduce air through a 3/4-inch pipe, and water, sand, and gravel were jetted out of the 5-inch casing. By this method the casing could be sunk rather rapidly unless a large cobble became lodged in the bottom of it, and driving was unnecessary, but the time required to complete a single test hole was still considerable. In a few of the test holes where serious loss of circulation occurred, the lower part of the water-bearing gravels was probed by driving a steel rod as far as it would go, but this procedure afforded no sample of the materials penetrated, and it could not be determined whether the rod actually reached the bedrock or stopped on a boulder. Materials encountered in three of the test holes (nos. 24, 25, and 27) resisted all efforts to drill, probe, and jet. As these sites were within 0.25 mile of each other and several successful test holes had been completed within reasonable distances in all directions, these test holes were abandoned without reaching bedrock. As test drilling advanced southward across the area, less coarse gravel was found, and most test holes could be completed from the surface to bedrock by ordinary rotary drilling methods.

Cuttings of the materials penetrated by the drill generally were collected from the ditch that led the drilling mud from the top of the hole to the slush pit, and usually within a foot of the hole itself. A small basin dug in the ditch 6 or 8 feet from the drill served to catch some of the finer materials, but much of the fine-grained sand and loose silt went into the slush pit. Some of these finer materials were caught by setting a can in the ditch and decanting the water from it at intervals. The clays were cut by the bit into shreds and small chunks an eighth to a quarter of an inch across, and these were easily collected; as the clays clearly are not water-bearing they were not saved after the first few test holes. As was expected, the coarser pebbles and cobbles were not recovered, and in this respect the samples failed to reflect accurately the character of the water-bearing materials. In several places test holes were drilled to bedrock without recovering anything coarser than sand, yet pebbles and cobbles were thrown from the same holes during jetting for water samples. It is evident, therefore, that in places the water-bearing materials may be coarser than indicated by the test drilling.

Water samples were obtained from the test holes by jetting with air inside 3-inch or 5-inch casing, except at hole 4, where the sample was pumped out with a pitcher pump. In most holes jetting began with irregular surges of very muddy water, and as the bottom of the hole was gradually cleared of mud the surges settled down to a regular pulse. The rate of pumping by this method was measured at test hole 19 as about 17 gallons per minute. At comparable rates, the water from most test holes cleared sufficiently in about 30 minutes to permit sampling.

Samples collected in 1944 and 1946 during the preliminary phases of the investigation were obtained by pumping from farm wells. The 12 samples of water collected in 1946 and the small samples taken at intervals during the pumping tests were analyzed by the Bureau of Reclamation. All the rest were analyzed in laboratories of the Geological Survey. Standard methods of water analysis were followed.

The pumping tests were made and interpreted according to methods in general use in the Geological Survey, and are described in detail in the section on pumping tests.

The locations of the test holes, the water table, the bedrock surface, and holes used for pumping tests are shown on plate I.

Laboratory study of the drill cuttings from the test holes consisted of sieving the samples in the size ranges from fine sand to fine gravel. Where pebbles and cobbles properly belonged in the sample, the sieve analyses were inadequate and were omitted. The analyses were made in the laboratory of the Oklahoma Geological Survey by E. Pinney and J. L. Moody of the University of Oklahoma Research Institute.



Vertical control was provided by K. C. Pinkerton and N. G. Flaigg, of the Bureau of Reclamation, who, with the assistance of Kenneth D. McCall, Jr., ran about 21 miles of level lines to determine ground-surface elevations at the test holes and elevations of measuring points of the wells used in the pumping tests. The leveling was tied to U. S. Coast and Geodetic Survey bench marks in Fort Gibson. The readings were made to 0.001 foot with shots not over 200 feet in length. Because of a possible later need for bench marks for topographic surveying in the area, the intended accuracy was according to the rule that the total error in feet must not exceed 0.05 times the square root of the length of the line in miles. Of the 43 bench marks set and leveled in the investigation, only 5 fell outside the intended limits.

*Acknowledgments.*—The writers are indebted to the residents of the area who permitted the measuring and sampling of their water wells in the preliminary stages of the investigation, and who provided much general information about subsurface conditions; and to the land owners who permitted test holes to be drilled or pumping tests to be made on their property. The Muskogee County Commissioners and the Oklahoma State Highway Department gave permission for the drilling of test holes along rights-of-way. The wholehearted support and active cooperation of staff members of the Oklahoma City office of the Bureau of Reclamation and the willing cooperation of the crew that did the actual testing are especially appreciated. The illustrations were prepared by D. F. Parker, of the Bureau of Reclamation, and some were modified to meet editorial requirements by J. B. Linderman and T. Vaughn, of the Oklahoma Geological Survey.

*Topography.*—The flood plain southwest of Fort Gibson is very flat, although in detail it is diversified by low, rather inconspicuous ridges or terraces created by the rivers as they meandered back and forth (plate II). An unusually high and steep bluff forms the south shore of Horseshoe Lake in sec. 15. It was once a river bank, for both Horseshoe Lake and Ross Lake occupy narrow, curved depressions that in very recent time were river channels. The fact that these lakes always contain water indicates that their bottoms descend into the zone of saturation and, accordingly, that their water surfaces are continuations of the water table.

## GEOLOGY AND WATER-BEARING PROPERTIES OF THE ROCKS

The Fort Gibson flood plain is correctly shown by Miser[2] and by Soyster and Taylor[3] as underlain by alluvium, and for the purpose of this report the geology of the area may be considered as rather simple, with a twofold classification: bedrock below, overlain by the alluvial deposits that are the principal water-bearing formation.

### Bedrock

The bedrock underlying the alluvium of the Fort Gibson flood plain is mainly of Pennsylvanian age and probably belongs in the upper part of the Atoka formation, although it is possible that formations of upper Mississippian age are present in the southeastern part of the area. The geologic maps by Miser and by Soyster and Taylor show large areas both east and west of the Arkansas River as underlain by the "Winslow" formation, with the obvious implication that most of the alluvium of the Fort Gibson flood plain also must be underlain by the "Winslow" formation. The name "Winslow," however, has been discarded because it proved to be "a blanket term covering rocks susceptible of subdivision into several formations" ranging from the Atoka formation upward into the lower part of the Boggy shale.[4]

The probable identity of the bedrock under the Fort Gibson flood plain is suggested by Wilson's map[5] of the Muskogee-Porum district, which shows the bedrock on the west side of the Arkansas River opposite Fort Gibson as the Hartshorne sandstone and the lower part of the McAlester shale. As the regional dip is westward,[6] and as the rock exposures above water level in the west bank of the Arkansas must be at a higher elevation than the bedrock under the Fort Gibson flood plain, the latter must be older than the Hartshorne sandstone—that is, probably the upper part of the Atoka formation.

2. Miser, H. D., "Geologic Map of Oklahoma": *U. S. Geol. Survey*, 1926.
3. Soyster, H. B., and Taylor, T. G., "Oil and Gas in Oklahoma, Muskogee County": *Oklahoma Geol. Survey Bull.* 40 FF, 1928, and *Bull.* 40, vol. 3, map 30, 1930.
4. Wilmarth, M. G., "Lexicon of Geologic Names of the United States": *U. S. Geol. Survey Bull.* 896, p. 2354, 1938.
5. Wilson, C. W., "Geology of the Muskogee-Porum District, Muskogee and McIntosh Counties, Oklahoma": *Oklahoma Geol. Survey Bull.* 57, Pl. I, 1937.
6. Wilson, *op. cit.*, p. 75.



Cuttings from the bedrock were recovered from 28 of the 37 test holes drilled in this investigation. In 23 of the test holes (nos. 1-a, 3-8, 11-15, 17, 20, 21, 26, 28-32, 34 and 36) the bedrock proved to be black shale. In test hole 9 it was blue shale; in holes 19 and 22, gray shale; in hole 16, fine brown sandstone; and in hole 18, gray sandstone. None of the test holes went far enough into the bedrock to permit identification of members within the Atoka formation, but the materials are in harmony, in a general way at least, with the Atoka formation as described by Wilson.[7]

Although the above identification of the bedrock appears probable for most of the Fort Gibson flood plain, it is likely that older rocks underlie the alluvium in the southern and southeastern parts of the area. The maps by Miser[8] and by Soyster and Taylor[9] show a fault projected southwestward across the flood plain from near the E¼ cor. sec. 24, and crossing the Arkansas River near the SW cor. sec. 27. It is buried, of course, under the alluvium. Wilson[10] shows the trace of it west of the Arkansas River in a slightly different location from that on the older maps, and refers to it as the Muskogee fault (south). For the segment of it west of the river he states: "The Muskogee fault (south) . . . . is covered by the alluvial silt of Arkansas River . . . . to N½ sec. 2, T. 18 N., R. 14 E., in which section it abruptly dies out. The presence of this fault beneath the alluvium was determined by the study of well logs. The throw is as much as 600 feet, and the downthrown side is to the north."

That the throw of the fault is considerable east of the Arkansas River is indicated by the older maps, which show the "Winslow" formation on the north side of the fault, in some places opposite the Fayetteville shale and the Pitkin limestone of upper Mississippian age and in other places opposite the Morrow series.[11] Only a little over 0.5 mile east of the Fort Gibson flood plain (sec. 19, T. 15 N.,

7. Wilson, *op. cit.*, pp. 24-35.
8. Miser, *op. cit.*
9. Soyster and Taylor, *op. cit.*, geologic map.
10. Wilson, *op. cit.*, pl. 1, and p. 80.

R. 20 E.) the "Winslow" formation is opposed to the Fayetteville and Pitkin (mapped as a unit), with the intervening Morrow series cut out. It is reasonable to assume that the Fayetteville and Pitkin, or some part thereof, should be present under the alluvium in parts of secs. 24-27 of the township of this report. The test drilling neither confirms nor disproves this assumption. Test hole 12 was almost directly over the trace of the fault as mapped, and in it the bedrock was hard black shale. Of two test holes within 0.25 mile of the fault on the south side, one (no. 13) encountered black shale, and the other (no. 14) encountered black shale and sandstone. Of four test holes within 0.5 mile of the fault on the north side, two (nos. 8 and 11) encountered dark-colored to black shale, and one (no. 16) encountered fine brown sandstone. Without deeper drilling to establish the stratigraphic succession on both sides, no conclusions can be drawn regarding the fault.

The bedrock materials encountered in the test drilling are fine-grained or tightly cemented, or both, and ground water is not likely to move readily through them. The general geology of the Fort Gibson area indicates that no sandstones or conglomerates capable of supplying large amounts of water to wells will be found within reasonable depths, and therefore that supplies of ground water adequate for irrigation cannot be developed in them. As the fine-grained bedrock can absorb little water from the alluvium, it functions chiefly as a container, as an impervious bottom preventing the water from sinking downward out of reach.

### Alluvium

The Fort Gibson flood plain is underlain by alluvium, which is the material deposited in recent geologic time principally by the Arkansas River, although some of it doubtless was deposited by the Grand (Neosho) River. It consists of gravel, sand and clay, and mixtures thereof, in varying proportions and thicknesses. The soil in the area is alluvium modified by weathering and growing plants.

11. The classification used here is that of the Oklahoma Geological Survey.

Table 1.--Summary of Test-Hole and Water-Well Data, Fort Gibson, Oklahoma

| Number of test hole | Elevation of land surface a/ | Thickness of alluvium (feet) | Elevation of bedrock surface a/ | Thickness of clay and soil (feet) | Thickness of sand and gravel (feet) | Depth to Water below land surface (feet) | Elevation of water table a/ | Thickness of saturated alluvium (feet) | Date of Measurement | Number of test hole |
|---|---|---|---|---|---|---|---|---|---|---|
| 1-a | 507.1 | 37 | 470.1 | 19 | 18 | 16.6 | 490.5 | 20.4 | 8-21-48 | 1-a |
| 2-a | 501.5 | 30.5 | 471.0 | 9 | 21.5 | 9 | 492.5 | 21.5 | 8-21-48 | 2-a |
| 3 | 503.4 | 31.5 | 471.9 | 19 | 12.5 | 13.0 | 490.4 | 18.5 | 7-12-48 | 3 |
| 4 | 513.7 | 32 | 481.7 | 20.5 | 11.5 | 8.3 | 505.4 | 23.7 | 8-21-48 | 4 |
| 5 | 505.9 | 37 | 468.9 | 21 | 16 | 14 | 491.9 | 23.0 | 7- 6-48 | 5 |
| 6 | 514.3 | 45.5 | 468.8 | 39 | 6.5 | 24.5 | 489.8 | 21.0 | 7-12-48 | 6 |
| 7 | 507.2 | 42 | 465.2 | 23 | 19 | 11.2 | 496.0 | 30.8 | 8-20-48 | 7 |
| 8 | 504.7 | 40 | 464.7 | 20 | 20 | 14.8 | 489.9 | 25.2 | 7-12-48 | 8 |
| 9 | 506.1 | 42 | 464.1 | 19 | 23 | 21.1 | 485.0 | 20.9 | 7-30-48 | 9 |
| 10 | 506.5 | 43 | 463.5 | 21 | 22 | 17.5 | 489.0 | 25.5 | 7-12-48 | 10 |
| 11 | 499.8 | 38.5 | 461.3 | 17 | 21.5 | 9.3 | 490.5 | 29.2 | 7-30-48 | 11 |
| 12 | 499.6 | 36.5 | 463.1 | 18 | 18.5 | 11.1 | 488.5 | 25.4 | 8-20-48 | 12 |
| 13 | 498.4 | 35.5 | 462.9 | 8 | 27.5 | 13.0 | 485.4 | 22.5 | 7-30-48 | 13 |
| 14 | 499.4 | 33 | 466.4 | 7 | 26 | 16.0 | 483.4 | 17.0 | 8-20-48 | 14 |
| 15 | 497.0 | 28 | 469.0 | 12 | 16 | 9.1 | 487.9 | 18.9 | 7-15-48 | 15 |
| 16 | 498.1 | 31.5 | 466.6 | 18 | 13.5 | 13.2 | 484.9 | 18.3 | 8-20-48 | 16 |
| 17 | 501.7 | 33 | 468.7 | 5 | 28 | 7 | 494.7 | 26.0 | 8-20-48 | 17 |
| 18 | 510.3 | 17.5 | 492.8 | 14 | 3.5 | 2.5 | 507.8 | 15.0 | 8-20-48 | 18 |
| 19 | 498.7 | 31 | 467.7 | 3 | 28 | .... | ..... | .... | ...... | 19 |
| 20 | 498.1 | 29 | 469.1 | 14 | 15 | 7.2 | 490.9 | 21.8 | 7-30-48 | 20 |

a/ Feet above sea level

Table 1.---Summary of Test-Hole and Water-Well Data, Fort Gibson, Oklahoma (Cont'd)

| Number of test hole | Elevation of land surface a/ | Thickness of alluvium (feet) | Elevation of bedrock surface a/ | Thickness of clay and soil (feet) | Thickness of sand and gravel (feet) | Depth to Water below land surface (feet) | Elevation of water table a/ | Thickness of saturated alluvium (feet) | Date of Measurement | Number of test hole |
|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 506.9 | 41.5 | 465.4 | 22.5 | 19 | 14.6 | 492.3 | 26.9 | 8-20-48 | 21 |
| 22 | 510.4 | 46.5 | 463.9 | 30 | 16.5 | 21.5 | 488.9 | 25.0 | 7-16-48 | 22 |
| 23 | 511.1 | 45.9 | 465.2 | 27 | 19 | 19.9 | 491.2 | 26.0 | 7-16-48 | 23 |
| 24 | 511.0 | .... | ..... | 10 | .... | .... | ..... | .... | ....... | 24 |
| 25 | 508.9 | .... | ..... | 8 | .... | 12 | 496.9 | .... | 8-21-48 | 25 |
| 26 | 507.9 | 40 | 467.9 | 36 | 4 | 17.8 | 490.1 | 22.2 | 8-21-48 | 26 |
| 27 | 505.2 | .... | ..... | 14.5 | .... | 12 | 493.2 | .... | 8-21-48 | 27 |
| 28 | 506.0 | 38.5 | 467.5 | 12 | 26.5 | 9.1 | 496.9 | 29.4 | 8-21-48 | 28 |
| 29 | 509.7 | 47 | 462.7 | 0 | 47 | 17.4 | 492.3 | 29.6 | 8-21-48 | 29 |
| 30 | 506.7 | 44 | 462.7 | 26 | 18 | 13.2 | 493.5 | 30.8 | 8-20-48 | 30 |
| 31 | 508.1 | 43.5 | 464.6 | 13 | 30.5 | 16.3 | 491.8 | 27.2 | 8- 3-48 | 31 |
| 32 | 504.0 | 35.5 | 468.5 | 14 | 21.5 | 6.4 | 497.6 | 29.1 | 8-21-48 | 32 |
| 33 | 507.4 | 42.7 | 464.7 | 10 | 32.5 | 12.9 | 494.5 | 29.8 | 8-12-48 | 33 |
| 34 | 507.3 | 40 | 467.3 | 27 | 13 | 12.2 | 495.1 | 27.8 | 8-20-48 | 34 |
| 35 | 510.7 | 43.2 | 467.5 | 31.5 | 11.7 | 17.4 | 493.3 | 25.8 | 8-21-48 | 35 |
| 36 | 510.6 | 44 | 466.6 | 8 | 36 | 14.0 | 496.6 | 30.0 | 8-21-48 | 36 |
| 37 | 506 + | 32 | 474 + | 8 | 24 | 16.6 | 489.4 | 15.4 | 8-21-48 | 37 |
| 0-4 | 502.4 | 38.5 | 463.9 | 5 | 33.5 | 15.6 | 486.8 | 22.9 | 8-21-48 | 0-4 |
| OG&E | 507.1 | 47.4 | 459.7 | .... | .... | .... | ..... | .... | ....... | OG&E |
| Foltz | 509 + | 39.5 | 469.5 | .... | .... | .... | ..... | .... | ....... | Foltz |

a/ Feet above sea level

Table 2. - Sieve Analyses of Silt, Sand, and Gravel from Test Holes, Fort Gibson, Oklahoma

| Test-hole number | Sample number | Depth of sample (feet) | Thickness (feet). | On pan -0.0029 | Percent of sample, by weight, retained on screen with openings shown (inches) .0029 | .0058 | .0116 | .0232 | .065 | .093 | .185 | .375 | .75 | Coefficient of uniformity. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1a | 1 | 19-21 | 2 | 0.76 | 1.00 | 2.03 | 3.13 | 6.70 | 12.30 | 20.16 | 29.60 | 21.40 | 3.0 | 7.1 |
| | 2 | 21-26 | 5 | 0.46 | 0.53 | 1.83 | 3.53 | 8.60 | 15.86 | 26.06 | 32.30 | 10.60 | .... | 5.8 |
| | 3 | 26-31.5 | 5.5 | 0.03 | 0.13 | 1.13 | 2.16 | 3.90 | 10.66 | 26.13 | 36.90 | 18.86 | .... | 4.4 |
| 2a | 3 | 9-11.5 | 2.5 | 8.20 | 4.06 | 34.80 | 49.36 | 2.86 | 0.53 | ..... | ..... | ..... | .... | 3.2 |
| | 4 | 11.5-16 | 4.5 | 0.26 | 0.20 | 0.73 | 0.56 | 0.43 | 1.03 | 4.30 | 27.70 | 56.40 | 8.30 | 22.7 |
| 3 | 5 | 24-25 | 1 | 1.73 | 0.40 | 16.47 | 55.31 | 19.56 | 5.23 | 1.43 | ..... | ..... | .... | 2.1 |
| | 6 | 25-30 | 5 | 1.43 | 0.20 | 20.06 | 64.40 | 12.26 | 1.50 | 0.36 | ..... | ..... | .... | 1.7 |
| 4 | 6 | 20.5-25 | 4.5 | 83.56 | 2.20 | 8.70 | 3.43 | 1.93 | 0.43 | ..... | ..... | ..... | .... | .... |
| | 7 | 27-32 | 5 | 38.86 | 6.46 | 26.03 | 17.00 | 9.43 | 2.16 | 0.10 | ..... | ..... | .... | .... |
| 6 | 11 | 39-45.5 | 6.5 | 0.36 | 0.06 | 0.54 | 2.70 | 7.76 | 51.70 | 32.40 | 4.46 | ..... | .... | 1.9 |
| 7 | 1 | 23-24 | 1 | 3.16 | 4.13 | 47.76 | 33.46 | 0.33 | 0.06 | ..... | ..... | ..... | .... | .... |
| | 2 | 24-25 | 1 | 7.33 | 3.80 | 64.06 | 23.36 | 1.13 | 0.30 | ..... | ..... | ..... | .... | 1.8 |
| | 3 | 25-29 | 4 | 5.60 | 1.56 | 46.90 | 41.26 | 2.93 | 1.26 | 0.16 | ..... | ..... | .... | 1.7 |
| | 4 | 20-32 | 3 | 4.40 | 1.13 | 21.16 | 61.66 | 9.16 | 2.40 | 0.40 | ..... | ..... | .... | 1.9 |
| | 5 | 32-33 | 1 | 3.16 | 0.34 | 11.36 | 44.66 | 24.16 | 14.33 | 1.74 | ..... | ..... | .... | 2.3 |
| | 6 | 33-35 | 2 | 4.83 | 2.73 | 24.50 | 45.83 | 7.40 | 11.70 | 2.93 | ..... | ..... | .... | 2.1 |
| | 7 | 35-40 | 5 | 3.00 | 0.43 | 8.46 | 56.16 | 22.33 | 8.23 | 1.33 | ..... | ..... | .... | 1.9 |
| | 8 | 40-41 | 1 | 2.30 | 0.13 | 3.53 | 38.76 | 45.20 | 9.50 | 0.76 | ..... | ..... | .... | 2.0 |
| 8 | 1 | 20-21 | 1 | 6.20 | 0.56 | 8.13 | 34.53 | 29.56 | 16.43 | 4.56 | ..... | ..... | .... | 3.6 |
| | 2 | 21-32.5 | 11.5 | 1.13 | 0.20 | 4.36 | 40.13 | 33.13 | 16.03 | 4.33 | 0.66 | ..... | .... | 2.1 |
| | 3 | 32.5-36 | 3.5 | 1.20 | 0.50 | 5.0 | 44.33 | 39.56 | 8.80 | 0.73 | ..... | ..... | .... | 18.8 |
| | 4 | 36-38 | 2.0 | 1.33 | 0.14 | 1.36 | 13.40 | 32.73 | 34.66 | 14.50 | 1.86 | ..... | .... | 14.8 |
| 9 | 1 | 19-21 | 2 | 8.76 | 10.13 | 45.03 | 15.40 | 3.76 | 0.80 | 0.20 | ..... | ..... | .... | ... |
| | 2 | 21-23 | 2 | 5.36 | 0.70 | 14.80 | 38.10 | 24.43 | 13.70 | 2.80 | ..... | ..... | .... | 2.7 |
| | 3 | 23-29 | 6 | 1.03 | 0.10 | 8.76 | 60.16 | 28.40 | 1.46 | ..... | ...... | ..... | .... | 1.8 |
| | 4 | 29-35 | 6 | 2.43 | 1.86 | 25.23 | 57.00 | 12.86 | 0.43 | 0.16 | ..... | ..... | .... | 1.9 |
| | 5 | 35-40 | 5 | 2.00 | 1.40 | 23.53 | 62.53 | 10.10 | 0.36 | ..... | ..... | ..... | .... | 1.8 |
| | 6 | 40-42 | 2 | 1.06 | 0.36 | 6.03 | 65.80 | 25.90 | 0.76 | 0.06 | ..... | ..... | .... | 1.6 |
| 10 | 1 | 21-23 | 2 | 58.74 | 18.86 | 19.03 | 1.03 | 1.53 | 0.20 | 0.30 | ..... | 0.53 | .... | .... |
| | 2 | 23-28 | 5 | 25.80 | 8.06 | 26.40 | 28.90 | 8.30 | 1.13 | 0.13 | ..... | ..... | .... | .... |
| | 3 | 28-33 | 5 | 4.40 | 3.43 | 16.43 | 43.53 | 25.03 | 6.63 | 0.59 | 0.03 | ..... | .... | 2.9 |
| | 4 | 33-38 | 5 | 2.40 | 1.26 | 10.63 | 46.00 | 32.10 | 7.10 | 0.33 | ..... | ..... | .... | 2.6 |
| | 5 | 38-41 | 3 | 1.66 | 0.66 | 3.33 | 17.33 | 30.33 | 39.00 | 8.00 | ..... | ..... | .... | 3.6 |
| 12 | 1 | 18-21 | 3 | 45.58 | 3.90 | 37.63 | 8.13 | 1.84 | 1.23 | 0.63 | 1.16 | ..... | .... | .... |
| | 2 | 21-25 | 4 | 5.13 | 3.06 | 32.06 | 43.73 | 12.70 | 2.70 | 0.30 | 0.06 | ..... | .... | 2.2 |
| | 3 | 25-30 | 5 | 4.86 | 2.20 | 23.26 | 43.93 | 20.70 | 4.66 | 0.10 | ..... | ..... | .... | 2.3 |
| | 4 | 30-35 | 5 | 4.16 | 1.70 | 15.16 | 45.76 | 26.56 | 5.73 | 0.33 | ..... | ..... | .... | 2.6 |
| | 5 | 35-36.5 | 1.5 | 5.26 | 2.06 | 18.23 | 40.33 | 23.63 | 9.36 | 0.86 | ..... | ..... | .... | 2.8 |

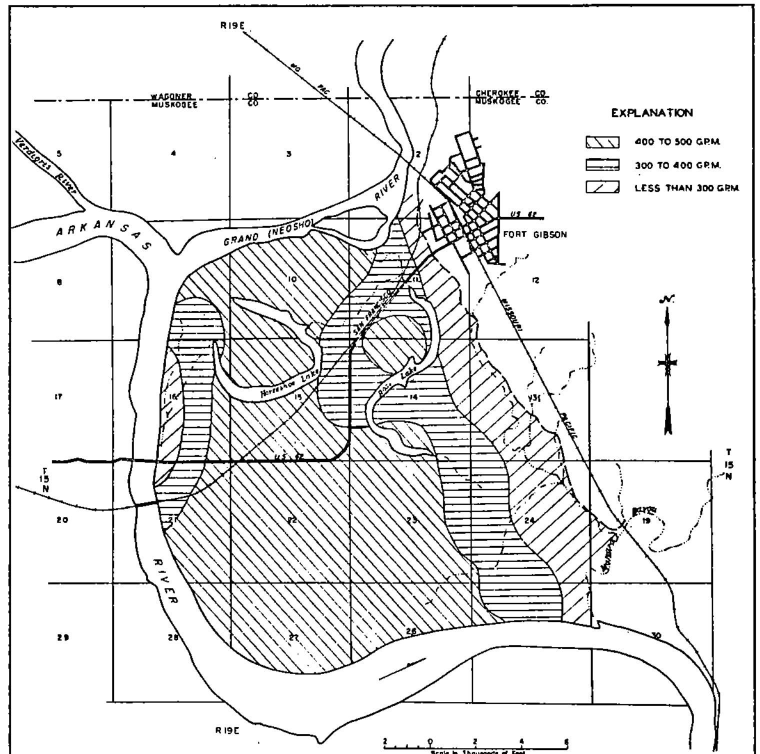
Table 2. - Sieve Analyses of Silt, Sand, and Gravel from Test Holes, Fort Gibson, Oklahoma (Cont'd)

| Test-hole number | Sample number | Depth of sample (feet) | Thickness (feet) | On pan -0.0029 | Percent of sample, by weight, retained on screen with openings shown (inches) .0029 | .0058 | .0116 | .0232 | .065 | .093 | .185 | .375 | .75 | Coefficient of uniformity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 1 | 8-15 | 7 | 13.10 | 30.76 | 5.16 | 5.26 | 2.60 | 1.97 | 2.66 | 1.86 | ..... | .... | .... |
| | 2 | 15-21 | 6 | 3.46 | 2.50 | 30.46 | 49.93 | 8.26 | 2.86 | 1.20 | 1.30 | ..... | .... | 1.9 |
| | 3 | 21-28 | 7 | 4.50 | 2.53 | 5.70 | 24.16 | 27.33 | 24.06 | 7.33 | 3.96 | ..... | .... | 5.0 |
| | 4 | 28-33 | 5 | 0.56 | 0.46 | 2.53 | 17.36 | 23.96 | 22.33 | 19.56 | 13.10 | ..... | .... | 4.5 |
| | 5 | 33-35½ | 2.5 | 1.06 | 0.46 | 3.16 | 20.06 | 25.33 | 25.43 | 16.03 | 8.43 | ..... | .... | 4.3 |
| | 6 | 35-35.5 | 0.5 | 0.96 | 0.30 | 3.23 | 26.56 | 29.46 | 17.60 | 12.70 | 8.93 | ..... | .... | 3.3 |
| 14 | 2 | 21-31 | 10 | 16.36 | 67.76 | 5.83 | 1.40 | 0.73 | 0.24 | ..... | ..... | ..... | .... | 2.2 |
| | 3 | 31-33 | 2 | 7.46 | 71.43 | 14.13 | 0.57 | 0.16 | ..... | ..... | ..... | ..... | .... | 2.0 |
| 15 | 1 | 12-17 | 5 | 5.20 | 23.33 | 68.83 | 0.36 | 0.66 | 1.30 | 0.30 | ..... | ..... | .... | 2.0 |
| | 2 | 17-21 | 4 | 2.26 | 18.63 | 76.65 | 0.86 | 0.63 | 0.90 | 0.13 | ..... | ..... | .... | 1.7 |
| | 3 | 21-28 | 7 | 1.43 | 18.10 | 78.03 | 2.00 | 0.13 | 0.30 | ..... | ..... | ..... | .... | 1.7 |
| 16 | 1 | 18-21 | 3 | 22.16 | 26.73 | 41.90 | 6.96 | 1.60 | 0.36 | 0.44 | ..... | ..... | .... | ... |
| | 2 | 21-25 | 4 | 1.33 | 0.26 | 62.07 | 27.63 | 3.13 | 2.23 | 0.53 | ..... | ..... | .... | 1.4 |
| | 3 | 25-30 | 5 | 1.23 | 1.10 | 69.26 | 25.10 | 1.76 | 1.33 | 0.20 | ..... | ..... | .... | 1.4 |
| | 4 | 30-31.5 | 1.5 | 1.06 | 3.24 | 62.76 | 28.70 | 2.54 | 1.43 | 0.40 | ..... | ..... | .... | 1.6 |
| 17 | 1 | 5-10 | 5 | 62.76 | 23.03 | 5.06 | 3.56 | 1.30 | 1.80 | 2.46 | ..... | ..... | .... | ... |
| | 2 | 10-21 | 11 | 65.57 | 17.30 | 17.54 | 3.73 | 0.43 | 0.46 | 0.90 | ..... | ..... | .... | ... |
| | 3 | 21-25.5 | 4.5 | 47.69 | 12.90 | 24.76 | 12.03 | 1.56 | 0.40 | 0.61 | ..... | ..... | .... | ... |
| | 4 | 25.5-33 | 4.5 | 48.89 | 13.23 | 19.00 | 13.13 | 2.76 | 0.96 | 2.0 | ..... | ..... | .... | ... |
| 19 | 1 | 3-21 | 18 | 20.06 | 53.06 | 24.04 | 2.33 | 0.36 | 0.10 | 0.03 | ..... | ..... | .... | ... |
| | 2 | 21-31 | 10 | 6.16 | 18.86 | 25.10 | 36.83 | 10.0 | 1.46 | 0.13 | ..... | ..... | .... | 4.3 |
| 20 | 2 | 21-29 | 8 | 19.36 | 37.60 | 24.20 | 15.20 | 3.34 | 0.13 | 0.03 | ..... | ..... | .... | ... |
| 21 | 1 | 22.5-32.5 | 10 | 19.08 | 8.14 | 41.81 | 22.59 | 5.48 | 1.14 | 0.70 | 0.47 | ..... | .... | ... |
| | 2 | 32.5-34.5 | 2 | 26.16 | 4.70 | 23.83 | 20.33 | 9.36 | 4.40 | 5.60 | 4.63 | 0.40 | .... | ... |
| | 3 | 34-38 | 4 | 0.90 | 0.23 | 1.20 | 9.43 | 26.50 | 26.36 | 19.40 | 14.46 | 0.33 | .... | 3.7 |
| | 4 | 38-41 | 3 | 0.76 | 0.33 | 1.10 | 8.60 | 25.86 | 26.06 | 19.86 | 16.30 | 0.90 | .... | 3.8 |
| 22 | 2 | 30-33 | 3 | 28.05 | 14.20 | 30.15 | 24.70 | 2.65 | 0.40 | 0.05 | ..... | ..... | .... | ... |
| | 3 | 33-38 | 5 | 3.60 | 1.06 | 1.53 | 5.36 | 21.10 | 30.53 | 19.23 | 12.90 | 4.26 | .... | 4.2 |
| | 4 | 38-41 | 3 | 0.96 | 0.30 | 0.33 | 1.80 | 11.03 | 26.40 | 24.96 | 20.96 | 13.26 | .... | 3.9 |
| | 5 | 41-46.5 | 5.5 | 1.10 | 0.30 | 0.56 | 7.20 | 34.50 | 37.96 | 16.33 | 2.26 | ..... | .... | 2.6 |
| 23 | 1 | 27-29.5 | 2.5 | 3.25 | 5.50 | 3.80 | 15.70 | 13.75 | 20.70 | 18.75 | 3.45 | ..... | .... | ... |
| 24 | 1 | 10-13 | 3 | 32.12 | 1.66 | 6.06 | 8.83 | 7.50 | 11.53 | 15.13 | 11.86 | 5.43 | .... | ... |
| 25 | 1 | 8-12 | 4 | 21.76 | 2.03 | 12.53 | 31.63 | 25.80 | 5.53 | 0.03 | ..... | ..... | .... | ... |
| 28 | 1 | 12-18 | 6 | 26.20 | 43.46 | 28.46 | 0.93 | 0.26 | 0.06 | .... | 0.60 | ..... | .... | ... |
| | 2 | 18-21 | 3 | 22.70 | 36.23 | 30.26 | 4.06 | 2.80 | 0.93 | 0.46 | 1.00 | 1.26 | .... | ... |
| | 3 | 21-31 | 10 | 7.03 | 8.90 | 16.36 | 39.16 | 19.60 | 6.66 | 1.40 | 0.80 | ..... | .... | 5.4 |
| | 4 | 31-38.5 | 7.5 | 5.37 | 6.26 | 14.06 | 41.03 | 25.13 | 6.20 | 1.03 | 0.40 | ..... | .... | 3.7 |

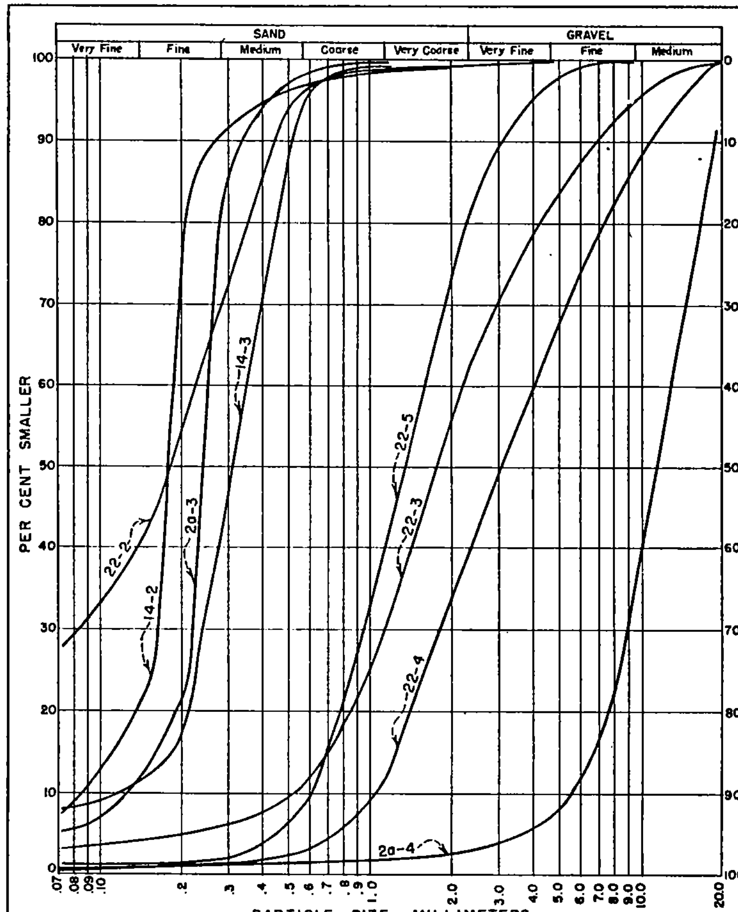
Table 2. - Sieve Analyses of Silt, Sand, and Gravel from Test Holes, Fort Gibson, Oklahoma (Cont'd)

| Test-hole number | Sample number | Depth of sample (feet) | Thickness (feet) | On pan -0.0029 | Percent of sample, by weight, retained on screen with openings shown (inches) .0029 | .0058 | .0116 | .0232 | .065 | .093 | .185 | .375 | .75 | Coefficient of uniformity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | 1 | 0-4 | 4 | 24.96 | 12.60 | 25.13 | 27.06 | 9.12 | 0.70 | ..... | ..... | ..... | .... | ... |
| | 2 | 4-21 | 17 | 41.23 | 14.16 | 16.86 | 18.36 | 7.50 | 1.56 | 0.33 | ..... | ..... | .... | ... |
| | 3 | 21-25 | 4 | 4.00 | 1.30 | 6.46 | 38.46 | 29.66 | 12.33 | 5.40 | 2.03 | ..... | .... | 2.5 |
| | 4 | 25-30 | 5 | 2.83 | 0.53 | 6.56 | 51.33 | 25.53 | 7.20 | 3.16 | 2.60 | ..... | .... | 1.9 |
| | 5 | 30-35 | 5 | 2.20 | 0.60 | 6.50 | 40.96 | 32.03 | 11.16 | 4.43 | 2.50 | ..... | .... | 2.2 |
| | 6 | 35-40 | 5 | 1.26 | 0.50 | 4.66 | 45.50 | 33.70 | 7.53 | 2.76 | 3.36 | 0.70 | .... | 2.1 |
| | 7 | 40-41 | 1 | 1.23 | 0.70 | 2.86 | 22.30 | 21.21 | 19.56 | 19.56 | 10.50 | 2.06 | .... | 4.1 |
| | 8 | 41-46.5 | 5.5 | 0.40 | 0.16 | 3.30 | 20.93 | 27.56 | 24.93 | 13.63 | 9.06 | ..... | .... | 3.2 |
| | 9 | 46.5-47 | 0.5 | 1.66 | 0.70 | 2.93 | 12.70 | 13.33 | 14.93 | 15.40 | 29.06 | 9.26 | .... | 10.7 |
| 30 | 1 | 10-15 | 5 | 80.22 | 14.83 | 2.11 | 1.20 | 0.66 | 0.40 | 0.10 | 0.16 | ..... | .... | ... |
| | 2 | 31-38 | 7 | 2.43 | 1.90 | 36.90 | 46.53 | 10.73 | 0.93 | 0.06 | ..... | ..... | .... | 2.0 |
| | 3 | 38-41 | 3 | 1.93 | 0.60 | 8.83 | 25.53 | 23.50 | 21.40 | 14.00 | 3.76 | ..... | .... | 4.0 |
| | 4 | 41-44 | 3 | 1.50 | 0.66 | 2.96 | 18.66 | 25.43 | 27.50 | 19.33 | 3.93 | ..... | .... | 4.2 |
| 31 | 1 | 7-19 | 12 | 59.61 | 35.92 | 4.89 | 0.27 | 0.16 | 0.05 | ..... | ..... | ..... | .... | ... |
| | 2 | 19-21 | 2 | 89.42 | 6.46 | 2.13 | 1.06 | 0.73 | 0.13 | 0.06 | ..... | ..... | .... | ... |
| | 3 | 25-29.5 | 4.5 | 3.70 | 1.20 | 6.70 | 35.80 | 19.03 | 13.80 | 11.80 | 7.06 | 1.23 | .... | 3.0 |
| | 4 | 29.5-33.5 | 4 | 3.43 | 0.90 | 5.83 | 24.63 | 24.73 | 17.90 | 11.07 | 9.10 | 2.93 | .... | 4.5 |
| | 5 | 33.5-36 | 2.5 | 4.00 | 1.20 | 4.06 | 24.63 | 31.40 | 20.43 | 8.06 | 3.16 | 3.23 | .... | 3.6 |
| | 6 | 36-41 | 5 | 5.10 | 10.73 | 21.53 | 19.40 | 25.16 | 13.86 | 3.03 | 1.30 | ..... | .... | 6.0 |
| | 7 | 41-43.5 | 2.5 | 10.25 | 7.05 | 14.50 | 44.55 | 19.60 | 3.25 | 0.60 | ..... | ..... | .... | 6.5 |
| 32 | 1 | 14-21 | 7 | 83.79 | 11.66 | 2.00 | 1.40 | 0.86 | 0.40 | ..... | ..... | ..... | .... | ... |
| | 2 | 21-35.5 | 14.5 | 36.16 | 11.13 | 13.83 | 30.16 | 6.83 | 1.36 | ...... | ..... | ..... | .... | ... |
| 33 | 1 | 10-18 | 8 | 25.87 | 43.14 | 20.27 | 5.68 | 1.89 | 2.25 | ..... | ..... | ..... | .... | ... |
| | 2 | 18-21 | 3 | 16.40 | 30.41 | 32.80 | 16.40 | 1.50 | 1.33 | 1.16 | ..... | ..... | .... | ... |
| | 3 | 21-32.5 | 11.5 | 2.96 | 6.13 | 33.36 | 54.93 | 2.60 | 0.16 | ..... | ..... | ..... | .... | ... |
| | 4 | 32.5-37.5 | 5 | 8.20 | 16.46 | 31.06 | 41.66 | 2.40 | 0.13 | 0.06 | ..... | ..... | .... | ... |
| 34 | 2 | 27-33 | 6 | 28.49 | 0.86 | 9.90 | 22.66 | 13.76 | 10.16 | 9.56 | 4.36 | ..... | .... | ... |
| | 3 | 33-40 | 7 | 5.16 | 4.23 | 7.16 | 6.86 | 12.00 | 15.10 | 25.80 | 23.93 | ..... | .... | ... |
| 35 | 1 | 31.5-34.5 | 3 | 11.16 | 0.33 | 1.40 | 10.66 | 27.40 | 23.43 | 16.72 | 8.86 | ..... | .... | 18.1 |
| 36 | 1 | 8-21 | 13 | 34.11 | 29.34 | 19.30 | 4.34 | 6.92 | 4.61 | 0.26 | ..... | ..... | .... | ... |
| | 2 | 21-31.5 | 10.5 | 22.90 | 38.18 | 32.00 | 3.72 | 2.00 | 1.09 | 0.09 | ..... | ..... | .... | ... |
| | 3 | 31.5-41 | 9.5 | 1.90 | 0.96 | 2.86 | 31.16 | 24.03 | 17.63 | 14.60 | 6.73 | ..... | .... | 3.1 |
| | 4 | 41-44 | 3 | 1.46 | 1.00 | 4.10 | 23.40 | 32.73 | 26.53 | 9.06 | 1.70 | ..... | .... | 3.1 |
| 37 | 1 | 8-18 | 10 | 5.10 | 2.53 | 26.53 | 46.46 | 7.76 | 5.23 | 4.53 | 1.50 | ..... | .... | 2.4 |
| | 2 | 18-21 | 3 | 9.23 | 1.26 | 10.53 | 18.70 | 21.10 | 13.03 | 12.70 | 13.33 | ..... | .... | 10.4 |
| | 3 | 21-24 | 3 | 1.76 | 1.23 | 10.30 | 28.16 | 44.80 | 12.50 | 0.76 | 0.20 | ..... | .... | 3.2 |
| | 4 | 24-25 | 1 | 1.60 | 1.53 | 14.50 | 22.46 | 23.06 | 18.80 | 16.56 | 1.46 | ..... | .... | 4.6 |

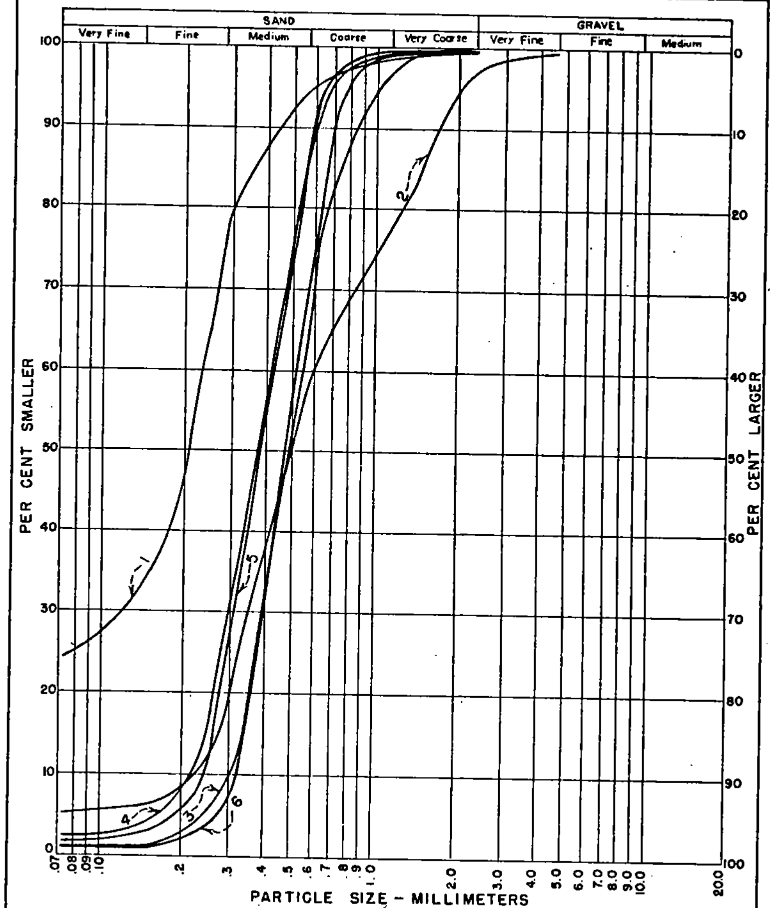
Note - Underlined figures represent dominant portion of sample



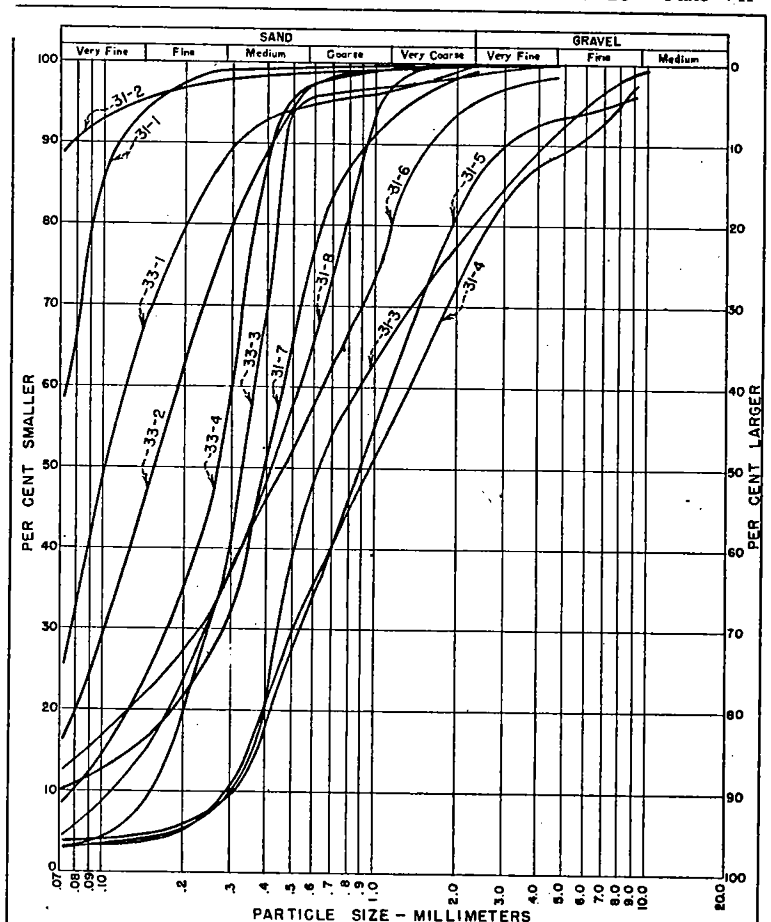

PROBABLE GROUND-WATER YIELDS, IN GALLONS PER MINUTE, FORT GIBSON AREA, OKLAHOMA




CUMULATIVE PERCENTAGE CURVES ILLUSTRATING GRAIN SIZES IN SAMPLES 3 AND 4, TEST HOLE 2a; SAMPLES 2 AND 3, TEST HOLE 14; AND SAMPLES 2-5, TEST HOLE 22




CUMULATIVE PERCENTAGE CURVES ILLUSTRATING
GRAIN SIZES IN SAMPLES 1-6 FROM TEST HOLE 9




CUMULATIVE PERCENTAGE CURVES ILLUSTRATING GRAIN SIZES IN SAMPLES 1-8, TEST HOLE 31, AND SAMPLES 1-4, TEST HOLE 33

In the test holes that were drilled to the bedrock or were probed with reasonable certainty of reaching the bedrock, the alluvium ranges from 17.5 to 47 feet in thickness, and averages 37.6 feet (table 1.) In most of the test holes the material immediately below the soil is clay or sandy clay, underlain by fine to coarse sand grading downward into gravel. An exception to this simple arrangement was found in test holes 30 and 31 (eastern part of sec. 22), where a lens of clay occurs between 7 and 19 feet below the surface, so that two layers of clay and two of sand and gravel are distinguishable. Another arrangement was found in test hole 29, near the S ¼ cor. sec. 16, where silt and fine sand grade down into gravel, the top clay layer being absent. The thickness of the clay in the test holes ranges from 0 to 39 feet, and averages 16.5 feet. The thickness of sand and gravel ranges from 3.5 to 47 feet, and averages 20.6 feet.

The coarsest gravels were found in a strip about 0.5 mile wide along the south side of the Grand (Neosho) River. Cobbles as much as 5 inches across were recovered, and great difficulty was experienced in completing the test holes. Larger cobbles may have been pushed aside as the casing was sunk, but of this there is no certainty because they could not be removed through the 5-inch casing. The construction of wells in these very coarse gravels may prove difficult and perhaps expensive, but if they can be completed properly they should yield water very freely.

The finest sands were found in a band a little over 0.5 mile wide along the eastern side of the area, adjacent to the bluff rising to the higher lands on the east. Some are so very fine grained that they can be kept out of wells only by special and relatively costly methods of construction, but in general moderately good yields may be obtained from properly constructed wells in them.

Throughout the central and southern parts of the Fort Gibson flood plain the water-bearing materials are medium to coarse sand, and fine to medium gravel. It is not clear just how well the sand and gravel are separated into layers, because the rotary drill penetrated them rapidly and seems to have pushed aside many pebbles instead of bringing them to the surface. The indications were that the gravel and sand are mixed, but it is probable that some layers of clean gravel, relatively free of sand, are present. The drilling problems in this area are not very difficult, but wells must be constructed with appropriate regard for the character of the aquifer if maximum yields are to be obtained.

Locally the sand and gravel may be so mixed that they possess only a relatively low permeability, or they may contain silt or clay that reduces the permeability. Test hole 29 is an example of such a situation. In it, silt and very fine sand were found beginning at the surface and grading down into medium-grained sand. Coarse sand and fine gravel were encountered at about 23 feet and continued to the bedrock at 47 feet, with much fine gravel—pea size and somewhat larger—coming from depths of 40 to 45 feet. With 29 feet of saturated material, most of it gravelly, it seemed that the hole should yield water freely, but the attempt to obtain a sample of water failed utterly. At the end of an hour of jetting practically the only water coming from the hole was the water put into it from the driller's tank truck, whereas the other holes sampled by this method began to produce with a steady pulse after a few minutes and furnished relatively clear water after about 30 minutes. Two facts from the record of the drilling pointed to the explanation: (1) No loss of drilling fluid occurred, although the drilling mud consisted only of the silts and sands washed from the hole, and (2) the hole showed little tendency to cave in. Furthermore, the water rose very slowly after the bit was pulled from the hole, instead of coming almost at once to the static level. These circumstances suggest that silt and clay were mixed with the sand and gravel and were washed from the sand and gravel, passing unnoticed into the slush pit and leaving the false impression that clean sand and gravel were present.

A diagrammatic cross section of the Fort Gibson area, based on the test holes, is shown in plate III, and the probable yields in different parts of the area are shown on plate IV.

## Laboratory tests

Sands and gravels are more permeable if they are coarse, well sorted as to size, and well rounded than if they are fine, poorly sorted, and angular. Their coarseness has a direct bearing on the



selection of the screens used in the construction of wells. If the particles are nearly uniform, less pumping will be required to remove the finer sizes during the development of wells, provided, of course, that the well screens are appropriate. The coarseness and uniformity of the particles making up sand and gravel may be measured by means of sieve analyses, but their angularity must be studied by other means.

Sieve analyses of 112 samples of silt, sand, and fine gravel from the test holes drilled in the alluvium of the Arkansas River flood plain near Fort Gibson are summarized in Table 2, which shows the size, as percentage by weight, of the fractions retained on each of nine sieves and on the bottom pan. The sieving was done with a mechanical shaker. Samples containing a large percentage of silt and clay proved difficult to disaggregate by rolling and crushing, and they therefore were washed through a 200-mesh sieve. After drying, the portion retained was sieved in the usual way, the resulting fractions being converted into percentages of the initial sample. Even after washing, a small fraction generally passed the 200-mesh sieve, and this was added to the portion washed through and discarded, thus making the total reported as "retained on the pan." Greater accuracy would have been achieved if the washed fraction had been dried and weighed, but the additional time required was hardly justified for highly disturbed samples collected from rotary-drilled holes.

The fraction retained in the bottom pan included the finer part—approximately the finer 20 percent—of the sizes described as "very fine sand," plus all the silt and clay. The relation of the grade sizes represented by the sieves to the descriptive terms "sand," "gravel," etc., and to the screens used in wells is indicated in Table 3.

Plates V, VI and VII show representative cumulative-percentage curves based on the sieve analyses, among them curves for test holes 31 and 33, where pumping tests 1, 2, and 2a were made, and test hole 9, which is nearest the site of pumping test 3. For any grade size, the percentage indicated by the curve is the percentage that is finer. For the grade sizes represented by the sieves actually used in the testing, this is the percentage that passed through the sieve. The farther the curve is to the right on the page, the coarser the particles in the sample are. For example, sample 4 from test hole 2a is much coarser than sample 3 from the same hole (plate V). The curves for many of the test holes progress from left to right across the page with increasing depth, indicating the coarsening of the materials downward. Thus the shallowest sample for a test hole—usually sample 1, 2, or 3—is farthest to the left, and the curves for the succeeding samples appear farther to the right and very nearly in numerical order (test hole 22, plate V).

The uniformity, or degree of sorting, of the materials is indicated by the steepness of the percentage curves. A steep curve, such as those for samples 2 and 3 from test hole 14, indicates a high degree of uniformity; a less steep curve, such as those for test hole 22, indicates lower uniformity (plate V).

To express the degree of sorting quantitatively so that different materials may be compared, an arbitrary value known as the coefficient of uniformity is used. This is defined by Meinzer[12] as

12. Meinzer, O. E., "Outline of Ground-water Hydrology, with Definitions": *U. S. Geol. Survey Water-Supply Paper* 494, p. 46, 1923.



TABLE 3
SIEVE SIZES, DESCRIPTIVE TERMS, AND WATER-WELL SCREENS

| | | Well screens[1] | | | |
|---|---|---|---|---|---|
| | | Cook, Johnson, and others | | Layne and Bowler | |
| Sieve opening (in.) | Descriptive name (approx.) | Slot number | Width of opening (in.) | Width of opening (in.) | Slot number |
| .75 | Coarse gravel | | | | |
| .375 | Medium gravel | | | | |
| | | | | 0.205 | 1 |
| .185 | Fine gravel | | | | |
| | | | | .180 | 2 |
| | | | | .155 | 3 |
| | | | | .130 | 4 |
| | | 125 | 0.125 | | |
| | | | | .105 | 5 |
| | | 100 | .100 | | |
| .093 | Very fine gravel | | | | |
| | | 80 | .080 | .080 | 6 |
| .065 | Very coarse sand | | | | |
| | | 60 | .060 | | |
| | | | | .055 | 7 |
| | | 50 | .050 | | |
| | | 40 | .040 | | |
| | | 30 | .030 | .030 | 8 |
| | | 24 | .024 | | |
| .0232 | Coarse sand | | | | |
| | | 20 | .020 | | |
| | | 16 | .016 | | |
| | | 14 | .014 | | |
| | | 12 | .012 | | |
| .0116 | Medium sand | | | | |
| | | 10 | .010 | | |
| | | 8 | .008 | | |
| | | 6 | .006 | | |
| 0.0058 | Fine sand | | | | |
| 0.0029 | Very fine sand | | | | |
| —.0029 | Very fine sand, silt, and clay | | | | |

1. Summarized from Anderson, K. E., "Water Well Handbook": *Missouri Water Well Drillers Assoc.*, p. 182, 1947.

"the quotient of (1) the diameter of a grain that is just too large to pass through a sieve that allows 60 percent of the material, by weight, to pass through, divided by (2) the diameter of a grain that is just too large to pass through a sieve that allows 10 percent of the material, by weight, to pass through." He explains, further, that the coefficient "is unity for a material whose grains are all of the same size, and it increases with variety in size." In other words, a low coefficient means high uniformity and good sorting; a high coefficient means poor uniformity and poor sorting.

The cumulative percentage curves for the samples from the Fort Gibson area were inspected to determine what grade sizes are represented where the curves intersect the lines for 10 percent and 60 percent, and coefficients of uniformity were computed as indicated by Meinzer. This procedure involves a degree of approximation, because the position of the curves on the page depends partly on how much curvature the draftsman elects to use in connecting the points determined by the analyses, but in most instances there is not much latitude in the position of the curves at the selected levels. Furthermore, the errors traceable to this cause may well be compensated by other errors. The curves for samples containing more than 10 percent in silt do not extend down to the 10-percent line, and coefficients of uniformity therefore cannot be determined for such samples.

The coefficients of uniformity for 74 of the samples are shown in the last column at the right in Table 2. They range from 1.4 for two samples from test hole 16 to 22.7 for one sample from test hole 2a. The average is about 4. Although some of the samples probably tested more nearly uniform than they really are in nature because of the loss of fine particles washed away in the drilling water, others may have tested less uniform than they really are because of the inclusion of materials from several beds of different texture. The mixing of materials from different beds is an inescapable consequence of rotary drilling, and it is therefore surprising that the coefficients of uniformity are no higher. It is noteworthy that some of the fine sands from the southeastern part of the area show a higher degree of uniformity than some of the gravels that yielded water freely. Fine texture generally means less permeability, but the rather high uniformity of these sands may partly compensate for the fineness, and moderately high yields might be obtained from appropriately constructed wells in them.



## PUMPING TESTS

The amount of water a well will yield depends primarily on the hydraulic properties of the aquifer. These include the permeability, the coefficient of storage, and the extent and thickness of the aquifer. The permeability[13] is the ability of the water-bearing material to transmit water, and usually is expressed as the number of gallons of water per day that can percolate through each mile of the water-bearing bed (measured at right angles to the direction of the flow) for each foot of thickness of the bed and for each foot per mile of gradient. In dealing with a single aquifer, it often is more convenient to multiply the (field) permeability by the thickness of the aquifer to obtain the coefficient of transmissibility, which represents the ability of the aquifer as a whole to transmit water. Furthermore, pumping tests generally give the transmissibility directly. The coefficient of storage is equal to the cubic feet of water discharged from each vertical column of the aquifer with a base 1 foot square as the water level falls 1 foot.

Measurements of the permeability, the coefficient of transmissibility, and the coefficient of storage can be made by means of controlled pumping tests, and the extent and thickness of an aquifer can be determined by geologic study and test drilling.

As part of the program of investigation, three pumping tests were made in different parts of the Fort Gibson flood plain, using three 8-inch wells, each equipped with a turbine pump. For each pumping test, six wells for observation of fluctuation of water level were provided. These consisted of well points on 1¼-inch casing constructed on a line passing through the pumped well. On either side there were three such wells, the distances between them increasing outward from the pumped well. As the same distances were used on both sides, the wells constituted pairs with the corresponding members of each pair at the same distance from the pumped well. The altitude of the tops of the casings of the pumped well and the observation wells was determined by leveling so that the water-level measurements made from the casings could be referred to mean sea level.

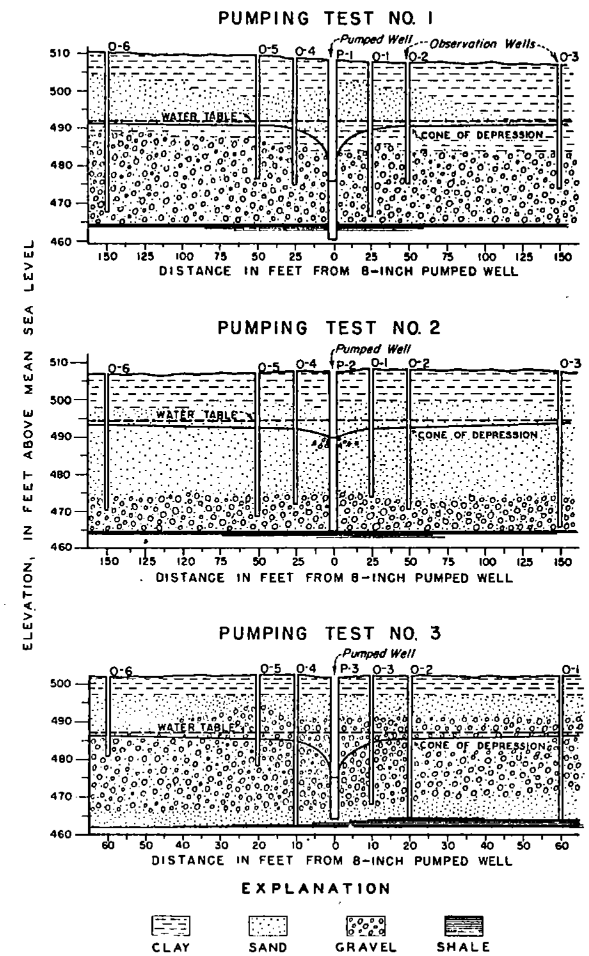
13. Field permeability, determined at the prevailing temperature of the water. The laboratory coefficient is the permeability at 60° F.

The general procedure was the same for all three pumping tests. The depths to water in the observation wells and in the pumped well were measured at intervals for several hours before the pump was started. After pumping was begun, the measurements of water level were made frequently at first, while the rate of decline was greatest, and then at longer intervals as the rate decreased. Measurements of the discharge of the pumped well were made throughout the test by means of a 2.5-inch orifice. The temperature of the water was measured and samples of the water were collected at intervals. After pumping was stopped, the recovery of the water levels in the pumped well and the observation wells was measured, at first frequently and then at longer intervals, until the water levels had returned almost to their original positions. Cross sections at the sites of the three pumping tests appear on plate VIII.

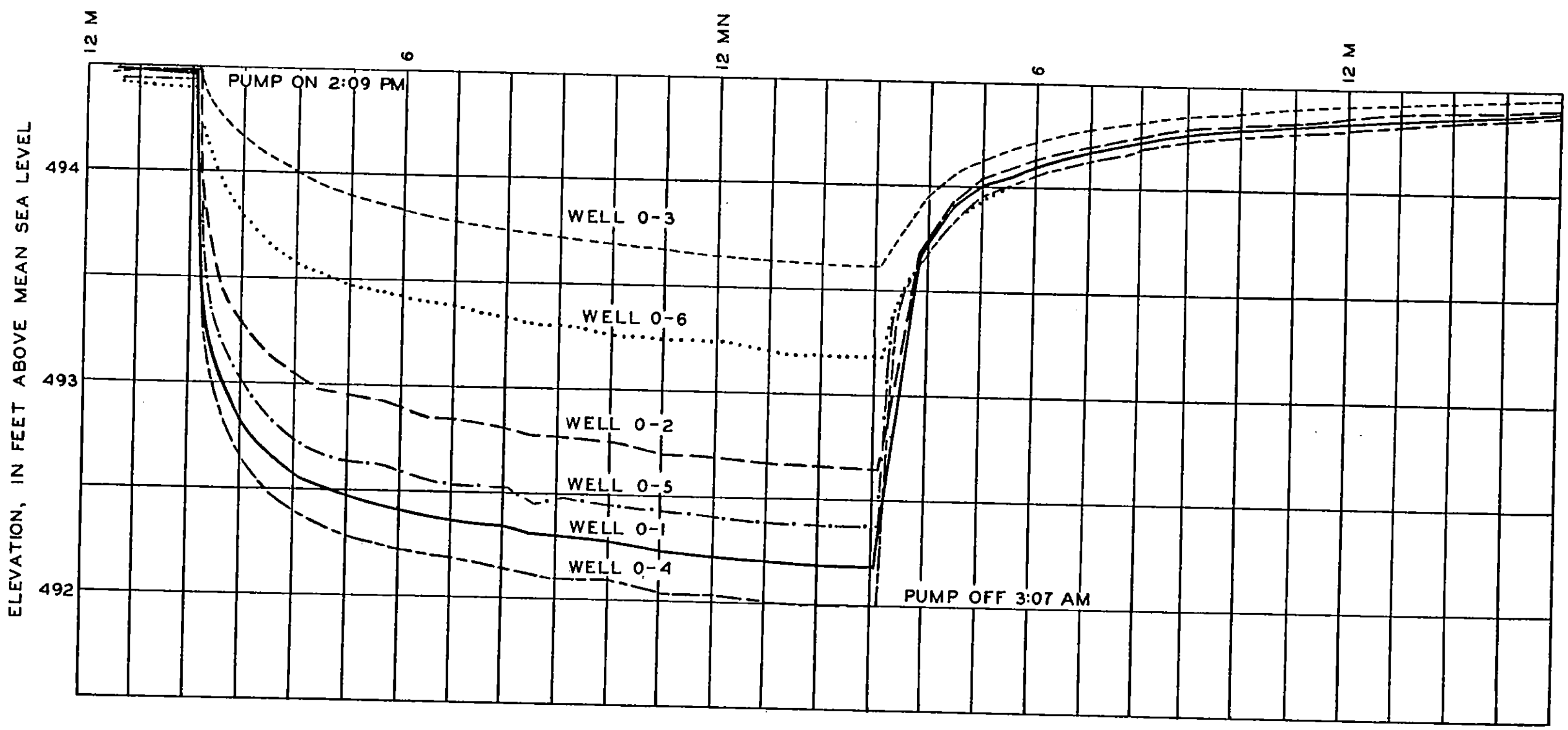
*Test 1.*—The first test well was drilled at the location of test hole 31, near the center of sec. 22. A 15-inch hole was drilled as deep as possible with rotary tools, and 8-inch casing was readily lowered in it to a depth of 39.5 feet. It was sunk an additional 2.4 feet by jetting with air, to 41.9 feet below the land surface, but it could not be sunk deeper with the available tools, although it failed to reach bedrock by 1.5 feet. The slotted section of the casing, which extended from 26.5 to 41 feet below the surface, contained 133 slots cut by blowtorch. Each slot was approximately 0.02 foot wide and 0.5 foot long, and the total area of the openings was about 1.33 square feet. Gravel was poured around the casing until no more would go down. Later developments indicated that this attempt to make a gravel-packed well was not entirely successful, probably because the water-bearing materials slumped against the casing, leaving no space for the gravel to enter. After completion the well was pumped to bring it to maximum capacity and to eliminate muddiness of the water; but this procedure had to be suspended after 2 hours and 47 minutes of intermittent pumping because arrangements for disposing of the water were inadequate.

The pumping test began at 10.21 a. m. on August 3, 1948, and ended at 5.23 a. m. on August 4, a period of 19 hours and 2 minutes. During the first 6 hours the discharge gradually increased from 162

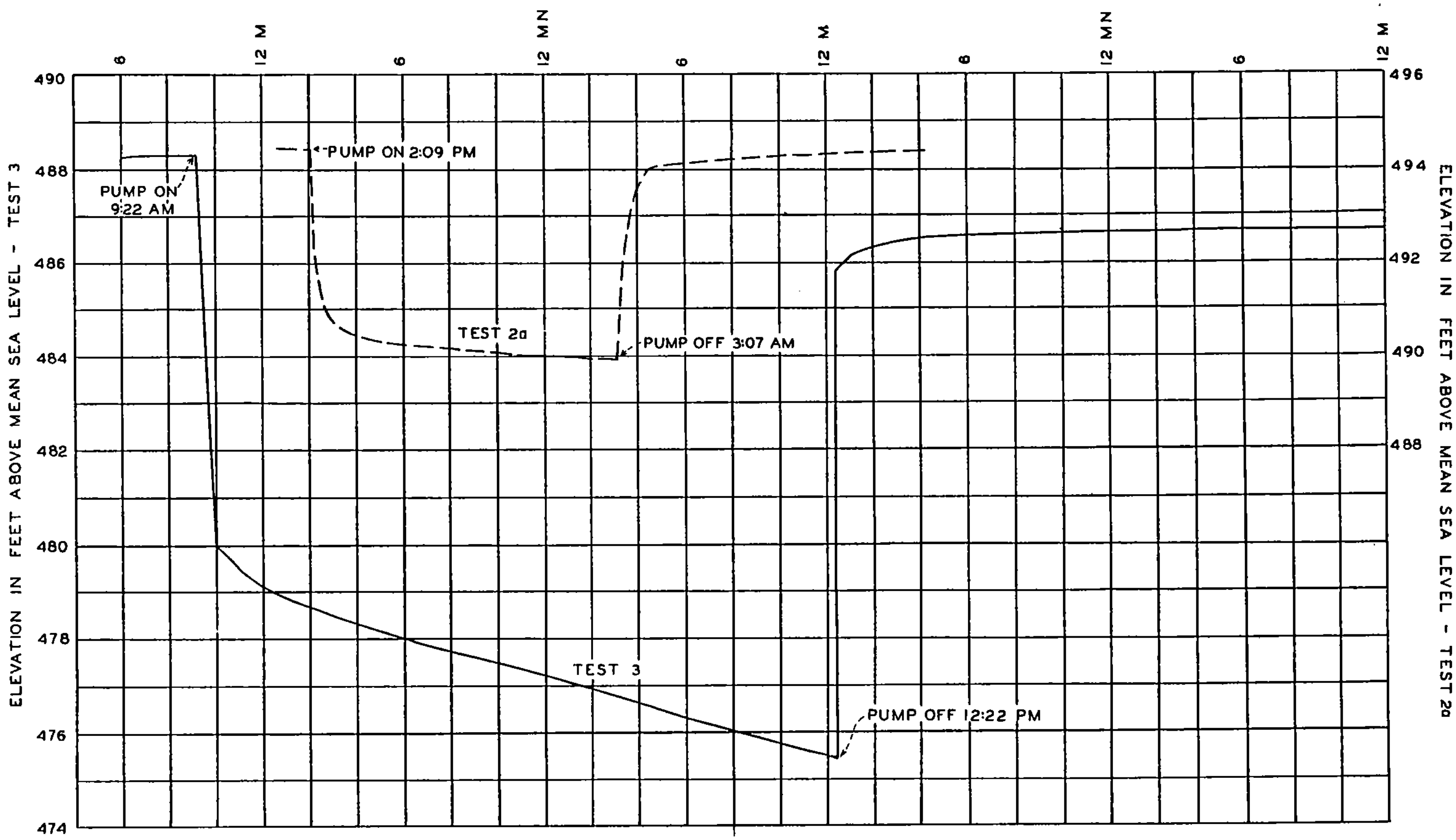




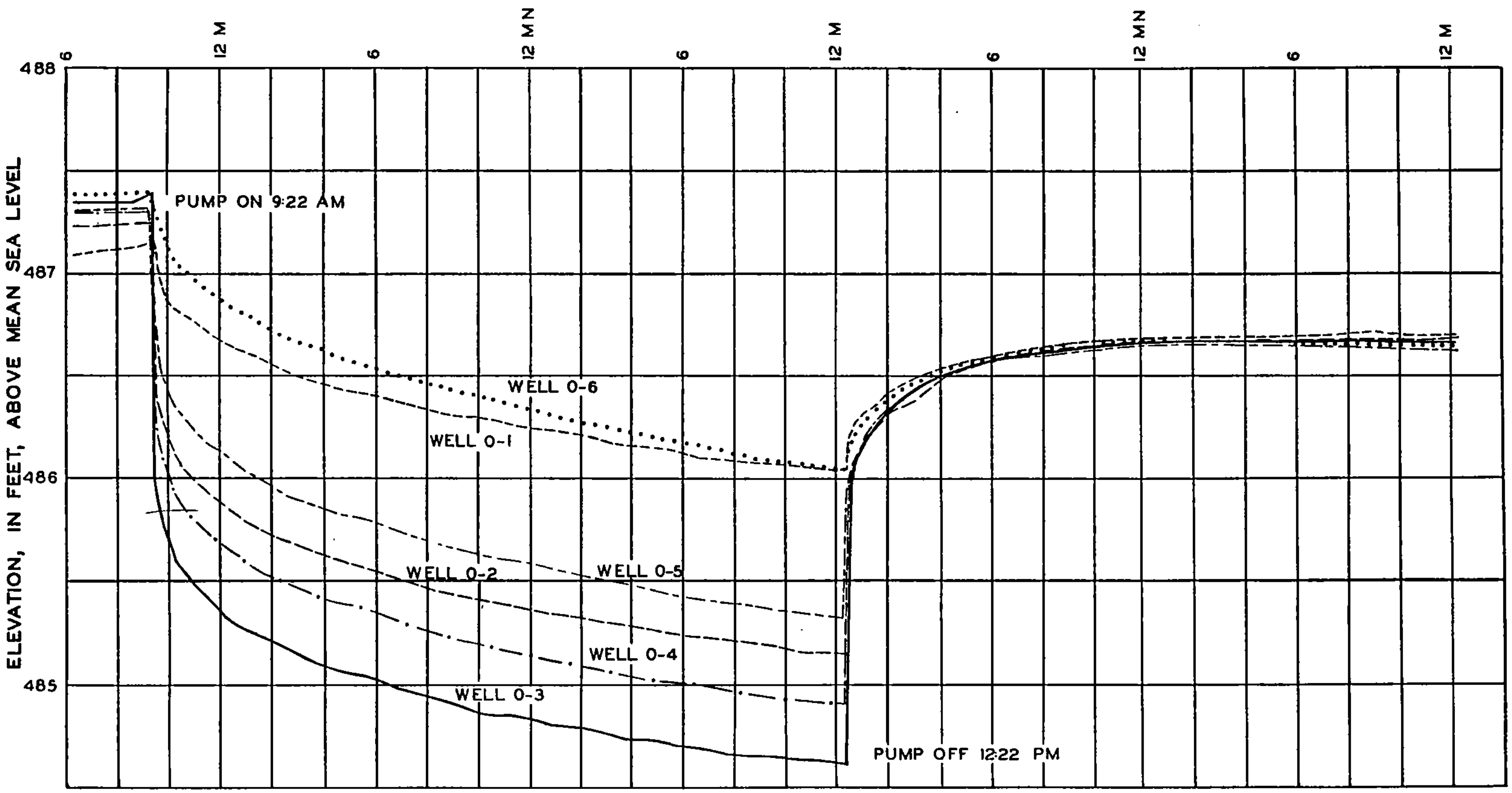

CROSS-SECTIONS AT PUMPING-TEST SITES, SHOWING WATER TABLE AND CONE OF DEPRESSION




DRAWDOWN AND RECOVERY OF WATER LEVELS IN OBSERVATION WELLS, TEST 2a, FORT GIBSON, OKLAHOMA




DRAWDOWN AND RECOVERY OF WATER LEVELS IN DISCHARGING WELLS, TESTS 2a AND 3, FORT GIBSON, OKLAHOMA




DRAWDOWN AND RECOVERY OF WATER LEVELS IN OBSERVATION WELLS, TEST 3, FORT GIBSON, OKLAHOMA to 188 gallons per minute, indicating that the previous pumping had been inadequate for full development of the well. Thereafter, the discharge began to decline, and just before the pump was stopped it was only 117 gallons per minute. Because of the large variation in the discharge, the drawdown of the water levels in the observation wells and in the pumped well was irregular. During the latter part of the test, the water levels in the four observation wells nearest the pumped well actually rose several hundredths of a foot. The specific capacity of the pumped well was only about 9 gallons per minute per foot of drawdown. When the casing was pulled from the hole after the test was over, it was found that much fine gravel had become wedged in the slots, materially reducing the total area of openings and doubtless accounting for the reduction in discharge and the low specific capacity of the well.

Because of the great variation in discharge and irregularities in the drawdown curves, this test is unreliable and is considered not truly indicative of the hydrologic characteristics of the aquifer.

*Test 2.*—The second test well was put down near test hole 33, near the center of sec. 23, T. 15 N., R. 19 E. It was constructed much like the first test well, and again the bottom of the casing was about 1.5 feet above the shale bedrock. The principal difference was that more slots were made in the casing so that the total area in openings was about 1.7 square feet, an increase of nearly 0.4 square foot. Because the location was on a curve in an abandoned railway grade, the six observation wells could not conveniently be put on a straight line through the pumped well, but the deviation was not great. The most distant observation wells were 150 feet from the pumped well and 300 feet from each other, yet they were within 10 feet of being on a straight line with the pumped well.

The pump was started at 8:30 a.m. on August 10, 1948, and produced more than 200 gallons per minute until 10:30 a.m., when the discharge declined considerably; by 1:10 p.m. it had dropped to less than 110 gallons per minute. Meanwhile, the water level in the pumped well had shown only a small drawdown, so it was evident that water was entering the well freely and the trouble was in the pump itself. The pump was pulled from the well, and the strainer below the bowls was found to be clogged with fine gravel. The holes in the strainer were enlarged, and the pump was replaced in the well.

*Test 2a.*—A second and successful attempt to test the same location was begun at 2:09 p.m. on August 11, 1948, and the well was pumped at an average rate of 212.1 gallons per minute until a severe rain storm stopped the gasoline engine used to drive the pump, at 3:07 a.m. on August 12, after 12 hours and 58 minutes. Shortly before pumping stopped, the drawdown in the pumped well was 4.49 feet. As indicated by this rather short test, therefore, the specific capacity of the well was 47.2 gallons per minute per foot of drawdown. The measurements of water levels show that the water table had been declining at similar rates in all the observation wells for several hours before pumping was stopped, and, hence, that approximate equilibrium had been reached. The recovery of the water levels in the wells was measured for 13 hours. Plates IX and X illustrate the drawdown and recovery of water levels in this test.

*Test 3.*—The third test well was near the Arkansas River, about 0.35 mile west of the SE cor. sec. 21, T. 15 N., R. 19 E., and was similar in construction to the others. The casing was set about 1.3 feet above the shale bedrock, and the six observation wells were in a straight line, paired at distances of 10, 20, and 60 feet on opposite sides of the pumped well. The pump was started at 9:22 a.m. on August 19, 1948, and produced an average of 196.5 gallons per minute for a 27-hour period. Near the end of the pumping period the drawdown was 11.93 feet in the pumped well; the specific capacity of the well, therefore, was 16.5 gallons per minute per foot of drawdown. Plates X and XI illustrate the drawdown and recovery of water levels in this test.

### Interpretation of pumping tests

The drawdown and recovery curves obtained from the pumping tests were analyzed by means of the Thiem formula and the Theis nonequilibrium formula using both the graphical method[14] and

14. Wenzel, L. K., "Methods for Determining Permeability of Water-bearing Materials": *U. S. Geol. Survey Water-Supply Paper* 887, pp. 87-89, 95, 96, 1942.



Jacob's modified method.[15] Pumping tests 2a and 3 yielded 36 determinations of the coefficient of transmissibility, which are summarized in table 4. These coefficients show some variation but, in view of the normal differences in lithologic character that are common to alluvial sediments, the results may be considered fairly consistent. The average coefficient of transmissibility for the two pumping tests is approximately 70,000 gallons per day per foot, which, from the lithologic character and thickness of the alluvium as revealed by the test drilling, appears to be close to the average for all but the extreme eastern part of the area.

TABLE 4
Summary of Results of Pumping Tests

| Test | Method of analysis | Well or wells | Field coefficient of permeability gpd/ft² | Coefficient of transmissibility gpd/ft |
|---|---|---|---|---|
| 2a | Fishel | East and west lines | 2540 | 71,145 |
| | Jacob | " " " " | 2470 | 73,767 |
| | Theis (drawdown) | " " " " | 3500 | 98,267 |
| | Theis (recovery) | " " " " | 2560 | 72,067 |
| | | Avg., test 2a | 2767 | 78,811 |
| 3 | Fishel | East and west lines | 3027 | 64,700 |
| | Jacob | " " " " | 2980 | 69,267 |
| | | Avg., test 3 | 3003 | 66,983 |
| | | Avg., tests 2-a and 3 | 2885 | 72,897 |

15. Jacob, C. E., "Notes on Determining permeability by Pumping Tests Under Water-table Conditions": *U. S. Geol. Survey mimeographed report*, June 1944.

## HYDROLOGY

### SOURCES OF RECHARGE

Recharge, which is the addition of water to the aquifer, may be derived in the Fort Gibson area from precipitation directly on the surface, from the surface runoff coming from adjacent uplands, from the underflow coming from the underlying bedrock, and from the influent seepage coming from the Grand (Neosho) and Arkansas Rivers.

#### Precipitation

According to the records of the U. S. Weather Bureau, the precipitation at Muskogee, which is about 3 miles west of the Fort Gibson area, averages 41.46 inches per year. A layer of water this deep over the 6,465 acres of the Fort Gibson flood plain would equal 22,336 acre-feet of water. As the estimated maximum requirement of water for a single irrigation season is only 3,850 acre-feet, it is evident that 17.3 percent of the precipitation would have to percolate to the zone of saturation if the precipitation were to be the sole source of recharge and if the recharge were to balance the demand exactly.

An accurate estimate of the recharge derived from precipitation would require several years of observation of water levels in many wells distributed widely over the area. This is an enterprise beyond the scope of the present investigation, but a consideration of the governing factors suggests that such recharge may well exceed 17.3 percent of the precipitation. The surface of the land is relatively flat and nearly level, it is poorly drained and is well covered with vegetation, and it has many shallow depressions. These conditions all retard and reduce the runoff and favor infiltration. On the other hand, the test holes revealed a layer of clay near the surface through which infiltration probably is slow, unless plant roots and cracks have made it permeable. During heavy rains the clay doubtless becomes saturated, and, with a rate of precipitation faster than the rate of infiltration, some water may be rejected and may run off which during a less intense rain might have become ground water.



#### Runoff from adjacent uplands

The upland draining toward the Fort Gibson flood plain is only about 4 square miles in area, but it is underlain principally by impermeable shale and sandstone, and it has relatively steep slopes; therefore the surface runoff probably is relatively high. An estimate of the runoff is not available, but for the three nearest and most nearly comparable drainage areas that have been studied the average annual runoff for the 5-year period ending September 30, 1943, was 12.6 inches.[16] At this rate, the average annual runoff from the adjacent upland onto the Fort Gibson flood plain would be about 2,700 acre-feet. Of course, only a fraction of the runoff percolates downward to become ground water, and the size of this fraction varies with the season and the previous condition of saturation of the alluvium, but even if it amounts to only 10 percent it is a significant contribution to the annual recharge.

#### Underflow from underlying bedrock

The bedrock underlying the alluvium of the Fort Gibson area consists mostly of shale with some tight sandstone. As its permeability is very low, the underflow from it into the alluvium doubtless is small and of little consequence in the general problem of recharge to the alluvium.

#### Rivers

Under natural conditions recharge may be received from the rivers during high stages as bank storage or as flood overflow. During the record-breaking flood of May 1943, all the flood plain was under water, but this flood was "the greatest known since June 1833, when a similar stage was probably reached."[17] The Fort Gibson dam, now under construction, will doubtless prevent future floods from reaching a comparable stage, and the proposed dams on the upper Arkansas River and its tributaries will, if constructed, further restrict and regulate flood flows. Recharge from the river will then be restricted to bank storage at high stages, unless recharge is induced by pumping water from wells.

16. U. S. Geol. Survey, "Oklahoma Water": *Oklahoma Planning and Resources Board*, p. 49, 1945.

17. Parker, G. L., and others, "Surface Water Supply of the United States, 1943, Pt. 7, Lower Mississippi River Basin": *U. S. Geol. Survey Water-Supply Paper* 977, p. 113, 1945.

Pumping test 3 was made near the Arkansas River in the hope of determining whether recharge could be induced by pumping but, unfortunately, the stage of the river was declining so rapidly that the effects of such recharge were largely obscured and, in this respect, the test was inconclusive.

The behavior of the water levels in the observation wells during the pumping test indicated flow to and from the river corresponding to different river stages. Before the pump was started, the water level in the observation well nearest the river was 0.26 foot higher than the level in the well farthest from the river, the distance between the two wells being 120 feet. Thus a gradient away from the river was evident, presumably being due to a rise in the river that occurred during the preceding day. During the pumping, the gradient was toward the pumped well from both sides, but near the end of the pumping the drawdown in the observation well nearest the river was 0.26 foot greater than in the well farthest from the river. This difference in drawdown could be due to a real difference in the transmissibility of the aquifer, but it could be due just as well to the decline in the stage of the river.

After pumping was stopped, the water levels in all the wells rose for 12 to 18 hours and then began to decline, and at the end of 24 hours they were 0.45 to 0.80 foot lower than before pumping was begun. The greatest net decline in water level occurred in the observation well nearest the river, and the least was in the well farthest from the river. At this time, then, the water level in the well farthest from the river was higher by 0.09 foot, and the gradient was toward the river.

A reversal of gradient occurred sometime during the 51-hour period covered by the test, probably during the early part of the pumping period. The drawdown and recovery curves derived from pumping test 3 (plate XI) show a general downward slope that is especially apparent if they are compared with the corresponding curves derived from pumping test 2a (plate IX), which was not affected by the stage of the river. The general inclination of the curves for pumping test 3 makes it clear that ground water was flowing toward the river during most of the test period.



The analyses of the water samples collected during pumping test 3 are further indication of easy underground communication between the river and the aquifer (table 5). The abrupt fluctuations in chlorides and dissolved solids suggest that, as pumping progressed, ground water from more and more remote parts of the aquifer was drawn into the well, and that the character of the ground water differed from place to place. Such local differences in the character of the ground water could well be due to the kinds of water recharged to the aquifer from the river under differing conditions during the weeks preceding the test. It is not possible, of course, to identify from the data at hand the river stage related to each irregularity in chemical character of the ground water, but the river had gone through several wide fluctuations in stage during the previous 2 months, with flood flows coming from different localities and having corresponding differences in composition.

An incident strengthening the conclusion that flow between the river and the alluvium is possible was the behavior of the water levels in test holes 1 and 1-a, which were about a foot apart and about 0.25 mile from the Grand (Neosho) River. On June 3, 1948, the water level in hole 1 was 486 feet above mean sea level. The elevation of the water surface in the river opposite the well, as estimated from the record at the gaging station about 2 miles downstream, was 480 feet, or 6 feet lower. The gradient of the water table, therefore, was toward the river.

On July 2, during a rainy period, the water level in hole 1-a was at 496 feet, or 5 feet lower than the elevation of the river, and the gradient of the water table was away from the river. By July 12 the gradient had reversed again, for the water level in hole 1-a was at 490 feet, 1 foot higher than the river. Although these comparisons cover a rainy period, the 16-foot range in the fluctuations of the water levels in holes 1 and 1-a is too large to be attributed to recharge from rainfall alone, and it must, therefore, be due in the greater part to changes in storage caused by inflow from the river to the alluvium and by discharge of water from the alluvium into the river.

TABLE 5
ANALYSES OF WATER SAMPLES FROM PUMPED WELLS

| Test well number | Date | Time | Dissolved solids (ppm) | Chloride (ppm) |
|---|---|---|---|---|
| 1 | 8- 3-48 | 10:59 a.m. | 415 | 14 |
| | | 11:46 a.m. | 415 | 18 |
| | | 2:22 p.m. | 330 | 14 |
| | | 4:25 p.m. | 336 | 14 |
| | | 5:51 p.m. | 315 | 16 |
| | | 7:28 p.m. | 305 | 14 |
| | | 11:35 p.m. | 320 | 14 |
| | 8- 4-48 | 1:50 a.m. | 280 | 14 |
| 2 | 8-10-48 | 8:35 a.m. | 175 | 11 |
| | | 8:41 a.m. | 178 | 11 |
| | | 8:46 a.m. | 176 | 11 |
| | | 9:00 a.m. | 176 | 11 |
| | | 9:15 a.m. | 176 | 11 |
| | | 9:32 a.m. | 176 | 11 |
| | | 9:47 a.m. | 173 | 11 |
| | | 10:02 a.m. | 176 | 11 |
| | | 10:30 a.m. | 175 | 11 |
| | | 11:30 a.m. | 176 | 11 |
| | | 9:20 p.m. | 176 | 11 |
| 2A | 8-11-48 | 2:21 p.m. | 176 | 11 |
| | | 3:26 p.m. | 173 | 11 |
| | | 6:25 p.m. | 173 | 11 |
| | | 11:17 p.m. | 175 | 11 |
| | 8-12-48 | 1:22 a.m. | 176 | 11 |
| 3 | 8-19-48 | 9:28 a.m. | 275 | 12 |
| | | 9:33 a.m. | 275 | 14 |
| | | 9:38 a.m. | 275 | 14 |
| | | 9:43 a.m. | 440 | 14 |
| | | 9:53 a.m. | 280 | 14 |
| | | 10:02 a.m. | 280 | 12 |
| | | 10:15 a.m. | 440 | 14 |
| | | 10:30 a.m. | 440 | 11 |
| | | 10:45 a.m. | 440 | 12 |
| | | 11:00 a.m. | 440 | 12 |
| | | 11:16 a.m. | 440 | 12 |
| | | 11:29 a.m. | 295 | 14 |
| | | 11:45 a.m. | 435 | 14 |
| | | 12:16 p.m. | 427 | 14 |
| | | 12:45 p.m. | 450 | 12 |
| | | 1:28 p.m. | 450 | 12 |
| | | 2:29 p.m. | 427 | 13 |
| | | 3:31 p.m. | 427 | 13 |
| | | 4:31 p.m. | 420 | 14 |
| | | 5:31 p.m. | 420 | 14 |
| | | 6:22 p.m. | 287 | 16 |
| | | 7:30 p.m. | 280 | 14 |
| | | 9:28 p.m. | 315 | 14 |
| | 8-20-48 | 12:34 a.m. | 300 | 14 |
| | | 3:28 a.m. | 287 | 14 |
| | | 5:30 a.m. | 285 | 14 |
| | | 7:28 a.m. | 425 | 14 |
| | | 9:28 a.m. | 435 | 14 |
| | | 11:29 a.m. | 348 | 14 |
| | | 12:17 p.m. | 425 | 14 |



## DISCHARGE

Under natural conditions the recharge to a ground-water reservoir over a protracted period is equal to the discharge from it. A measure of the discharge, therefore, is a measure of the recharge. The discharge from the alluvium of the Fort Gibson area takes place by underflow into the Arkansas and Grand Rivers, and by transpiration and evaporation. To this natural discharge should be added the water pumped from wells, but as the pumpage in the Fort Gibson area was very small at the time of the investigation it may be neglected without danger of invalidating the conclusions.

Evaporation and plant use (transpiration) probably exceeded pumpage, but means were not at hand to evaluate these forms of discharge. The major fraction of the discharge appears to have been underflow to the rivers, and a rough estimate of its magnitude was made as follows.

A water-table map was prepared on the basis of measurements of the depths to water made on August 20 and 21, 1948 in all the test holes that were still open (plate I). The direction of ground-water flow is at right angles to the water-table contours, and the rate of flow depends on the hydraulic gradient and the coefficient of transmissibility of the aquifer. The flow of ground water is expressed by Darcy's law,[18] which may be written

$$Q=TIW$$

where Q is the flow in gallons per day, T is the coefficient of transmissibility in gallons per day per foot, I is the hydraulic gradient in feet per mile, and W is the width of the aquifer in miles. The equation may be applied in the following manner, using as an example the 495-foot contour, which encloses an area of about 0.5 square mile southwest of Ross Lake. The flow (Q) across the 495-foot water-table contour is equal to 70,000 gallons per day per foot (T, the average coefficient of transmissibility as determined by the pumping tests) times 5 feet per mile (I, the average hydraulic gradient across the 495-foot contour) times 4 miles (W, the width of the aquifer, which in this case is the length of the 495-foot

18. Darcy, Henri, "Les Fontaines Publique de la Ville de Dijon" [The Water Supply of Dijon], Paris, 1856.

contour), or 1,400,000 gallons per day. Similarly, by making allowances for the differences in hydraulic gradient in different parts of the area and thinning of the aquifer in the northeastern part, it was estimated that more than 12,000,000 gallons per day was flowing from the alluvium into the Grand and Arkansas Rivers.

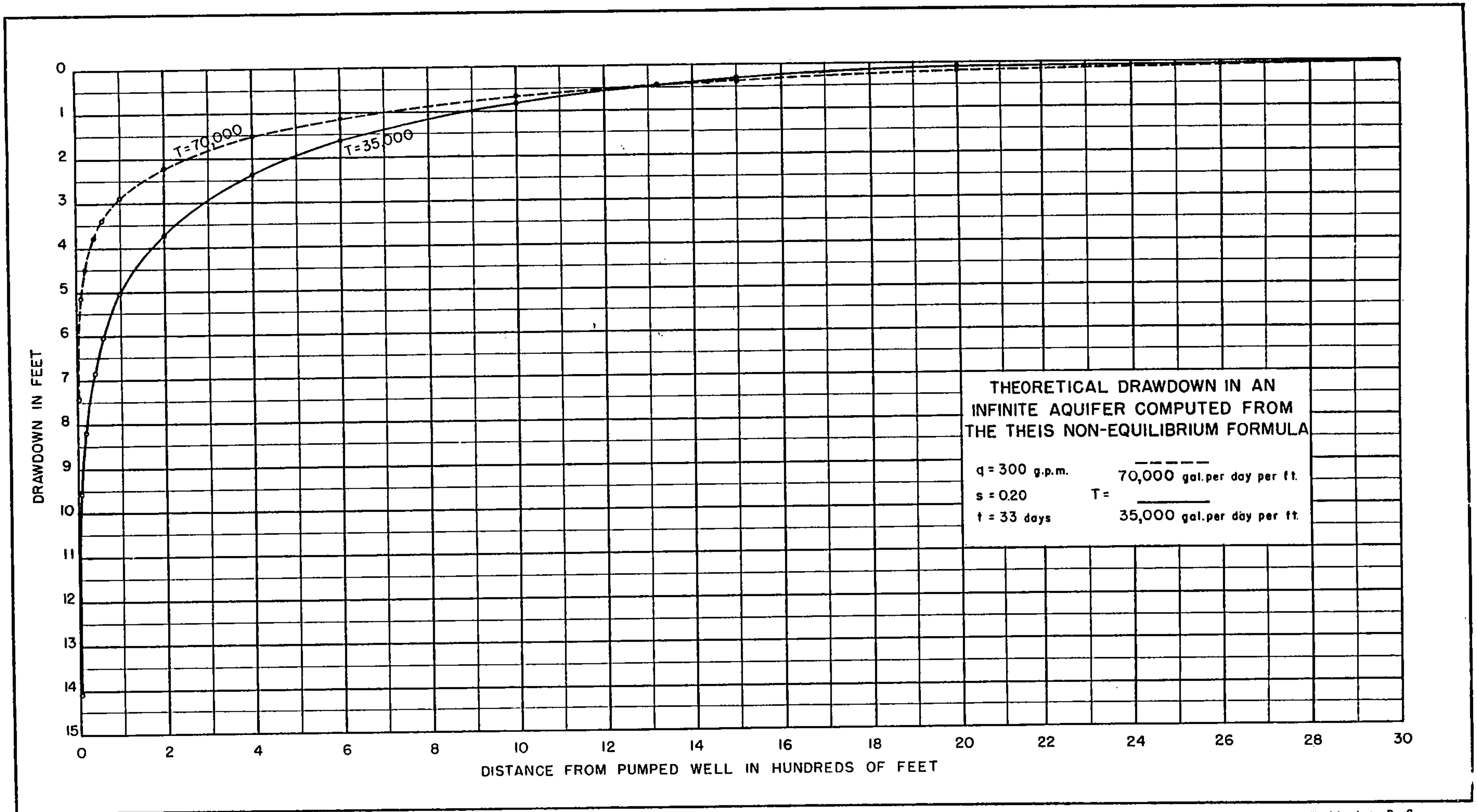
Measurements of water levels made in some of the test holes on July 15 and 30 suggest that no major change in position of the water-table contour lines occurred between those dates and August 20 and 21, and hence that about 12,000,000 gallons of water per day was draining into the rivers during this period without greatly changing the total amount of water in the alluvium. The recharge required to match the discharge during this 1-month period, therefore, must have been 12,000,000 gallons per day (36.8 acre-feet).

## STORAGE

The alluvium of the Fort Gibson area contains a large quantity of water moving from points of recharge to points of discharge. As this movement is relatively slow, the aquifer acts as an underground reservoir.

The amount of water in storage that would be available to wells depends on the thickness and lateral extent of the saturated material and its coefficient of storage. The saturated part of the alluvium of the Fort Gibson area averages 24.3 feet in thickness (table 1), and it underlies 6,465 acres. Its coefficient of storage cannot be calculated precisely from the records of the pumping tests, because the tests lasted long enough for only partial dewatering of the material within the cone of depression, and this material consisted of the finer sands and clays, which are not representative of the aquifer as a whole. A conservative estimate of 20 percent was therefore used, which means that not less than 20 percent of the volume of the saturated material is occupied by water that could be recovered, theoretically at least, by pumping from wells. On this basis, the available water in storage is more than 31,000 acre-feet, or more than enough to meet the requirements for eight seasons of irrigation.

Under actual conditions of development, of course, the quantity of water in storage will vary with the fluctuations of the water table,




Interior—Duplicating Section, Washington, D. C. 83432

and it would not be practical to recover all of it by pumping from wells. It is evident, however, that sufficient water is stored in the alluvium to permit irrigation during dry seasons. That is, if the recharge for several seasons is not enough to replace all the water pumped, the reserve in storage will be ample.

## EFFECT OF PUMPING ON THE WATER TABLE

To forecast the effect of heavy pumping on the water table and the magnitude of the interference between pumping wells, the curves in plate XII were plotted from probable drawdowns computed by means of the Theis nonequilibrium formula. These curves represent the drawdown of the water table in an infinite aquifer at several distances from a well pumping 300 gallons per minute continuously for 33 days. The broken-line curve represents a drawdown in an aquifer having the coefficient of transmissibility derived from the pumping tests—that is, 70,000 gallons per day per foot; the solid-line curve represents a drawdown in an aquifer having a coefficient half as high—that is, 35,000. In computing for both curves, a coefficient of storage of 20 percent was used. The rate of 300 gallons per minute and the period of 33 days were selected because this rate and duration of pumping will produce sufficient water to irrigate 40 acres for one season if the water requirement is 1.1 acre-feet per acre per year. The curves therefore represent the largest drawdowns to be expected for this rate of pumping during one irrigation season.

In plate XII, the curves cross at about 1,330 feet from the pumped well. Because the assumed rate of pumping and the total pumpage are the same for both curves, the lower transmissibility requires a deeper but less extensive cone of depression than the higher transmissibility and consequently more water is withdrawn from storage within 1,330 feet of the pumped well, and less from greater distances.

As the broken-line curve shows, the drawdown after 33 days of pumping at a distance of 0.25 mile (1,320 feet) from the pumped well will be 0.47 foot, and at 0.5 mile (2,640 feet) it will be 0.08 foot. The Theis formula, however, assumes a constant thickness of saturated material, a condition that obviously does not hold true under water-table conditions because the drawdown in the water table surrounding the well reduces the thickness of saturated material. The solid-line curve makes allowance for this factor under an extreme condition not likely to be met in the Fort Gibson area, for it assumes a 50-percent reduction in the coefficient of transmissibility. Under the assumed condition, the drawdown at a distance of 0.25 mile from the pumped well would be 0.48 foot and at 0.5 mile it would be less than 0.01 foot. In all probability, the drawdown around the pumped well will not reduce the coefficient of transmissibility by one-half, and the true curve under operating conditions should be somewhere between those shown on plate XII.

The curves indicate that if full development of the area were to mean a well pumping 300 gallons per minute in the middle of each 40-acre tract with all wells pumping simultaneously and continuously for 33 days to obtain all the water required for one season of irrigation, the additional drawdown in any one well due to the pumping in all the others would not exceed 4 feet. Such an extreme condition of pumping probably would never occur. It is clear, therefore, that unless wells are closely spaced and are pumped simultaneously for long periods, the interference between them will be negligible.

## CHEMICAL CHARACTER OF THE WATER

The general chemical character of the ground water in the alluvium of the Arkansas River flood plain near Fort Gibson is indicated by analyses of samples of water from 15 of the test holes drilled in the course of this investigation and from 13 water wells (table 7). The analyses show the quantities of calcium, magnesium, sodium, bicarbonate, sulfate, and chlorides. These are the constituents that make up practically all the dissolved mineral matter in most natural waters. The quantities and proportions of these constituents largely determine the value of a water for industrial, agricultural, and domestic uses that are affected by the mineral content without any reference to the sanitary aspect. Analyses usually show the quantities of the various constituents in parts per million.

Table 7. - Analyses of water from test holes and water wells in the alluvium of the Arkansas River near Fort Gibson, Oklahoma
(Analyzed in laboratories of the U. S. Geological Survey and U. S. Bureau of Reclamation)

| Test hole number or name of owner | Location in T. 15 N., R. 19 E. | Depth (feet) | Date of collection | Temp. °F. | Calcium (Ca) | Magnesium (Mg) | Sodium and Potassium (Na + K) | Carbonate ($CO_3$) | Bicarbonate ($HCO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Dissolved solids | Hardness as $CaCO_3$ Non-carbonate | Hardness as $CaCO_3$ Total | Specific Conductance a/ | Percent Sodium | pH | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | (parts per million) | | | | | | | | | | | | | | | |
| 2a | W¼-cor. sec. 10 | b/29.2 | 7/8/48 | .... | 65 | 11 | 15 | 0 | 240 | 20 | 15 | 0.05 | 1.5 | 255 | 11 | 207 | 448 | 14 | ... | Sampled by jetting with air |
| 3 | SE¼SE¼NW¼ sec. 11 | b 30 | 7/1/48 | .... | 18 | 3.9 | 39 | 0 | 131 | 32 | 3.0 | .1 | 0 | 181 | 0 | 61 | 282 | 58 | ... | Do. |
| 4 | NE¼ sec. 12 | b 30 | do. | 72 | 33 | 13 | 102 | 0 | 193 | 110 | 40 | .1 | 40 | 442 | 0 | 136 | 724 | 62 | ... | Do. |
| 5 | Cent. sec. 10 | b 30 | 7/2/48 | .... | 82 | 15 | 14 | 0 | 312 | 24 | 7.0 | 0 | 7.5 | 318 | 11 | 266 | 529 | 10 | ... | Do. |
| 6 | NE cor. sec. 15 | b 43.5 | 7/7/48 | .... | 44 | 11 | 80 | 0 | 317 | 55 | 7.0 | 0.2 | 2.0 | 373 | 0 | 155 | 604 | 53 | ... | Do. |
| 7 | NE cor. sec. 22 | b 39.3 | 7/9/48 | 65 | 44 | 18 | 6.8 | 10 | 202 | 7.9 | 5.0 | .15 | 1.0 | 204 | 1.6 | 184 | 355 | 8 | ... | Do. |
| 8 | NE cor. sec. 27 | b 39 | do. | 67 | 86 | 20 | 6.9 | 0 | 342 | 25 | 4.0 | .1 | 0.2 | 317 | 16 | 296 | 467 | 5 | ... | Do. |
| 9 | NE cor. sec. 28 | b 40 | do. | .... | 76 | 24 | 6.0 | 0 | 311 | 31 | 8.2 | .1 | 2.8 | 316 | 33 | 288 | 584 | 4 | ... | Do. |
| 13 | NW cor. NE¼ sec. 25 | b 33.6 | 7/13/48 | .... | 64 | 27 | 19 | 0 | 369 | 2.1 | 4.2 | .1 | 1.2 | 298 | 0 | 270 | 445 | 13 | ... | Do. |
| 19 | NW cor. sec. 24 | b 29.5 | 7/14/48 | .... | 72 | 22 | 23 | 0 | 307 | 39 | 18 | .2 | 2.5 | 402 | 18 | 270 | 596 | 16 | ... | Do. |
| 21 | NW cor. sec. 22 | b 35.5 | 7/15/48 | 67.5 | 100 | 27 | 16 | 0 | 442 | 21 | 5.8 | .1 | 3.8 | 391 | 0 | 360 | 680 | 9 | ... | Do. |
| 26 | NE cor. sec. 16 | b 38 | 7/27/48 | .... | 89 | 18 | 26 | 0 | 377 | 11 | 12 | 0 | 18 | 371 | 0 | 296 | 633 | 16 | ... | Do. |
| 31 | 267 ft. W. cent. sec. 22 | b 26.5-41 | 8/4/48 | 62 | 94 | 30 | 12 | 0 | 370 | 40 | 10 | .3 | 30 | 417 | 55 | 358 | 691 | 7 | ... | Collected after pumping 19¾ hrs. |
| P3 | SE¼SW¼NE¼ sec. 21 | b 21.5-37 | 8/18/48 | 64.5 | 116 | 26 | 21 | 0 | 449 | 59 | 9.0 | .1 | 1.0 | 453 | 28 | 396 | 715 | 10 | ... | From pumped well, test 3, after pumping 1 hr. |
| do. | do. | 21.5-37 | 8/20/48 | 64 | 115 | 25 | 11 | 0 | 435 | 35 | 8.5 | 0 | 1.2 | 421 | 25 | 382 | 719 | 6 | ... | Same, after pumping 27 hrs. |
| V. Paydon | Cent. SE¼SW¼ sec. 10 | c/33 | 6/6/46 | 62 | 53 | 8.9 | 12 | 0 | 180 | 23 | 16 | .... | .2 | 266 | 21 | 168 | 345 | 13 | 6.8 | Used for domestic supply. |
| Dr. Fite | SW cor. NW¼ sec. 15 | c 33 | do. | 62 | 84 | 14 | 5.8 | 0 | 313 | 12 | 7.1 | .... | .6 | 382 | 10 | 267 | 504 | 4 | 7.0 | Do. |
| Max Stoops | NW cor. sec. 23 | c 75 | do. | 62 | 53 | 16 | 12 | 0 | 253 | 8.4 | 5.3 | .... | .06 | 332 | 0 | 198 | 357 | 12 | 7.0 | Used for domestic supply and stock. |
| T. E. Dodds | NW cor. NE¼NE¼ sec. 23 | c 42 | do. | 62 | 62 | 18 | 12 | 0 | 254 | 23 | 9.6 | .... | .06 | 308 | 12 | 226 | 455 | 10 | 6.9 | Used for stock. |
| Lena Evart | SW cor. sec. 23 | c 38 | do. | 61 | 76 | 24 | .... | 0 | 296 | 33 | 4.6 | .... | 1.2 | 374 | 46 | 283 | 555 | ... | 7.0 | Used for domestic supply. |
| Kearns | SW cor. NW¼SW¼ sec. 22 | c 30 | do. | .... | 102 | 18 | 13 | 0 | 410 | 13 | 5.1 | .... | 0 | 382 | 0 | 326 | 617 | 8 | 7.1 | |
| D. L. Steeber | SW¼SW¼NE¼ sec. 25 | c 31 | do. | 62 | 106 | 30 | 11 | 0 | 447 | 18 | 18 | .... | .3 | 422 | 22 | 388 | 697 | 6 | 7.4 | Used for domestic supply and stock. |
| Dr. Fite | SW cor. SE¼ sec. 15 | c 30 | 6/6/46 | .... | 83 | 24 | 2.5 | 0 | 332 | 17 | 14 | .... | 1.9 | 372 | 34 | 306 | 591 | 2 | 7.2 | Used for domestic supply. |
| M. E. Fisher | SW¼ sec. 12 | c 51 | 9/20/44 | 64 | 28 | 3.8 | 44 | 21 | 163 | 9.0 | 3.0 | .... | .2 | 231 | 0 | 86 | ... | 53 | 8.7 | Borate, 0.5 ppm. 6-in. domestic well. |
| Jack Berry | NE¼ sec. 15 | c 38 | do. | 63 | 100 | 32 | 17 | 24 | 394 | 31 | 13 | .... | 5.0 | 415 | 18 | 381 | ... | 9 | 8.4 | Borate, 0.5 ppm. Stock well. |
| do. | NE¼ sec. 15 | c 26 | do. | 64 | 78 | 29 | 11 | 0 | 280 | 40 | 8.0 | .... | 68 | 424 | 84 | 314 | ... | 7 | 8.6 | Borate, 1.0 ppm. |
| R. C. Sullivan | Cent. sec. 11 | c 45 | do. | 63 | 37 | 7.2 | 21 | 14 | 125 | 27 | 10 | .... | .2 | 205 | 0 | 122 | ... | 27 | 8.6 | Borate, 0.5 ppm. |
| Oklahoma Gas and Elec. Co. | SE¼NW¼ sec. 21 | c 47.4 | do. | 63 | 63 | 24 | 8.5 | 11 | 266 | 34 | 1.0 | .... | .5 | 272 | 19 | 256 | ... | 7 | 8.3 | Borate, 0.5 ppm. |

a/ Micromhos at 25° C. b/ Depth at which sample was obtained c/ Depth of well

The samples that were analyzed had the following range: dissolved solids 181 to 453 parts per million; calcium 18 to 116 parts per million; magnesium 3.8 to 32 parts per million; sodium and potassium, calculated as sodium, 5.8 to 102 parts per million; bicarbonate 125 to 449 parts per million; sulfate 2.1 to 110 parts per million and chloride 1.0 to 40 parts per million. The total hardness as calcium carbonate ranged from 61 to 396 parts per million in the 28 samples. The non-carbonate hardness ranged from 0 to 84 parts per million. Fluorides were determined on 15 of the samples and their range was from 0 to 0.2 parts per million.

The requirements of different industries are diverse, but the suitability of water for many uses may be determined largely by the three properties or characteristics of hardness, alkalinity, and corrosiveness. These depend on the content of dissolved solids and gases.

Water having a hardness of less than 60 parts per million is generally rated as soft, and its treatment for the removal of hardness is not essential for ordinary use. Hardness between 61 and 120 parts per million is not objectionable, but hardness in the range of 121 to 180 parts per million is noticeable by almost everyone. If the hardness is above 180 parts per million it is common practice to soften the water for household use.[19] Accordingly the water from 20 of the wells reported in this investigation would be improved if softened before being used for household purposes.

Standards by which to ascertain the suitability of waters for human consumption have been established by the U. S. Public Health Service,[20] which indicates the maximum concentration, in parts per million, that should be tolerated in some of the constituents generally found in water. Among the constituents included in table 6, four are considered significant, and the limits for them are given below.

19. Collins, W. D., Lamar, W. L., and Lohr, E. W., "The Industrial Utility of Public Water Supplies in the United States, 1932." *U. S. Geological Survey Water Supply Paper* 658.

20. U. S. Public Health Service, "Public Health Reports," Vol. 58, No. 3, p. 81, Jan. 15, 1943.

| | Should not exceed (parts per million) |
|---|---|
| Magnesium (Mg) | 125 |
| Chloride (Cl) | 250 |
| Sulfate ($SO_4$) | 250 |
| Dissolved solids | 500 |

All ground waters from the Arkansas River flood plain near Fort Gibson are acceptable by these standards.

Whether a water is satisfactory for irrigation depends on several factors in addition to the mineral content of the water, among them the amount of water applied to the soil, the rainfall, the drainage and the characteristics of the soil. Several writers have suggested limits of concentration in waters used for irrigation. The table of standards by Magistad and Christiansen[21] is given below. They have classified irrigation waters according to the concentration of dissolved mineral matter in them. Waters of class 1 range from excellent to good and are suitable for most plants under most conditions. Waters of class 2 range from good to injurious and probably are harmful to the more sensitive crops. Waters of class 3 range from injurious to unsatisfactory and probably are harmful to most crops and are unsatisfactory for all but the most tolerant plants. If a water comes within class 3 on any basis, it should be considered unsuitable under most conditions. If the salts are largely sulfates, the values for the salt content in each class can be raised 50 percent. Comparison of the analyses in table 7 with the standards in table 6 shows that the ground waters of the Fort Gibson flood plain fall in class 1 with the exception of the water from test hole 4, in which the percentage of sodium is 62. This water falls in class 2. In the water from test holes 3, 6, and the M. E. Fischer well the percentage of sodium approaches the limit for class 1, but in all the other waters it is satisfactory.

TABLE 6
STANDARDS FOR IRRIGATION WATERS

| Class | Conductance-micromhos at 25°C. | Salt Content | | Sodium (percent) | Boron (p.p.m.) |
|---|---|---|---|---|---|
| | | Total (p.p.m.) | Per acre-foot (tons) | | |
| 1 | 1000 | 700 | 1 | 60 | 0.5 |
| 2 | 1000-3000 | 700-2000 | 1-3 | 60-75 | 0.5-2.0 |
| 3 | 3000 | 2000 | 3 | 75 | 2.0 |

21. Magistad, O. C., and Christiansen, J. E., "Saline Soils; Their Nature and Management": *U. S. Dept. Agric. Cir.* 707, p. 9, 1944.



## GROUND-WATER POSSIBILITIES ELSEWHERE ALONG THE ARKANSAS RIVER

Gravel and sand are certain to have been deposited in the alluvium elsewhere along the Arkansas River, and much doubtless is water bearing, but test drilling generally will be required to outline the thickest, coarsest, and most extensive deposits. Dott[22] has called attention to a deposit of gravel and sand extending about a mile and a half along the west side of the Arkansas in secs. 13, 14, and 24, T. 13 N., R. 19 E. Sieve analyses of 22 samples from this locality showed that pebbles and cobbles larger than 0.25 inch made up 28 percent of the material, on the average. In two samples they were as low as about 13 percent; in one they were 69 percent. In only three were they less than 25 percent. This deposit was described as a source of construction material, and its water-bearing properties were not considered.

Reports indicate that moderate to large yields are obtainable here and there in the Arkansas Valley, and suggest that water of fairly good quality may be found by careful selection of sites with respect to the possibilities for runoff from adjacent areas. One of the larger yields reported in the State is 1,700 gallons per minute[23] from a well at Ponca City that taps water in the alluvium of the Arkansas River. An analysis of a sample of water collected at the municipal filter plant in February 1948 showed only 324 parts per million of dissolved solids, of which 64 parts per million was chloride and 48 was sulfate. The total hardness was 252 parts per million, reported as calcium carbonate.[24] Except for the hardness, this is good water. It is not invariably this good, however, for during the drought of the 1930's the chloride content of water from some wells in the alluvium at Ponca City was 500 parts per million, and sulfate was 150.[25]

22. Dott, R. H., "Miscellaneous Mineral Resources", in "Geology of the Muskogee-Porum District, Muskogee and McIntosh Counties, Okla.": *Oklahoma Geol. Survey Bull.* 57, pp. 116-119, 1937.
23. Schlesinger, Patrick, Ponca City Water Department, oral communication.
24. Unpublished analysis made in laboratory of Quality of Water Branch, U. S. Geological Survey, Stillwater, Okla.
25. Smith, O. M., "The Chemical Analyses of the Waters of Oklahoma": *Oklahoma Agr. and Mech. College, Engr. Exp. Sta. Pub.* 52, p. 309, 1942.

The Arkansas River flood plain at Fort Gibson appears to be especially favored. Factors that have contributed to the occurrence of coarse water-bearing sediments and water of good quality in that area are given below:

1. The Fort Gibson area is immediately below the mouth of a large tributary that brings water of good quality into the Arkansas River.

2. The flood plain at Fort Gibson is on the same side of the main stream as the tributary, and the course of the main stream is such that recharge by infiltration will consist largely of water of good quality from the tributary. Along one side of the flood plain such infiltration is directly from the tributary. Along two sides infiltration is from the main stream, but the water is not typical of the main stream. It is a mixture of the latter with good water from the tributary, in which the tributary water generally predominates.

3. The tributary and streams that feed it drain a large area underlain by cherty limestone. Pebbles of chert and limestone brought by the tributary have been deposited in the alluvium of the Fort Gibson flood plain as beds of coarse, permeable gravel. Pebbles also may be derived from sandstone beds crossed by the tributary in the last few miles above its mouth, but these are likely to disintegrate more readily than pebbles of limestone and chert.

The analysis suggests that locations near the mouths of tributaries draining areas underlain by cherty limestone should be especially favorable. Within the Arkansas Basin of Oklahoma, the principal large area of cherty limestone is in Adair, Cherokee, Mayes, Delaware, and Ottawa Counties. The principal rivers draining this area are the Illinois and the Grand (Neosho), and the flood plain at the mouth of the latter is the main subject of this report.

The Illinois River empties into the Arkansas in western Sequoyah County near Gore. It and its principal tributary, Barren Fork,



drain many square miles underlain by cherty limestone, and gravel from this source probably is incorporated in the alluvium along the lower 4 or 5 miles of its course. The Arkansas River makes no loop at the mouth of the Illinois comparable to the one at the mouth of the Grand, and the two streams therefore embrace no such large area of flood plain. Conservatively estimated, the flood-plain area adjacent to the lower reaches of the Illinois may amount to 5 or 6 square miles, or some 3,000 to 4,000 acres. It should be noted, however, that gravel brought by the Illinois may be found not only in this area, but also for several miles downstream along the Arkansas. The water of the Illinois River usually is good, and the infiltration of it into the alluvium of the Arkansas should result in a body of ground water of good quality. Furthermore, the water of the Illinois should improve by dilution the water flowing in the Arkansas, and for a few miles downstream the infiltration of water into the alluvium from the Arkansas itself should result in ground water of fairly good quality.

Other tributaries draining from the east and northeast below the mouth of the Grand (Neosho) bring good water to the Arkansas, but they are shorter and offer less promise of contributing coarse water-bearing gravels. Sallisaw Creek heads near Stilwell in Adair County and empties into the Arkansas near Sadie, in Sequoyah County. For 10 miles in the upper part of its course it crosses cherty limestone, but the remainder is over formations consisting largely of shale with some interbedded sandstone. The sandstone may break down into gravel, but the gravel so derived is likely to be rather readily disintegrated. Hence, by the time this gravel reaches the Arkansas River it may no longer be coarse. Moreover, it may be mixed with clay derived from the shale beds. The bottom lands bordering the Arkansas at the mouth of Sallisaw Creek are narrow and the storage capacity of the alluvium therefore is not great, but the alluvium of Sallisaw Creek itself may be worth investigation.

Vian Creek and its principal tributary, Little Vian Creek, head in the hills of north-central Sequoyah County, near the Cherokee County line. They run over formations of shale, limestone, and sandstone as far as the Arkansas River bottom lands, where they join and empty into the river about 3 miles below Tamaha. The sediments deposited by Vian Creek near its mouth may include beds of gravel composed of limestone and sandstone pebbles. As indicated by an analysis of water from the Vian public supply, the water of Vian Creek is of good quality.[26]

The Verdigris River heads in Kansas, where it crosses cherty limestones in the Flint Hills, and it empties into the Arkansas River about 5 miles northeast of Muskogee, or less than 1 mile upstream from the mouth of Grand River. The alluvium along it should contain more or less cherty water-bearing gravel. Near the mouth is about 2,500 acres of flood plain bounded by the Verdigris, the Grand, and 0.7 mile of the Arkansas. Beds of gravel in the alluvium of this area should be approximately as prolific in ground water as those of the Fort Gibson flood plain across the Grand to the southeast. Analyses of three samples of water from wells in this area show the following range in mineral content, in parts per million: dissolved solids, 264 to 536; calcium (Ca), 26 to 92; magnesium (Mg), 8 to 20; sodium and potassium (Na and K), 23 to 32; bicarbonate ($HCO_3$), 103 to 308; sulfate ($SO_4$), 8 to 25; and chloride, 21 to 73. Specific conductance (micromhos at 25° C.) ranged from 345 to 687, and percent sodium ranged from 14 to 41. Ground-water recharge to this alluvial deposit by infiltration should be almost entirely water of good quality from the Verdigris and Grand Rivers, with only minor contributions of water of poor quality from the Arkansas River.

Between the Verdigris and the Arkansas Rivers, also, is a large area of flood plain, totaling about 1,500 acres, where cherty gravel brought by the Verdigris probably is included in the alluvium. Recharge of good water may come by infiltration from the Verdigris River along the east side of this area, but along the west and south sides infiltration is from the highly mineralized Arkansas River.

Other tributaries emptying into the Arkansas River cross no areas of cherty limestone. The Poteau River empties into the Arkansas River near Fort Smith, Arkansas, where it has a flood plain about 2 miles wide. The water of the Poteau is of excellent

26. Smith, O. M., *op. cit.*, pp. 225, 379.



quality,[27] and by dilution it may improve the water in the Arkansas and in the adjacent alluvium. It is not likely, however, that the Poteau has deposited much coarse sand or gravel in the alluvium along its course or at its mouth, for it drains an area underlain principally by shale. Its sediments, therefore, are likely to be fine-grained and of low permeability, offering little promise of ground water in sufficient volume for irrigation or other large uses.

Likewise, Sans Bois Creek, which heads near Featherston in Pittsburg County and empties into the Arkansas near the northeast corner of Haskell County, drains an area of fine-grained rocks and is likely to have little coarse sand or gravel in its alluvium, although the quality of its water may be satisfactory.

The Canadian River and its principal tributary, the North Canadian River, rise in northeastern New Mexico and cross the High Plains of the Texas and Oklahoma Panhandles, where a thick and extensive deposit of sand, gravel, caliche, and clay underlies the surface. Sand and gravel from this source are brought to the rivers by their tributaries and are carried downstream. Some wells drilled in the alluvium of the North Canadian have yielded as much as 1,100 gallons per minute. Although doubtless reduced in particle size by the wear and tear of transportation, the sand and gravel brought by the Canadian and its tributaries are incorporated in the Arkansas River alluvium and may be capable of yielding moderate to large quantities of ground water, but the water discharged into the Arkansas by the Canadian is highly mineralized.[28]

The Cimarron River also has access to deposits of coarse sand and gravel in the High Plains. The permeability of these materials as included in the Cimarron River alluvium is demonstrated by yields up to 250 gallons per minute from wells scattered along the valley, as near Perkins and Kingfisher.[29] The water flowing in the Cimarron is salty, however, and adjacent to the channel the ground

27. Smith, O. M., *op. cit.*, pp. 400, 417.
28. Walling, I. W., District Chemist, Quality of Water Branch, U. S. Geological Survey, oral communication.
29. Schoff, S. L., "Ground Water in Kingfisher County, Oklahoma": *Oklahoma Geol. Survey Mineral Rept.* 19 (mimeographed), 1949.

water also is salty. At some locations farther from the channel the ground water is of better quality, partly because of the introduction of better water from tributaries, but the water emptied by the Cimarron into the Arkansas River and moving thence by infiltration into the alluvium along the Arkansas is not of good quality.

The Salt Fork of the Arkansas River heads in southern Kansas and empties into the Arkansas River at the southeast corner of Kay County, Okla. Although parts of its drainage basin are underlain by fine-grained rocks, the upper reaches of its headwaters drain areas having deposits of sand and gravel. Through Oklahoma it is flanked on the north by terrace deposits and windblown sand. Some of these coarse materials doubtless find their way into the alluvium of Salt Fork. Although ground water of acceptable mineral content has been obtained in places along Salt Fork, as at Alva and Pond Creek,[30] the stream itself is salty, in part because of salt dissolved from the rocks over which it passes, and in part because of the influx of salty water from the Great Salt Plains.[31]

A tributary contributes to the main stream both rock materials and water, whose characteristics are determined by a complex of geologic, hydrologic, climatic, and other conditions peculiar to the drainage basin. The paragraphs above attempt to point out the salient features of the main tributaries as related to the occurrence of ground water along the Arkansas River. In addition, smaller tributaries, too numerous to describe in this report, make their distinctive contributions. Bodies of good ground water, some large and some small, may occur near the mouths of such tributaries, but in each case test drilling to determine the thickness and extent of the water-bearing beds and the quality of the water is a logical prelude to the construction of production wells.

30. Smith, O. M., *op. cit.*, pp. 146, 240, 295, and 394.
31. Smith, O. M., *op. cit.*, pp. 423.



## CONCLUSIONS

The alluvium of the Arkansas River Valley near Fort Gibson consists of clays, silts, sands, and gravels. The sands and gravels underlie all but the extreme eastern portion of the area and are highly permeable. They contain relatively large amounts of water suitable for irrigation, and should yield up to 500 gallons per minute to properly constructed wells. The recharge from rainfall on the area and runoff from adjacent uplands normally will be sufficient to supply the estimated maximum requirement of 3,850 acre-feet per year, and enough water is in storage to permit irrigation through periods of drought. Wells close to the rivers can probably induce significant amounts of recharge from the rivers, but most of the wells will derive their water from storage, to be replenished later by recharge—mostly from precipitation. Interference between wells will be negligible unless wells are spaced close together and are pumped simultaneously for long periods. Irrigation of 3,500 acres by means of ground water from wells appears to be hydrologically feasible.

Much ground water appears to be available in other parts of the Arkansas Valley, but in each locality test drilling to determine the character and thickness of the water-bearing beds and analysis of the ground water are desirable before wells are constructed for production of water in large volume.

## LOGS OF TEST HOLES AND WELLS

The logs on the following pages record the materials penetrated in the drilling of the test holes, as identified by representatives of the Geological Survey and the Bureau of Reclamation from field examination of the drill cuttings and subsequently revised to accord with results of the sieve analyses. The elevations refer to ground level at the mouth of the test holes, and are in feet above mean sea level. Also given are the logs of three water wells, as reported by the owners, and two oil wells, as reported to the Corporation Commission of Oklahoma.

## WELL LOGS—FORT GIBSON AREA

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| **TEST HOLE NO. 1A** | | |
| SW corner NW¼ sec. 11, T. 15 N., R. 19 E. | | |
| Elevation 507.1 feet | | |
| Clay, black, silty to sandy | 19 | 19 |
| Gravel, fine to coarse, with sand | 18 | 37 |
| Shale, black | 1½ | 38½ |
| **TEST HOLE NO. 2A** | | |
| SW corner NW¼ sec. 10, T. 15 N., R. 19 E. | | |
| Elevation 501.5 feet | | |
| Clay, dark-brown, silty | 9 | 9 |
| Sand, medium | 2½ | 11½ |
| Gravel, mixed with sand | 4½ | 16 |
| Gravel, some sand | 14 | 30 |
| **TEST HOLE NO. 3** | | |
| SW corner SE¼SE¼NW¼ sec. 11, T. 15 N., R. 19 E. | | |
| Elevation 503.4 feet | | |
| Clay, gray, silty with pebbles | 19 | 19 |
| Sand and gravel, medium to coarse, angular | 5 | 24 |
| Sand, medium to coarse | 7½ | 31½ |
| Shale, black, alternately hard and soft | 3½ | 35 |
| **TEST HOLE NO. 4** | | |
| SW¼SE¼NE¼ sec. 11, T. 15 N., R. 19 E. | | |
| Elevation 513.7 feet | | |
| Soil and clay, dark-gray | 5 | 5 |
| Clay, black, a few sand grains | 2 | 7 |
| Clay, light-brown, sandy | 8½ | 15½ |
| Clay and silt, brown | 5 | 20½ |
| Silt | 6½ | 27 |
| Sand, medium, with flat white chert grains | 5 | 32 |
| Shale, black, hard | 3 | 35 |
| **TEST HOLE NO. 5** | | |
| 28 feet south of center sec. 10, T. 15 N., R. 19 E. | | |
| Elevation 505.9 feet | | |
| Soil and clay, black | 4 | 4 |
| Clay, black with layers of hard red clay | 6 | 10 |
| Clay, black | 5 | 15 |
| Clay, black, a few pieces of red clay | 6 | 21 |
| Gravel, coarse, some sand | 16 | 37 |
| Shale, black | 1 | 38 |
| **TEST HOLE NO. 6** | | |
| 65 feet south and 6 feet west of NE corner sec. 15, T. 15 N., R. 19 E. | | |
| Elevation 514.3 feet | | |
| Clay, red-brown | 25 | 25 |
| Clay, red-brown, some gray clay | 5 | 30 |
| Clay, blue-gray | 9 | 39 |
| Gravel, coarse, gray chert | 6½ | 45½ |
| Shale, black | 1½ | 47 |



| | Thickness (feet) | Depth (feet) |
|---|---|---|
| **TEST HOLE NO. 7** | | |
| 115 feet south and 22 feet west of NE corner, sec. 22, T. 15 N., R. 19 E. | | |
| Elevation 507.2 feet | | |
| Clay, red-brown | 10 | 10 |
| Clay, brown | 5 | 15 |
| Clay, red-brown, sandy | 8 | 23 |
| Sand, brown, fine | 6 | 29 |
| Sand, brown, medium, some coarse grains | 3 | 32 |
| Sand, brown, coarse | 1 | 33 |
| Sand, brown, coarse and medium to fine gravel | 8 | 41 |
| Sand, brown, fine to medium | 1 | 42 |
| Shale, black | 3 | 45 |
| **TEST HOLE NO. 8** | | |
| 43 feet south and 8 feet west of NE corner, sec. 27, T. 15 N., R. 19 E. | | |
| Elevation 504.7 feet | | |
| Clay, brown | 20 | 20 |
| Sand, coarse, and fine gravel | 12½ | 32½ |
| Sand, coarse, a little fine gravel | 3½ | 36 |
| Gravel, fine, and coarse sand | 4 | 40 |
| Shale, black | 6 | 46 |
| **TEST HOLE NO. 9** | | |
| 100 feet south of NE corner, sec. 28, T. 15 N., R. 19 E. | | |
| Elevation 506.1 feet | | |
| Clay, brown, silty | 19 | 19 |
| Sand, fine | 2 | 21 |
| Sand, medium to coarse | 2 | 23 |
| Sand, medium, some gravel | 19 | 42 |
| Shale, blue | 6 | 48 |
| **TEST HOLE NO. 10** | | |
| NE corner NW¼ sec. 27, T. 15 N., R. 19 E. | | |
| Elevation 506.5 feet | | |
| Clay, red-brown, silty | 21 | 21 |
| Silt, some sand | 2 | 23 |
| Sand, medium-fine, some clay | 5 | 28 |
| Sand, medium, some coarse sand | 5 | 33 |
| Sand, medium-coarse | 5 | 38 |
| Sand, coarse, some coarse gravel | 5 | 43 |
| Shale | 1½ | 44½ |
| **TEST HOLE NO. 11** | | |
| 48 feet east of NW corner NE¼ sec. 26, T. 15 N., R. 19 E. | | |
| Elevation 499.8 feet | | |
| Clay, red-brown | 17 | 17 |
| Sand, very fine, some silt | 1 | 18 |
| Sand, fine | 10 | 28 |
| Sand, medium, with a few pebbles | 5 | 33 |
| Sand, coarse, some gravel | 3 | 36 |
| Sand, coarse, with fine gravel | 2 | 38 |
| Gravel, fine | ½ | 38½ |
| Shale | 1½ | 40 |

### TEST HOLE NO. 12

NE corner sec. 26, T. 15 N., R. 19 E.
Elevation 499.6 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay, brown | 18 | 18 |
| Sand, silty to medium | 7 | 25 |
| Sand, medium to coarse, a few pebbles | 10 | 35 |
| Sand, medium | 1½ | 36½ |
| Shale, black | ½ | 37 |

### TEST HOLE NO. 13

NW corner NE¼ sec. 25, T. 15 N., R. 19 E.
Elevation 498.4 feet

| | | |
|---|---|---|
| Clay, brown | 8 | 8 |
| Silt, sand, fine to coarse, some gravel | 7 | 15 |
| Sand, medium, and gravel | 6 | 21 |
| Sand, coarse, and gravel | 7 | 28 |
| Sand, coarse, some gravel | 7½ | 35½ |
| Shale, black | 4½ | 40 |

### TEST HOLE NO. 14

0.11 mile west of NE corner sec. 25, T. 15 N., R. 19 E.
Elevation 499.4 feet

| | | |
|---|---|---|
| Road gravel, and brown clay | 7 | 7 |
| Sand, very fine | 3 | 10 |
| Sand, brown, very fine | 11 | 21 |
| Sand, gray-brown, fine | 12 | 33 |
| Shale | ½ | 33½ |

### TEST HOLE NO. 15

NW¼NW¼SE¼ sec. 24, T. 15 N., R. 19 E.
Elevation 497.0 feet

| | | |
|---|---|---|
| Clay, brown | 12 | 12 |
| Sand, brown, fine | 9 | 21 |
| Sand, gray-brown, fine | 7 | 28 |
| Sandstone, hard, some black shale | 8 | 36 |

### TEST HOLE NO. 16

0.43 mile north of SE corner sec. 23, T. 15 N., R. 19 E.
Elevation 498.1 feet

| | | |
|---|---|---|
| Road gravel and clay | 3 | 3 |
| Clay, brown, some gray clay | 11 | 14 |
| Clay, gray | 2 | 16 |
| Clay, gray, some gravel | 2 | 18 |
| Sand, brown, fine | 7 | 25 |
| Sand, fine to medium | 5 | 30 |
| Sand, fine to medium, some gravel and sandstone cuttings | 1½ | 31½ |

### TEST HOLE NO. 17

38 feet south of NW corner SW¼ sec. 13, T. 15 N., R. 19 E.
Elevation 501.7 feet

| | | |
|---|---|---|
| Road gravel and brown clay | 5 | 5 |
| Silt and fine brown sand | 20½ | 25½ |
| Sand, fine to medium, with a few pebbles | 7½ | 33 |
| Shale, black | 6 | 39 |



### TEST HOLE NO. 18

168 feet east of SW corner. 12, T. 15 N., R. 19 E.
Elevation 510.3 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Road gravel and gray clay | 5 | 5 |
| Clay, yellow | 9 | 14 |
| Sand, very fine | 3½ | 17½ |
| Sandstone, gray | 1 | 18½ |

### TEST HOLE NO. 19

45 feet south and 93 feet east of NW corner sec. 24, T. 15 N., R. 19 E.
Elevation 498.7 feet

| | | |
|---|---|---|
| Clay | 3 | 3 |
| Sand, very fine | 18 | 21 |
| Sand, medium, with some gravel | 10 | 31 |
| Shale, gray | 2½ | 33½ |

### TEST HOLE NO. 20

100 feet north of SW corner SE¼ sec. 13, T. 15 N., R. 19 E.
Elevation 498.1 feet

| | | |
|---|---|---|
| Clay, brown and gray | 14 | 14 |
| Sand, very fine | 15 | 29 |
| Shale, black | 1 | 30 |

### TEST HOLE NO. 21

105 feet south of NW corner sec. 22, T. 15 N., R. 19 E.
Elevation 506.9 feet

| | | |
|---|---|---|
| Road gravel | 1½ | 1½ |
| Clay, brown, some pebbles and sand | 14½ | 16 |
| Clay, gray, some pebbles | 6½ | 22½ |
| Sand, fine | 10 | 32½ |
| Sand, fine to coarse | 2 | 34½ |
| Gravel, fine to coarse | 7 | 41½ |
| Shale, black | 3½ | 45 |

### TEST HOLE NO. 22

NW corner SW¼ sec. 22, T. 15 N., R. 19 E.
Elevation 510.4 feet

| | | |
|---|---|---|
| Loam, red, fine sandy | 5 | 5 |
| Clay, brown, with some fine sand | 8½ | 13½ |
| Sand, fine, and gravel, very tight | 1½ | 15 |
| Clay, gray | 6 | 21 |
| Clay, gray, with some sand | 9 | 30 |
| Sand, fine | 3 | 33 |
| Sand, coarse, and gravel | 13½ | 46½ |
| Shale, gray | 2 | 48½ |

### TEST HOLE NO. 23

SW corner NW¼ sec. 15, T. 15 N., R. 19 E.
Elevation 511.1 feet

| | | |
|---|---|---|
| Clay, brown and gray—with trace of sand at 11 feet | 21 | 21 |
| Clay, gray | 6 | 27 |
| Sand, coarse, and gravel | 2¼ | 29¼ |

Lost circulation repeatedly at 29¼ feet; drove sucker rod to refusal at 45 9/10 feet, probably top of shale.

### TEST HOLE NO. 24

130 feet east of NW corner NE¼ sec. 15, T. 15 N., R. 19 E.
Elevation 511.0 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay, brown and red-brown | 9 | 9 |
| Clay, green-gray | 1 | 10 |
| Gravel, fine to medium, silty | 3 | 13 |

Lost circulation repeatedly at 13 feet, drove sucker rod to 17 feet; probably stopped on boulder; hole abandoned.

### TEST HOLE NO. 25

270 feet west of NE corner NW¼ sec. 15, T. 15 N., R. 19 E.
Elevation 508.9 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay, brown and dark gray | 8 | 8 |
| Sand, medium | 4 | 12 |
| Lost circulation; probably coarse sand or gravel | 7 | 19 |
| Lost circulation | 3 | 22 |

Abandoned hole.

### TEST HOLE NO. 26

60 feet west of NE corner sec. 16, T. 15 N., R. 19 E.
Elevation 507.9 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay, brown | 22 | 22 |
| Clay, brown, some red and gray clay with a few sand grains | 14 | 36 |
| Gravel, coarse | 4 | 40 |
| Shale, black | 2 | 42 |

### TEST HOLE NO 27

45 feet east of NE corner NW¼NW¼ sec. 15, T. 15 N., R. 19 E.
Elevation 505.2 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay, brown and gray | 14½ | 14½ |
| Sand, coarse and fine gravel | 3 | 17½ |
| Gravel, coarse (lost circulation) | 2½ | 20 |

Abandoned hole.

### TEST HOLE NO. 28

SW corner SE¼ sec. 14, T. 15 N., R. 19 E.
Elevation 506.0 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Road gravel and clay | 5 | 5 |
| Clay, | 7 | 12 |
| Sand, very fine | 9 | 21 |
| Sand, fine to coarse | 5 | 26 |
| Sand, medium to coarse, and fine gravel | 12½ | 38½ |
| Shale, black | 2½ | 41 |

### TEST HOLE NO. 29

SW corner SE¼ sec. 16, T. 15 N., R. 19 E.
Elevation 509.7 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Silt, dark gray | ½ | ½ |
| Silt, brown and fine sand, with flakes of black shale | 3½ | 4 |
| Sand, fine to medium, with flakes of black shale | 17 | 21 |
| Sand, medium and fine gravel | 14 | 35 |
| Sand, medium, and gravel, coarse | 5 | 40 |
| Sand, coarse, and gravel, fine | 6 | 46 |
| Gravel, fine, and sand | 1 | 47 |
| Shale | 1 | 48 |

Note: Hardly lost circulation during drilling, which indicates poor permeability of material, possibly clay mixed with sand and gravel.



### TEST HOLE NO. 30

82 feet south and 12 feet west of NE corner SW¼ sec. 22, T. 15 N., R. 19 E.
Elevation 506.7 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay, dark gray and brown | 10 | 10 |
| Silt | 5 | 15 |
| Clay, brown | 6 | 21 |
| Clay, dark gray | 10 | 31 |
| Sand, medium | 7 | 38 |
| Sand and gravel | 6 | 44 |
| Shale | 1 | 45 |

### TEST HOLE NO. 31

About 267 feet west of center of sec. 22, T. 15 N., R. 19 E.
Elevation 508.1 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay, brown | 7 | 7 |
| Silt | 12 | 19 |
| Clay, gray and brown | 6 | 25 |
| Gravel, fine, and sand with flakes of black shale near bottom | 18½ | 43½ |
| Shale, black | 4½ | 48 |

### TEST HOLE NO. 32

At center sec. 14, T. 15 N., R. 19 E.
Elevation 504.0 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay, dark gray | 8 | 8 |
| Clay, brown | 6 | 14 |
| Silt and sand | 11½ | 25½ |
| Sand, medium | 10 | 35½ |
| Shale | 2 | 37½ |

### TEST HOLE NO. 33

Center of sec. 23, T. 15 N., R. 19 E.
Elevation 507.4 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay | 10 | 10 |
| Sand, very fine | 8 | 18 |
| Sand, some gravel | 3 | 21 |
| Sand, medium | 11½ | 32½ |
| Sand, medium, and gravel | 5 | 37½ |

Lost circulation at 37½ feet; drove sucker rod to 42 2/3 feet, probably through gravel to shale.

### TEST HOLE NO. 34

About 200 feet north and 30 feet west of SE corner NE¼ sec. 15, T. 15 N., R. 19 E.
Elevation 507.3 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay, dark gray | 14 | 14 |
| Clay and very fine sand | 7 | 21 |
| Clay, brown, and some fine sand | 6 | 27 |
| Sand, coarse, and gravel | 3 | 30 |
| Shale | 1 | 31 |

### TEST HOLE NO. 35

Center of sec. 15, T. 15 N., R. 19 E.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Elevation 510.7 feet | | |
| Silt and clay | 5 | 5 |
| Clay, gray and brown | 5 | 10 |
| Clay, dark gray | 7 | 17 |
| Clay, brown | 4 | 21 |
| Clay, dark gray | 10½ | 31½ |
| Sand, coarse, and gravel | 3 | 34½ |

Lost circulation at 34½ feet; drove sucker rod to 43 1/5 feet, probably through sand and gravel to top of shale.

### TEST HOLE NO. 36

90 feet east and 30 feet north of SW corner SE¼ sec. 15, T. 15 N., R. 19 E.
Elevation 510.6 feet

| | | |
|---|---|---|
| Soil, silt and clay | 3 | 3 |
| Clay, brown | 5 | 8 |
| Sand, very fine | 23½ | 31½ |
| Sand, medium to coarse, and gravel | 12½ | 44 |
| Shale | 1 | 45 |

### TEST HOLE NO. 37

465 feet west and 10 feet south of NE corner NW¼ sec. 14, T. 15 N., R. 19 E.
Elevation 506 feet

| | | |
|---|---|---|
| Clay, dark gray | 8 | 8 |
| Sand, fine to medium | 10 | 18 |
| Sand, coarse, and gravel | 7 | 25 |

Lost circulation at 25 feet; drove sucker rod to 32 feet, probaby through gravel to top of shale.

### OBSERVATION WELL 0-4, TEST NO. 3

SW corner SE¼SW¼NE¼ sec. 21, T. 15 N., R. 19 E.
Elevation 502.4 feet

| | | |
|---|---|---|
| Sand, very fine, and silt | 4 | 4 |
| Clay, brown | 1 | 5 |
| Sand, very fine | 3 | 8 |
| Sand, medium | 2½ | 10½ |
| Sand and gravel, coarse | 24 | 34½ |
| Log | 2 | 36½ |
| Sand, black, coarse | 2 | 38½ |
| Shale, black | 1½ | 40 |

### OKLAHOMA GAS & ELECTRIC CO. RIVER BANK STATION

SE¼SE¼NW¼ sec. 21, T. 15 N., R. 19 E.
Elevation 507.1 feet

| | | |
|---|---|---|
| Loam, brown, sandy | 24 | 24 |
| Water, sand, and gravel | 23.4 | 47.4 |
| Sandstone | .6 | 48 |

Struck log at 29 feet.



### W. E. FOLTZ

NE¼NW¼NW¼ sec. 14, T. 15 N., R. 19 E.
Elevation 510 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay and soil | 4½ | 4½ |
| Clay, sand | 2½ | 7 |
| Blowsand | 14½ | 21½ |
| Sand, water-bearing, and gravel | 4½ | 26 |
| Clay, blue, tough | 6 | 32 |
| Sand, water-bearing | 2 | 34 |
| Clay, blue, tough | ¼ | 34¼ |
| Gravel, water-bearing | 5¼ | 39½ |
| Gravel, too coarse for bucket | | |

### WELL NO. CC-2 [33]

C. D. Bradley, SW¼SW¼NW¼ sec. 15, T. 15 N., R. 19 E.
Elevation 510 feet

| | | |
|---|---|---|
| Soil | 12 | 12 |
| Gravel | 33 | 45 |
| Shale | 25 | 70 |
| Sand, water-bearing | 15 | 85 |

### WELL NO. CC-3 [33]

E. C. Lantz, NW corner, SE¼ NE¼ sec. 22, T. 15 N., R. 19 E.
Elevation 508 feet

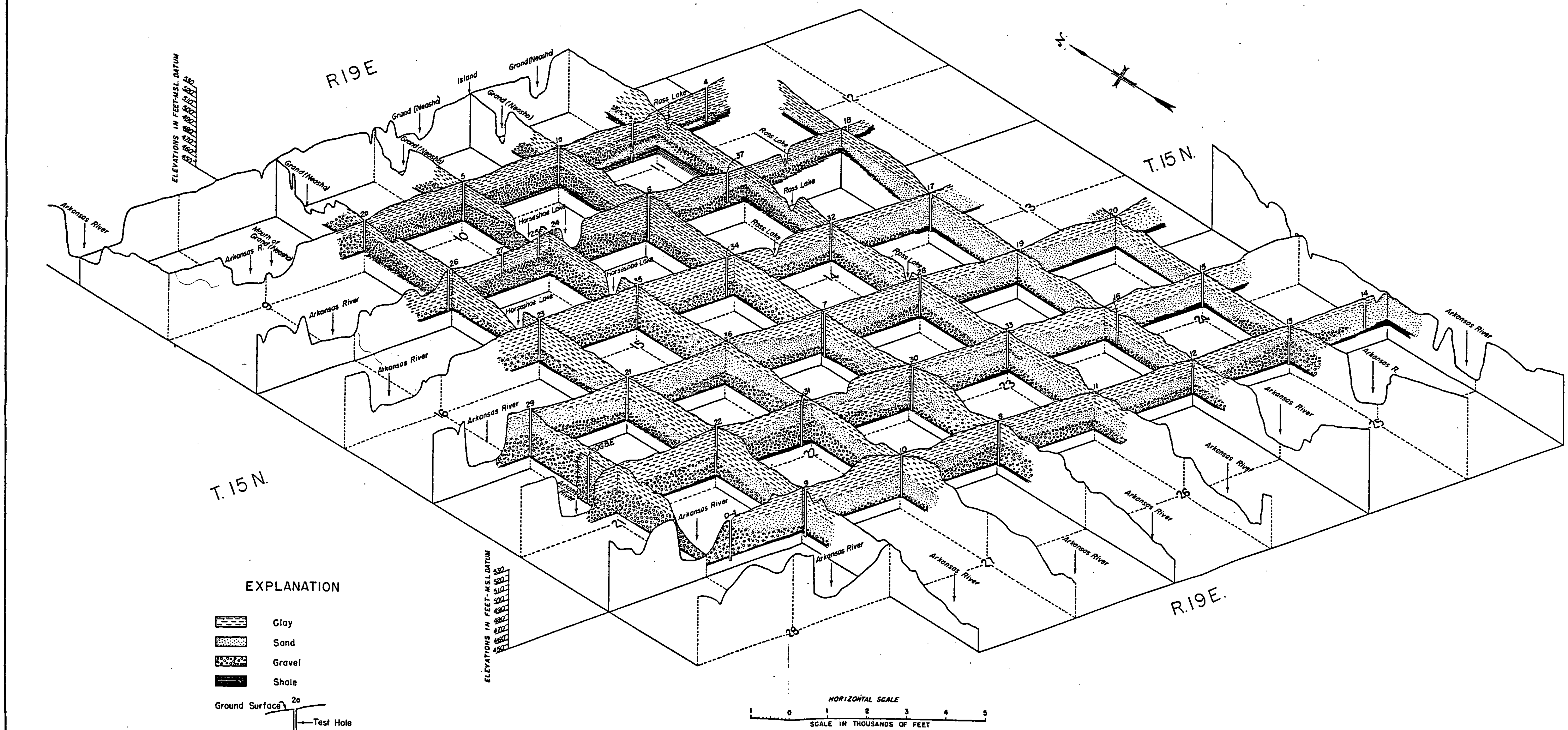
| | | |
|---|---|---|
| Soil | 6 | 6 |
| Clay, mud, yellow | 31 | 37 |
| Sand, gravel, brown | 23 | 60 |
| Shale, blue | 175 | 235 |

### WELL NO. CC-4 [33]

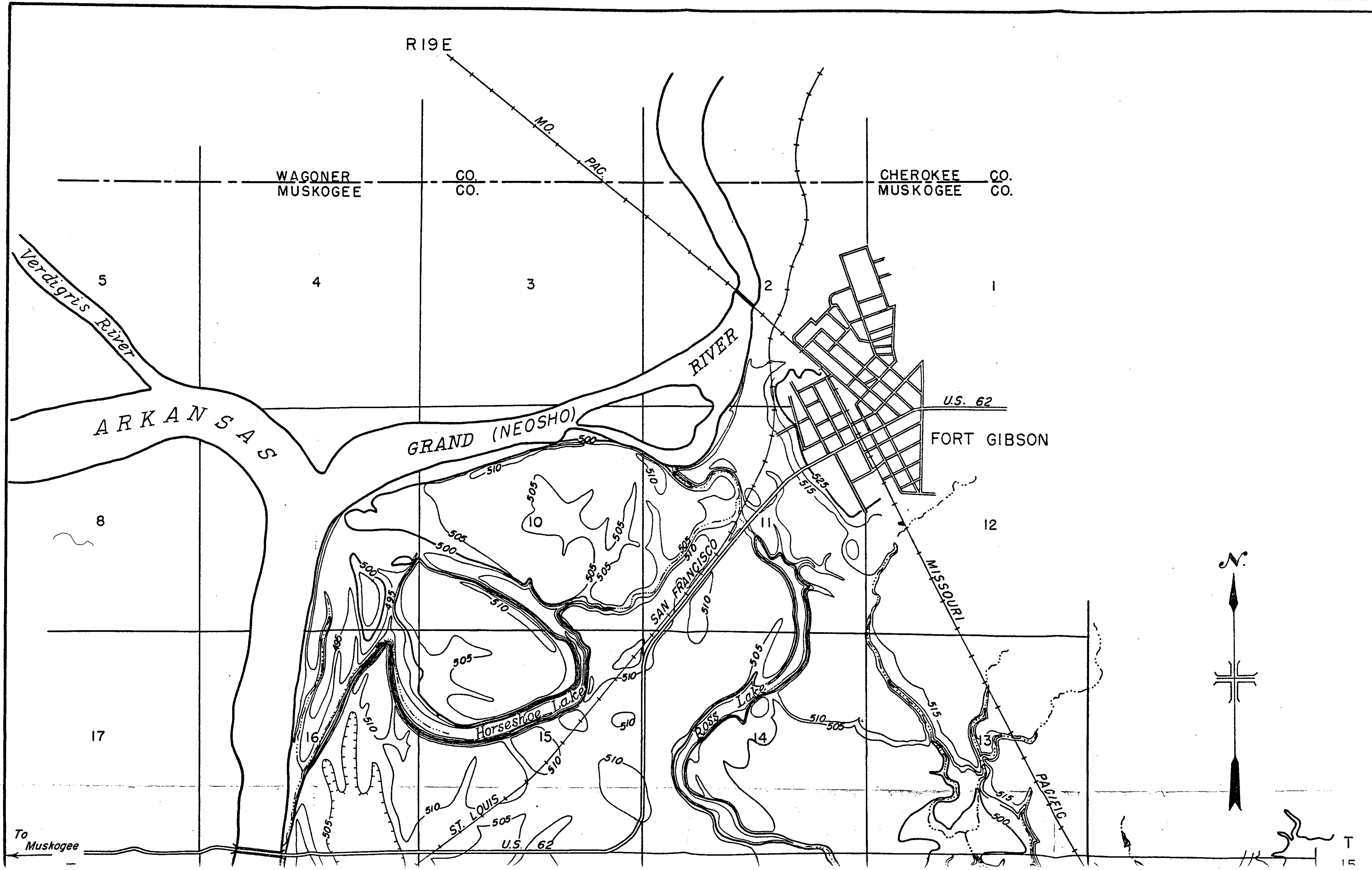
Samuel N. McPherson, SW¼NE¼SE¼ sec. 24, T. 15 N., R. 19 E.
Elevation 498 feet

| | | |
|---|---|---|
| Soil | 25 | 25 |
| Sand rock | 25 | 50 |
| Slate | 400 | 450 |

33. Logs CC-2, 3 and 4 represent oil wells and were reported to the Oklahoma Corporation Commission. Surface elevations are estimated from the topographic map (pl. II).




DIAGRAMMATIC CROSS SECTION, FORT GIBSON AREA, OKLAHOMA


R19E
MO. PAC.
WAGONER CO.
MUSKOGEE CO.
CHEROKEE CO.
MUSKOGEE CO.
Verdigris River
ARKANSAS
GRAND (NEOSHO) RIVER
FORT GIBSON
U.S. 62
MISSOURI PACIFIC
SAN FRANCISCO
ST. LOUIS
Horseshoe Lake
Ross Lake
To Muskogee
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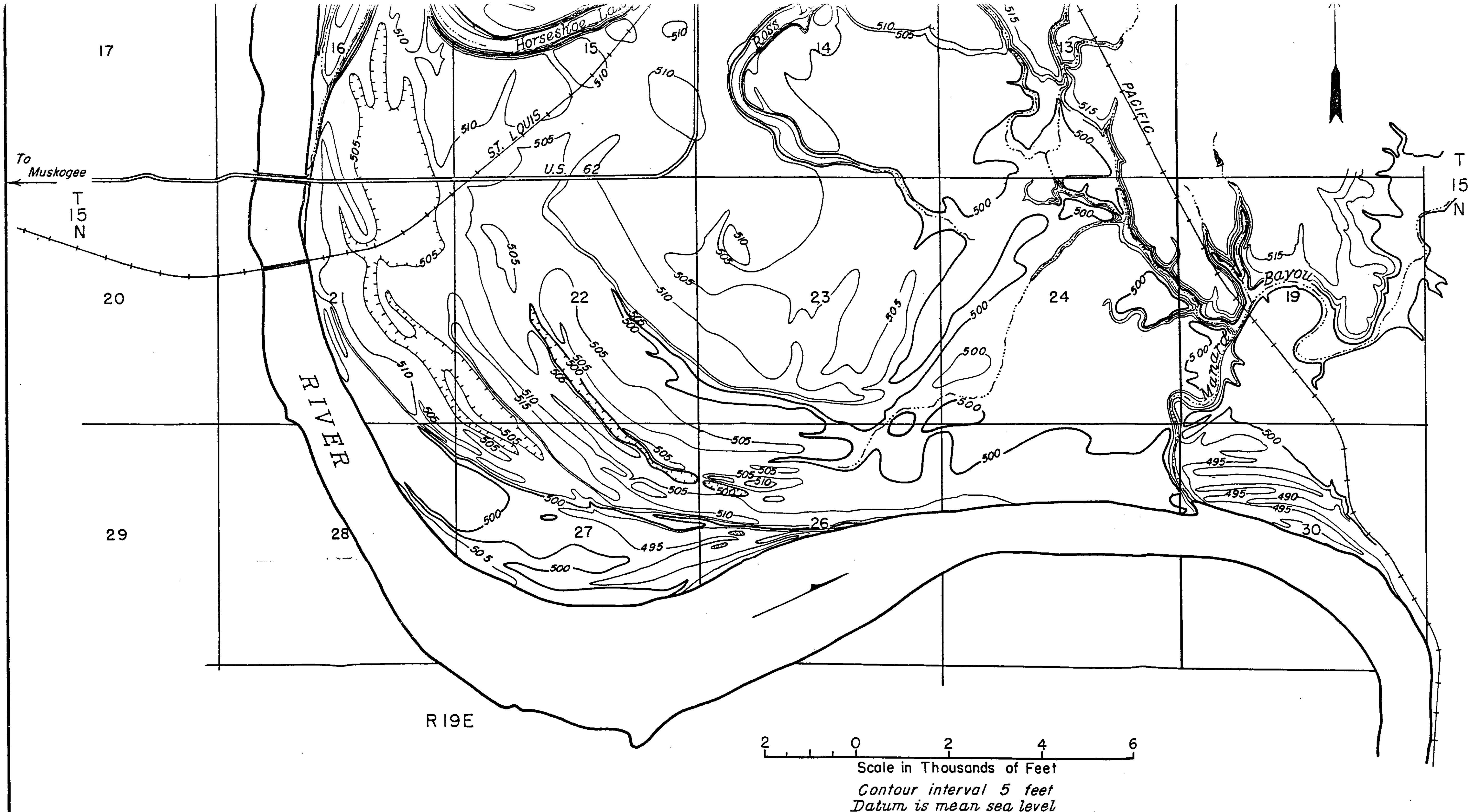
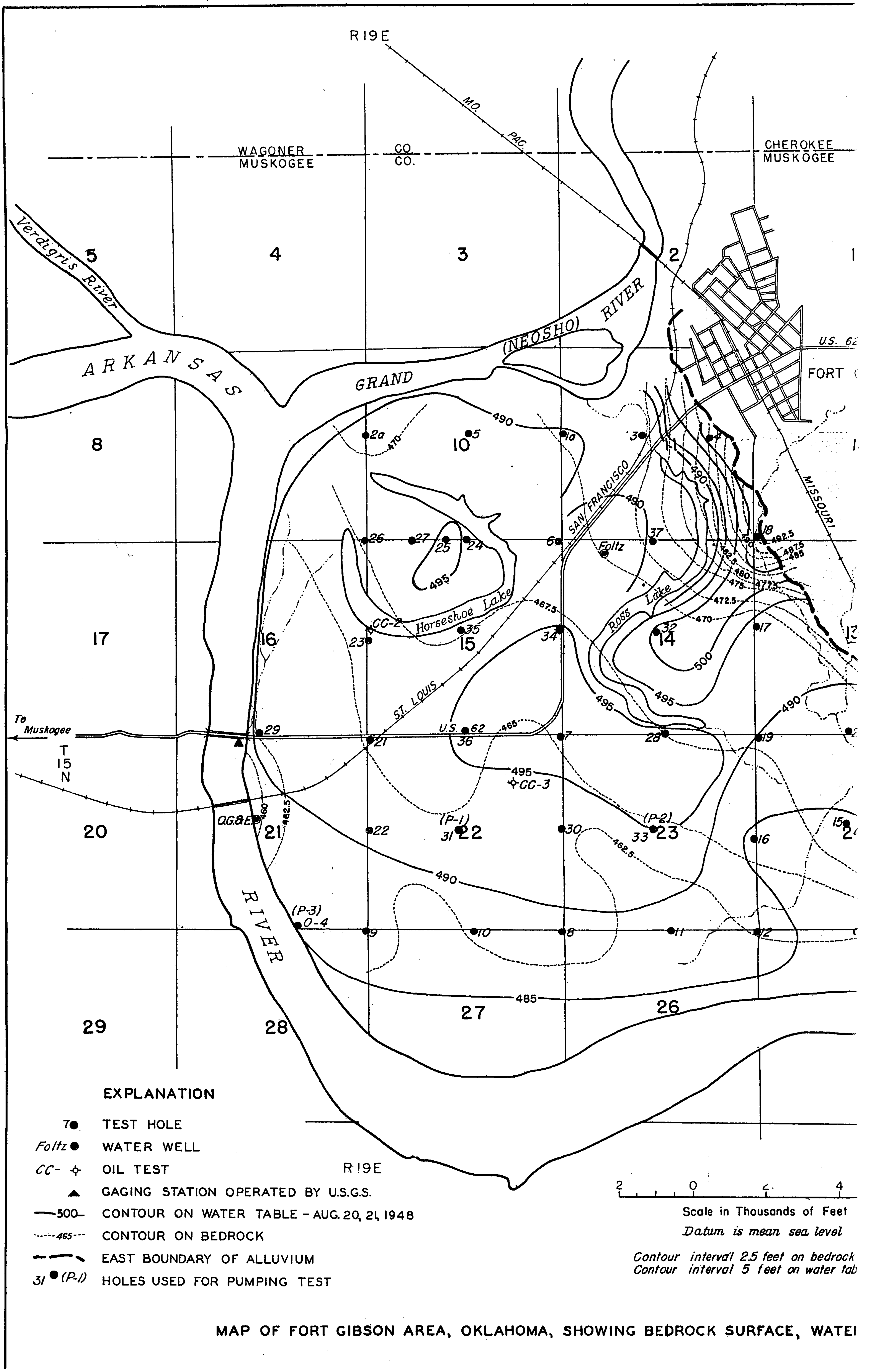
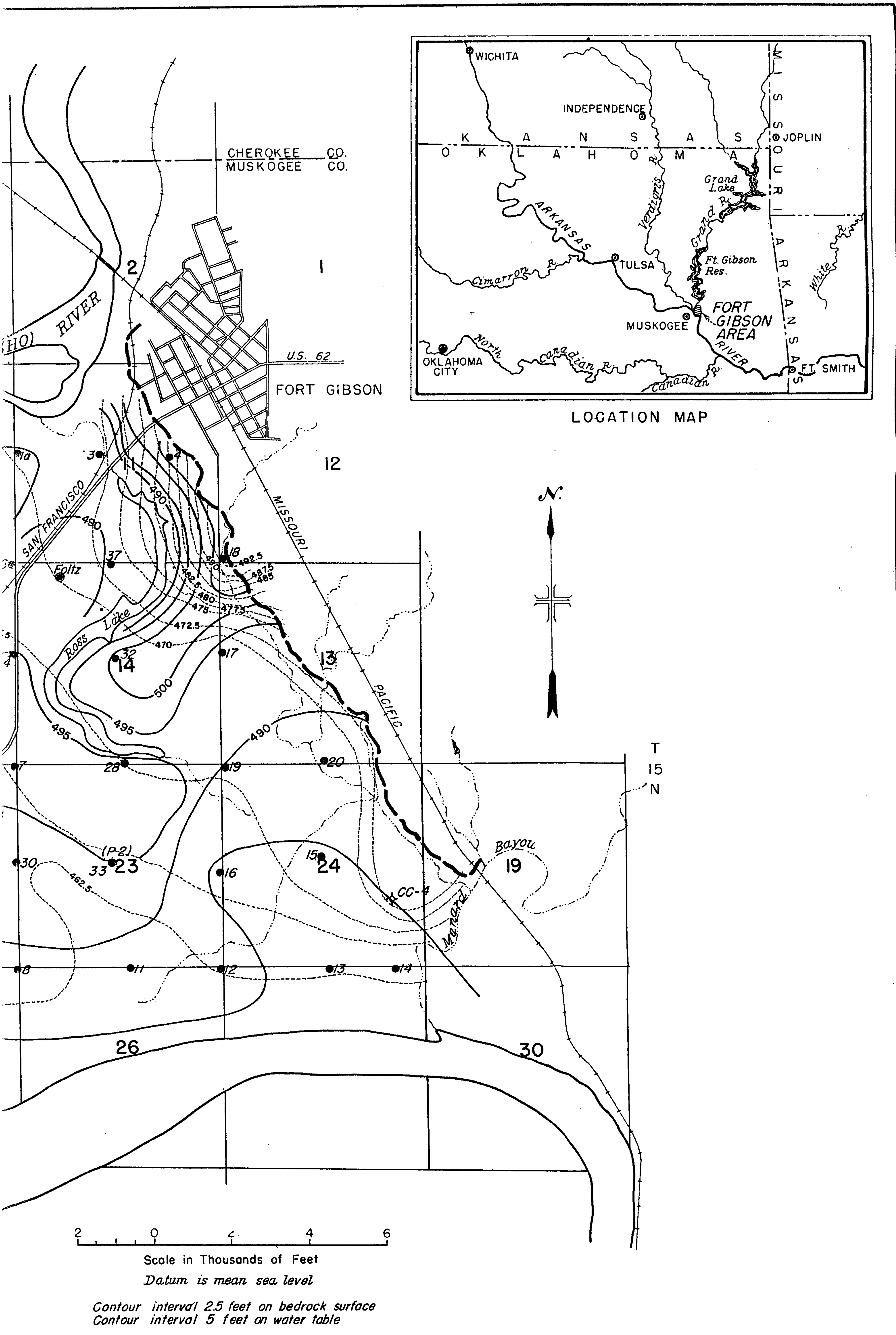



*Note:*
*This map was traced from valley topography sheets titled "Arkansas River and Tributaries, Arkansas and Oklahoma," prepared under the direction of the Arkansas River Survey Board, Published by Corps of Engineers U.S. Army, Little Rock District, edition 1940.*

TOPOGRAPHIC MAP OF THE FORT GIBSON AREA




MAP OF FORT GIBSON AREA, OKLAHOMA, SHOWING BEDROCK SURFACE, WATE




SHOWING BEDROCK SURFACE, WATER TABLE, AND LOCATIONS OF TEST HOLES