Geohydrology of the Lower Verdigris River Valley Between Muskogee and Catoosa, Oklahoma

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1999-A

Prepared in cooperation with the U.S. Army Corps of Engineers

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By H. H. TANAKA

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GEOHYDROLOGY OF THE LOWER VERDIGRIS RIVER VALLEY BETWEEN MUSKOGEE AND CATOOSA, OKLAHOMA

By H. H. TANAKA

ABSTRACT

Alluvium is the principal aquifer along the Verdigris River between Muskogee and Catoosa, Okla. Yields of 1 to 10 gallons of water per minute, adequate for most domestic and stock uses, are available in almost all areas underlain by alluvium. In places where the proportion of gravel to fine material is high, yields ranging from 10 to 30 gallons per minute are possible from large-diameter wells. Terrace deposits yield small amounts of water (1 to10 gallons per minute), adequate for most domestic and stock uses.

Water-level fluctuations, in response to seasonal changes in recharge and discharge, range from 1 to 5 feet. Long-term fluctuations, measured as changes in seasonal high or low water levels during 8 years of record, are about 10 feet in the alluvium and less than 5 feet in the terrace deposits.

Recharge to the alluvium is mainly by precipitation. Recharge maintains ground-water levels above the level of the Verdigris River, which, in turn, is the natural drain of the aquifer. Discharge from the alluvium is by seepage into the river and its tributaries and by evapotranspiration.

Generally, the quality of the water in the alluvium and terrace deposits is suitable for domestic, stock, and irrigation uses.

INTRODUCTION

This report is part of a comprehensive study of ground-water conditions along the Arkansas and Verdigris Rivers in Oklahoma and Arkansas being made by the U.S. Geological Survey in cooperation with the U.S.

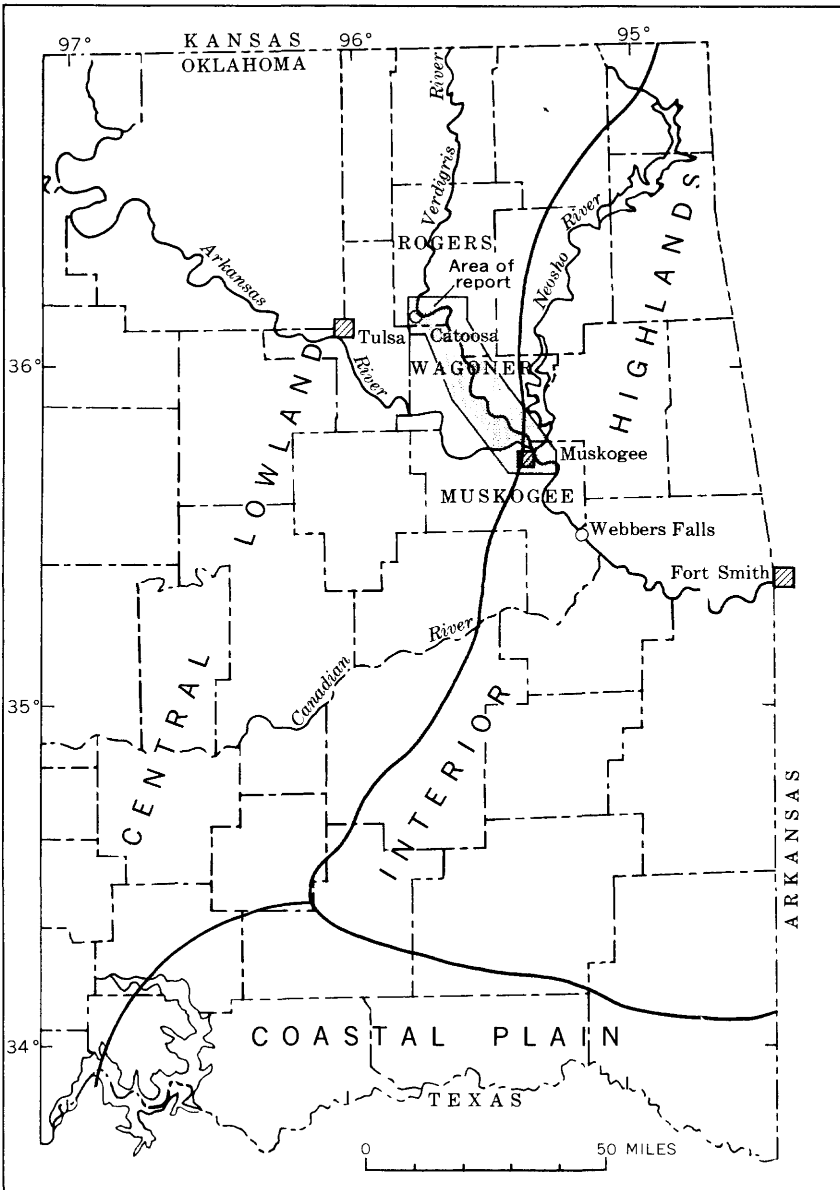

FIGURE 1.—Index map of eastern Oklahoma, showing location of report area.

Army Corps of Engineers. Other reports from this study are Bedinger, Emmett, and Jeffery (1963), Bedinger and Jeffery (1964), and Tanaka and Hollowell (1966). This report provides information on the occurrence, availability, and chemical quality of ground water along the Verdigris River between Muskogee and Catoosa, Okla., a distance of about 60 river miles (fig. 1). The basic data in this report are from an open-file report by Tanaka, Hart, and Knott (1965).

The area described in this report is underlain by flood-plain alluvium, terrace deposits, and bedrock formations. It is an area of about 85 square miles. The flood plain is generally one-half to 3 miles wide and averages about 2 miles wide. The terrace deposits range in width from less than 1 mile to 5 or more miles and average about 3 miles wide.

Field and laboratory data for this investigation were collected from 1957 through 1965. Domestic wells were inventoried, and a program of test drilling, water-level measurement, and quality-of-water sampling was started to obtain data on the geologic and hydrologic properties of the alluvial and terrace deposits. Between 1958 and 1962, 192 observation and test wells were augered or drilled in the Verdigris River valley. Selected samples collected during drilling were analyzed for hydraulic conductivity, porosity, specific yield, and grain size in the hydrologic laboratory of the U.S. Geological Survey, Denver, Colo. Aquifer tests to determine the transmissivity and storage coefficient of the alluvium were made at three locations.

Water levels are measured monthly in certain wells to relate fluctuations of ground water, stream stage, and precipitation. All observation wells were measured quarterly during 1958–60. Since 1960, all wells have been measured semiannually. Six wells were drilled, and instruments were installed to record continuous water-level fluctuations. Water samples collected from wells during the investigation were analyzed for chemical quality in the U.S. Geological Survey laboratory in Oklahoma City.

WELL-NUMBERING SYSTEM

Wells and test holes referred to in this report are numbered according to their location with respect to the Federal land-survey system used in Oklahoma. The first numeral in the number indicates the township; the second, the range; and the third, the section in which the well is located. The lowercase letters that follow the section number indicate the position of the well within the section: the first letter indicates the quarter section (160-acre tract); the second letter, the quarter-quarter section (40-acre tract); the third letter, the quarter-quarter-quarter section (10-acre tract). These letters are assigned in a counterclockwise direction, beginning with "a" in the northeast quarter. Within each 10-acre tract, the wells are numbered serially, as indicated by the final digit of the number. Thus, well 18N–16E–13bcc1 is the first well listed in the SW$\frac{1}{4}$SW$\frac{1}{4}$NW$\frac{1}{4}$ of sec. 13, T. 18 N., R. 16 E. (fig. 2).

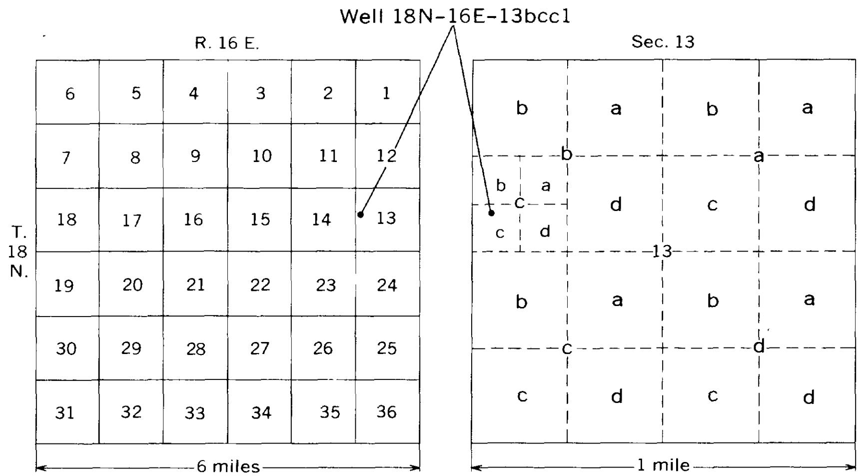

FIGURE 2.—Well-numbering system.

GEOLOGY AND HYDROLOGIC PROPERTIES OF THE ROCKS

BEDROCK

The term "bedrock" used in this report includes all consolidated sedimentary rocks of Pennsylvanian age that border or lie beneath the alluvial and terrace deposits of the Verdigris River between Muskogee and Catoosa, Okla. The distribution of the bedrock in relation to the alluvial and terrace deposits is shown on plate 1.

Most of the bedrock that crops out is sandstone or shale having little intergranular porosity. Water in this bedrock occurs mainly in fractures and joints. Sandstone contains significant amounts of water where the beds are thick and where the cementing material has been partly dissolved by solution. Shale ordinarily is too impermeable to transmit usable quantities of water to wells. Domestic wells that tap the shale obtain water from openings along joints, fractures, and bedding planes; these openings are best developed at shallow depths.

Depths to water in five wells in bedrock bordering the alluvial valley ranged from 17 to 33 feet below land surface. The well depths ranged from 56 to 101 feet. Potable water in bedrock aquifers generally grades with depth into highly mineralized impotable water. Fresh water probably does not occur at depths greater than 200 feet in the report area. Bedrock wells generally yield less than 5 gpm (gallons per minute); however, a few wells that intersect networks of joints and fractures can produce as much as 10 gpm of water.

TERRACE DEPOSITS

Terrace deposits that border the Verdigris River generally range in thickness from a few feet to about 80 feet and consist of unconsolidated clay, silt, sand, and gravel. These deposits may contain significant amounts of ground water for domestic use and for watering stock.

Terrace deposits along the Verdigris River cover an area ranging from less than 1 mile to 5 or more miles in width and several miles in length. The most extensive deposits are along the east side of the river and south of T. 19 N. In and north of township 19, the terrace deposits have been eroded to isolated remnants, which are generally less than 1 square mile. These remnants, especially where thin, are not favorable for the development of ground water.

Terraces can be distinguished at two levels along both sides of the Verdigris River. The surface of the low terrace ranges from 20 to 60 feet above the flood plain, and the surface of the high terrace ranges from 80 to 100 feet above the flood plain. In this report, the low and high terrace deposits are mapped and described as a single unit because they function as a single aquifer. The potentiometric surface passes from one terrace into the other without noticeable changes in slope. Some of the terrace deposits are connected hydraulically to the alluvium, and ground water moves slowly from these deposits to the alluvium.

The high terrace north of Muskogee, in the southern part of T. 16 N., R. 18 E. (pl. 1), is underlain by deposits ranging in thickness from 27 to 82 feet. Samples collected from these deposits during drilling were mostly silt and very fine sand but contained some medium to coarse sand. Depths to water in eight observation wells ranged from 15 to 41 feet, and the thickness of the saturated section ranged from 5 to 46 feet. Most wells on this terrace yield an adequate supply of water for domestic and stock purposes. The most favorable area for development of ground water probably is along and west of U.S. Highway 69, because the area and thickness of the deposit seem to increase toward the west.

The terrace northwest and southeast of Okay, in parts of T. 16 N., Rs. 18 and 19 E., is 25 to 40 feet above the flood plain. The deposits beneath this terrace range in thickness from 9 to 28 feet. Samples collected during drilling were mainly silt and very fine to fine sand. Wells 16N–18E–11bcc1 and 16N–19E–7ccc1 penetrate a few feet of fine gravel mixed with poorly sorted sand. Depths to water in four wells ranged from 6 to 16 feet, and the thickness of the saturated section ranged from 8 to 18 feet. Although this deposit is relatively thin, it will yield enough water for a domestic supply. Thicker terrace deposits may be in secs. 2 and 3, T. 16 N., R. 18 E., and in secs. 33, 34, and 35, T. 17 N., R. 18 E.

The terrace in T. 17 N., R. 17 E., southwest of the bridge that crosses the Verdigris River on State Highway 51, is 15 to 25 feet above the flood plain. The deposit beneath this terrace ranges in thickness from 15 to 42 feet. Samples collected during drilling were mostly silt but contained some very fine to fine sand. Samples from two wells, 17N–17E–27bca1 and –32aaa1, contained very fine to medium sand and fine gravel. Depths to

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water in five wells ranged from 8 to 18 feet, and the thickness of the saturated section ranged from 2 to 29 feet. The terrace deposit in T. 17 N., R. 17 E., is moderately thick, except near its contact with bedrock and alluvium, and should yield sufficient water for domestic purposes.

A large terrace deposit lies in parts of Tps. 17 and 18 N., R. 17 E., and in the southwest corner of T. 17 N., R. 18 E., west of U.S. Highway 69. The terrace surface is 25 to 50 feet above the flood plain. The thickness of the deposit in 15 test and observation wells ranged from 17 to 48 feet. Samples collected during drilling were mostly clay, silt, and very fine to fine sand. Depths to water in 13 wells ranged from 7 to 29 feet, and the thickness of the saturated section in 10 wells ranged from 4 to 28 feet. This extensive terrace deposit is moderately thick; and although it consists primarily of very fine grained material, it should yield sufficient water for most domestic needs.

In the north-central part of T. 18 N., R. 17 E., test holes indicate that the terrace deposit is relatively thin; and although ground-water yields probably would not be adequate for domestic needs during prolonged periods of dry weather, the deposit probably would yield a small amount of water. East of the Verdigris River and north and south of State Highway 33, in Tps. 19 and 20 N., R. 16 E., farm wells probably obtain water from the terrace deposit; however, the thickness and lithology of the deposit were not determined during this investigation.

Except for small isolated areas, the terrace deposits along the Verdigris River yield small amounts of water (1 to 10 gpm), adequate for most domestic and stock supplies. Larger yields are not available from terrace deposits.

ALLUVIUM

Deposits of Holocene alluvium underlying the flood plain consist of clay, silt, sand, and gravel. The alluvium consists mainly of clay and silt in the upper part, and it grades downward to coarser material. At many places near the base of the alluvium, a fairly distinct change occurs from very fine and fine sand to coarser sand and gravel in a poorly sorted matrix of clay, silt, and very fine sand.

Alluvium along the Verdigris River ranges in thickness from 0 feet, at its contact with the terrace or bedrock formations, to 60 feet, and it averages about 38 feet thick. The coarse material near the base of the alluvium ranges in thickness from 0 to 20 feet and averages about 5 feet thick. The surface of the alluvium is relatively flat, so differences in thickness of the alluvium are largely due to irregularities in the bedrock surface.

Two types of alluvium make up the flood plain of a river: point-bar deposits and overbank deposits. Point-bar deposits represent deposition within the river channel; overbank deposits represent deposition from floodwater flowing or standing outside the channel. Natural-levee, backswamp, and channel-fill deposits are types of overbank deposits. The alluvium of the Verdigris River flood plain was divided into various types of flood-plain deposits by interpretation of aerial photographs and by surface mapping (pl. 1).

Point bars are formed on the inside of bends of a river channel by lateral accretion of sediment and are composed of material that ranges greatly in size and texture. Their formation is part of the process by which erosion on the outside, or concave, bank and simultaneous deposition or the inside, or convex, bank cause the channel to migrate laterally. At the present time (1968), lateral migration of the Verdigris River channel is not apparent, but the broad flood plain indicates that migration has occurred in the past. In most of the Verdigris valley, point-bar deposits are overlain by thick overbank deposits, which consist mainly of clays and silts, and therefore cannot be identified at the surface.

Overbank deposits form when floods are too great to be contained by the stream channel. Under natural conditions, the Verdigris River periodically overtops its banks, and the sudden decrease in flow velocity as the water leaves the channel causes the coarser particles to be deposited along the banks of the river, forming natural levees. The coarser materials are deposited along the crest of the natural levee, and the finer materials are carried farther into the adjacent backswamp. From the crests, 5 to 10 feet above the adjacent flood plain, the natural levees slope gently landward and more steeply toward the channel. The natural levees are composed principally of fine sand, silt, and varying amounts of clay near the surface and of sandy and silty material at greater depth. Landward, the materials of the levees become progressively finer grained throughout and finally merge with the finer grained material of the adjacent backswamp part of the flood plain, so that the boundary of the levee away from the riverbank is indistinct. Because of their composition, natural levees normally are well drained, and this condition makes them well suited for agriculture. Consequently, most bottom land in the Verdigris valley that is first cleared for agriculture is wholly or partly on a natural-levee deposit.

Backswamps comprise the areas of the flood plain away from the river and natural levees. The deposits laid down in backswamps are composed of the very fine sediments that were carried during periodic floods to the lower areas of the flood plain marginal to the natural-levee deposit. They consist principally of clay and silt and include minor amounts of sand. The deposits are typically dark brown and contain some organic materials.

Channel-fill deposits occur where former stream channels have been abandoned and later filled with the channel-fill material. In the Verdigris River valley, these deposits represent abandoned meander loops, cut off from subsequent channels during times of flood. Examples of abandoned meander loops are in Tps. 17 and 18 N., R. 17 E. (pl. 1). The great volume and velocity of floodflow causes a stream to attempt to shorten its course, and frequently a new channel is cut across a meander loop in the old channel. As the floodwater subsides, the stream may return to its old channel, or it may remain in the new channel. If it remairs in the new channel, the upstream arm of the cutoff meander loop will gradually fill with sand or silty material. Eventually, the downstream arm of the cutoff river channel will also be filled. After complete isolation, most of the central part of the old channel will form a lake, which in turn will slowly fill with relatively impermeable silt and clay from periodic floods and may become farther removed from the new channel as the river migrates from the old channel.

Apparently, the Verdigris River has been stabilized in its present course for a long time, and the present flood plain is composed of sediment from many floods and has not been reworked by a meandering river. The dense vegetation on the flood plain has helped to reduce the velocity of floodwater and, as a result, has facilitated deposition of sediment.

The alluvium of streams tributary to the Verdigris River, mapped as tributary alluvium, is composed of very fine grained material of low hydraulic conductivity.

The quantity of water that a water-bearing material will yield and the rate at which water will move through the material are governed by the porosity, specific yield, storage, hydraulic conductivity, and transmissivity of the aquifer. Porosity relates to the total holding capacity of the aquifer; specific yield and storage relate to the recoverable part of the total holding capacity; hydraulic conductivity relates to the water-carrying capacity of part of the aquifer; and transmissivity relates to the water-carrying capacity of the full thickness of the aquifer.

The hydrologic characteristics of the alluvium and of the terrace deposits were determined by laboratory and field methods. The physical and hydrologic properites of selected samples, collected during drilling of test holes and wells, were determined in the U.S. Geological Survey hydrologic laboratory at Denver, Colo. These determinations included porosity, specific yield, and hydraulic conductivity of disturbed samples (table 1). The samples were also analyzed mechanically to determine size, distribution, and percentages of constituent grains (table 2).

Porosities of materials analyzed in the laboratory range from 30 to 50 percent and average about 37 percent (table 1). Generally, there is no wide variation in values of porosities of clay, silt, sand, or gravel. The variations probably are due more to the degree of sorting of the sample than to particle size. Specific yields of materials range from 1 to 29 percent and average about 15 percent. The wide variation in specific yield is due mainly to differences in grain size and in the degree of sorting of the

TABLE 1.—*Hydrologic properties of samples from selected test holes*

Well number (pl. 1)	Depth interval (ft)	Porosity (percent)	Specific yield (percent)	Hydraulic conductivity (gpd per sq ft)
Wagoner County				
16N-18E-15abb1	8–16	46.9	5.1	0.0020
	16–31	46.9	8.2	.002
	31–32	37.4	20.3	.6
	32–34	35.7	14.2	.08
23bba1	6–17	47.2	5.5	.0007
	17–30	37.7	21.1	.05
	30–36	36.5	15.8	.4
	36–42	37.3	19.8	6
16N-19E-19cdd1	25–30	33.0	14.8	3.0
17N-17E-8bbb1	30–35	38.0	12.5	.02
	35–41	31.2	10.4	1.0
18aab1	30–35	43.5	16.5	.08
	35–42	32.9	--------	.07
34bba1	25–35	34.1	15.2	2.0
	35–38	39.0	11.6	20
36ddd1	25–30	40.7	15.2	.1
	30–37	34.1	10.5	.2
18N-17E-6cbb2	40–45	33.8	7.1	.1
	45–50	35.8	1.1	.03
17daa1	30–38	39.3	29.2	8
19N-16E-9ccc1	35–41	32.7	16.2	.8
17dcc1	35–43	38.7	16.0	.1
	43–47	31.3	7.3	4
23abb2	35–40	36.2	25.4	3.0
	40–49	36.2	27.5	4
	49–53	32.1	10.6	.8
26cda1	30–35	38.8	28.4	3.0
	35–40	36.3	27.6	20
	40–47	34.6	18.5	2.0
Rogers County				
20N-15E-23bcb1	35–40	43.9	10.6	0.06
	40–46	30.5	--------	.9
24aaa1	35–40	35.6	26.7	6
	40–45	35.6	25.0	5
	45–50	35.6	21.6	3
20N-16E-8ddd1	40–45	35.6	3.9	.09
20abd1	45–50	49.6	17.9	.1
	50–55	39.7	10.6	.1
	55–59	35.6	2.3	.1
Average, both counties	--------	37.4	15.3	--------

sample. Fine-grained materials such as clay and silt have low specific yields, whereas well-sorted sands and gravel tend to have higher specific yields.

Laboratory values of hydraulic conductivity range from 0.002 to 20 gpd per sq ft (gallons per day per square foot). Small values indicate a proportionately large amount of silt and clay in the test samples, whereas larger values reflect a smaller percentage of the finer particles and more uniform sorting of the larger sized particles.

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TABLE 2.—*Percentage distribution of particle-size diameter (in millimeters) in samples from selected test holes*

[Numbers in size groups indicate percentage by weight of material retained on U.S. Standard Sieve Series sieves]

Well number (pl. 1)	Depth interval (ft)	Clay (<0.004)	Silt (0.004–0.0625)	Sand					Gravel
				Very fine (0.0625–0.125)	Fine (0.125–0.25)	Medium (0.25–0.5)	Coarse (0.5–1)	Very coarse (1–2)	Very fine to very coarse (2–64)
Wagoner County									
16N–18E–9ddd1	10–15	33.0	50.0	10.4	5.6	1.0	0.0	----------	----------
	15–20	6.4	7.0	2.9	3.9	14.4	5.4	7.8	52.2
	20–25	2.8	2.4	1.5	5.1	20.7	7.3	6.9	53.3
	25–30	4.7	4.3	2.0	6.5	33.8	13.9	13.7	21.1
	30–35	2.8	2.5	1.2	2.7	12.2	9.2	7.6	61.8
15abb1	8–16	27.5	35.6	15.7	15.7	1.3	1.2	1.0	2.0
	16–31	24.0	47.8	15.8	11.2	.8	.2	.2	----------
	31–32	12.0	20.3	10.1	27.6	16.8	7.1	5.2	.9
	32–34	11.5	23.7	8.3	7.3	5.7	11.5	18.7	13.3
23bba1	6–17	27.9	43.9	17.4	10.4	.2	.2	----------	----------
	17–30	9.8	15.2	7.4	43.5	21.3	.4	.0	2.4
	30–36	14.8	18.9	6.8	24.1	15.7	7.8	9.8	2.1
	36–42	9.2	12.5	3.7	8.9	11.7	11.6	22.8	19.6
23cdc1	20–25	21.6	37.0	16.8	20.4	4.0	.2	.0	----------
	25–30	10.1	18.0	8.8	9.6	5.7	1.6	3.8	42.4
	30–35	8.1	17.0	5.8	5.7	3.5	2.4	8.1	49.4
16N–19E–19cdd1	15–20	50.0	48.8	.8	.2	.2	.0	----------	----------
	20–25	41.6	52.0	4.2	2.0	.2	.0	----------	----------
	25–30	9.5	10.2	2.5	3.8	16.5	10.6	8.7	38.2
17N–17E–8bbb1	20–25	41.4	44.0	6.8	6.6	1.0	.2	----------	----------
	25–30	32.5	34.2	6.4	18.7	6.5	.8	.2	.7
	30–35	23.0	18.0	4.0	19.9	16.7	4.2	4.9	9.3
	35–41	10.2	11.5	3.4	11.6	11.4	6.5	9.2	36.2
18aab1	15–20	39.0	51.6	5.8	3.0	.6	----------	----------	----------
	20–25	31.8	51.4	11.2	5.2	.4	----------	----------	----------
	25–30	31.0	52.4	11.0	5.2	.4	----------	----------	----------
	30–35	22.4	37.0	11.7	8.5	6.2	5.2	5.4	3.6
	35–42	7.3	12.0	6.0	4.1	1.6	1.2	4.3	63.5

18dba1	7–22	57.0	37.6	3.2	1.6	.4	.2	--------	--------
	22–36	9.5	20.1	14.8	46.0	9.0	.4	.2	--------
24cdd1	15–20	22.0	28.0	6.7	13.9	19.1	5.5	2.9	1.9
	20–25	13.0	13.5	3.8	7.9	13.6	5.2	7.1	35.9
	25–29	14.0	14.7	4.5	12.4	10.0	5.4	6.3	33.7
26ccb1	7–27	23.2	46.0	21.2	9.0	.6	--------	--------	--------
	27–34	20.0	41.6	13.6	19.6	5.2	--------	--------	--------
27bca1	10–15	12.6	17.0	6.6	22.6	21.2	8.1	6.2	5.7
	15–18	14.0	18.6	7.5	13.2	8.5	4.8	9.1	24.3
34bba1	15–20	34.2	40.8	7.8	11.6	5.6	--------	--------	--------
	20–25	30.0	32.4	6.3	12.8	10.8	2.3	1.1	4.3
	25–35	11.0	7.4	1.1	3.4	10.1	5.5	7.8	53.7
	35–38	10.5	5.3	.5	.8	1.4	1.7	4.0	75.8
36ddd1	15–20	41.8	45.8	6.4	5.0	1.0	.0	--------	--------
	20–25	33.5	51.5	8.8	5.8	.4	.0	--------	--------
	25–30	19.1	32.0	5.4	15.9	24.0	2.4	.6	.6
	30–37	16.7	21.2	4.5	7.5	14.5	7.1	8.8	19.7
18N–16E–12aaa2	25–30	38.0	52.0	5.8	3.8	.4	.0	--------	--------
	30–32	12.2	19.5	4.1	10.2	7.0	3.9	6.5	36.6
13bbb1	12–22	33.0	47.8	15.6	3.0	.4	.2	--------	--------
	22–32	14.3	25.5	26.0	32.6	1.6	--------	--------	--------
	32–42	8.0	19.4	23.8	39.4	9.2	.2	--------	--------
13daa2	15–20	21.6	29.8	8.4	24.0	6.9	.2	.2	8.9
	20–25	13.5	23.3	11.5	36.0	13.1	.2	.2	2.2
	25–30	10.0	13.0	8.2	38.0	29.0	1.8	--------	--------
	30–35	--------	[1]11.4	8.7	40.1	31.8	5.4	2.2	.4
	35–37	--------	[1]9.8	8.5	37.9	30.0	7.5	4.5	1.8
18N–17E–6cbb2	30–35	34.0	49.0	10.4	6.0	.6	--------	--------	--------
	35–40	32.5	50.0	9.9	5.7	.4	.2	.4	.9
	40–45	15.0	22.5	5.9	8.5	18.7	4.7	5.1	19.6
	45–50	21.0	29.8	5.3	5.3	6.2	2.4	3.8	26.2
17daa1	20–25	32.4	48.0	13.2	6.2	.2	--------	--------	--------
	25–30	23.8	33.0	11.2	26.4	5.6	--------	--------	--------
	30–35	6.6	7.8	4.4	31.7	47.4	1.6	.4	.1
	30–38	6.0	8.2	2.8	27.7	52.7	2.2	.2	.2
19N–16E–5aaa3	17–27	34.0	53.6	9.8	2.4	.2	--------	--------	--------
	27–42	30.4	55.8	10.2	3.2	.2	.2	--------	--------
	42–52	28.0	53.4	11.8	6.0	.6	.2	--------	--------
	52–59	26.0	47.0	11.2	10.0	5.2	.4	.2	--------

See footnote at end of table.

TABLE 2.—*Percentage distribution of particle-size diameter (in millimeters) in samples from selected test holes*—Continued

Well number (pl. 1)	Depth interval (ft)	Clay (<0.004)	Silt (0.004–0.0625)	Sand					Gravel
				Very fine (0.0625–0.125)	Fine (0.125–0.25)	Medium (0.25–0.5)	Coarse (0.5–1)	Very coarse (1–2)	Very fine to very coarse (2–64)
Wagoner County—Contiuued									
19N–16E–5baa1	7–17	28.0	31.8	11.0	24.2	4.8	0.2	----------	----------
	17–32	8.5	11.9	22.2	54.0	3.2	.2	----------	----------
	32–39	10.2	17.7	22.7	40.6	7.7	.0	0.0	1.1
9ccc1	20–25	34.2	53.6	7.2	4.4	.6	.0	----------	----------
	25–30	36.4	50.2	7.6	4.8	.8	.2	.0	----------
	30–35	10.2	13.0	2.4	4.7	11.3	5.2	6.8	46.6
	35–41	7.8	11.3	2.8	10.6	27.3	8.2	9.8	22.2
15cbc1	30–35	32.0	50.4	8.8	7.8	1.0	.0	----------	----------
	35–40	32.4	52.0	7.0	6.6	2.0	.0	----------	----------
	40–45	14.0	24.6	6.3	9.1	11.0	4.8	6.1	24.1
	45–50	13.1	17.0	4.5	5.6	4.1	2.0	3.4	50.3
17dcc1	25–30	28.0	53.4	12.4	5.2	1.0	----------	----------	----------
	30–35	21.7	45.5	18.2	12.4	2.0	.2	----------	----------
	35–43	14.4	25.5	12.4	23.7	14.5	.9	.6	8.0
	43–47	4.0	7.3	2.3	3.7	3.5	2.2	6.5	70.6
20cdd1	30–35	33.6	40.0	11.6	12.2	2.6	.0	----------	----------
	35–40	25.6	37.0	12.2	18.8	6.4	.0	----------	----------
	40–45	14.2	17.0	5.7	9.7	28.0	7.8	5.8	11.8
	45–53	10.5	14.6	4.4	10.8	17.3	10.2	11.6	20.6
22ccc1	7–27	39.0	43.4	10.2	7.2	.2	----------	----------	----------
	27–43	22.0	26.2	19.1	22.5	9.3	.8	.1	----------
23abb2	20–25	50.0	47.8	1.6	.4	.2	----------	----------	----------
	25–30	48.0	48.6	2.0	1.0	.4	----------	----------	----------
	30–35	29.5	36.7	14.2	17.4	2.0	.2	----------	----------
	35–40	7.8	11.2	4.8	23.5	43.6	6.5	1.6	1.0
	40–49	7.0	9.0	5.3	26.2	45.1	4.9	1.0	1.5
	49–53	8.0	13.0	5.8	13.1	10.1	4.7	8.6	36.7
26cda1	15–20	32.0	48.8	9.2	9.0	1.0	.0	----------	----------
	20–25	32.2	47.0	8.0	10.8	2.0	.0	----------	----------
	25–30	31.6	48.0	8.0	10.4	2.0	.0	----------	----------
	30–35	9.9	12.2	3.6	33.1	39.3	1.4	.2	.3
	35–40	5.0	6.2	2.9	21.0	36.3	4.5	2.2	21.9
	40–47	4.3	5.4	2.2	3.8	7.7	5.0	4.9	66.7

Rogers County

20N-15E-15cdc1	27–42	23.0	46.4	19.6	10.0	0.8	0.2	----	----
	42–49	22.0	50.4	16.2	8.4	2.8	.2	----	----
23bcb1	15–20	48.0	50.6	.8	.4	.2	----	----	----
	20–25	36.2	53.0	7.0	3.6	.2	----	----	----
	25–30	38.0	50.0	7.4	4.2	.4	----	----	----
	35–40	28.5	39.4	5.9	7.7	10.2	2.9	2.7	2.7
	40–46	7.0	13.9	3.7	2.8	3.2	1.8	3.5	64.1
24aaa1	20–25	27.2	43.0	17.6	11.8	.4	----	----	----
	25–30	9.3	15.7	10.6	40.2	24.0	.2	----	----
	30–35	15.8	29.4	16.0	27.4	11.4	----	----	----
	35–40	6.0	9.5	7.1	35.9	35.6	1.7	.8	3.4
	40–45	5.9	10.8	7.4	31.4	31.7	5.5	2.3	5.0
	45–50	10.5	11.0	3.8	16.1	37.0	15.3	5.8	.5
20N-16E-8ddd1	20–25	32.0	51.4	10.6	5.2	.8	----	----	----
	25–30	25.0	45.0	12.8	15.4	1.8	----	----	----
	30–35	26.2	50.8	10.0	11.6	1.4	----	----	----
	35–40	29.8	45.5	10.4	10.8	2.4	.8	.2	.1
	40–45	15.8	25.5	7.7	9.5	4.9	3.9	5.4	27.3
20abd1	30–35	31.0	45.2	10.8	11.4	1.4	.2	----	----
	35–40	31.4	48.6	9.6	9.2	1.2	----	----	----
	45–50	31.6	54.0	8.4	5.2	.8	----	----	----
	50–55	17.0	32.9	5.7	6.6	14.1	7.6	5.2	10.9
	55–59	13.9	27.0	6.3	5.7	7.0	4.5	5.6	30.0

[1] Includes both silt and clay sizes.

Aquifer tests were made at three locations (pl. 1) to determine the hydrologic properties of the alluvium under field conditions. The field method for determining the hydraulic conductivity, transmissivity, and storage coefficient ordinarily consists of steadily pumping a well at a known rate. Measurements are made of the discharge rate from the pumped well and of the drawdown and of the recovery of water levels in one or more observation wells. The rate at which water levels in the observation wells decline or rise in response to starting or stopping the pump in the discharging well is related to the transmissivity and storage coefficient of the aquifer.

Measured yields from three large-diameter wells constructed for aquifer tests range from 10 to 29 gpm. This range in yield is typical of expected yields from large-diameter wells constructed in locations where the proportion of coarse sand and gravel to finer grained material is relatively large, although locally yields of as much as 75 gpm may be obtained.

Results of the three tests are summarized below:

Location	Thickness of aquifer (ft)	Rate of pumping (gpm)	Trans-missivity (gpd per ft)	Hydraulic conductivity (gpd per sq ft)	Storage coefficient	Length of test (hr)
17N-17E-18aab1	12	9.5	1,400	115	0.026	72
19N-16E-23abb2	19	29.2	12,000	630	.03	72
26cda1	15	28.1	12,000	800	-----	72

A relationship between the average grain size and laboratory values of hydraulic conductivity from table 1 was plotted, and a range of hydraulic conductivity was assigned for different average particle sizes. The hydraulic conductivities were revised after comparing them with the average grain sizes and transmissivities from aquifer tests at the three sites mentioned above. The revised table of hydraulic conductivities is shown in table 3.

TABLE 3.—*Hydraulic conductivities of alluvium and terrace deposits in the Verdigris River valley*

Type of material	Range in hydraulic conductivity (gpd per sq ft)
Sand, very coarse, and very fine gravel	250 –1,000
Sand, very coarse	120 – 500
Sand, coarse and very coarse	80 – 250
Sand, coarse	30 – 120
Sand, medium and coarse	15 – 80
Sand, medium	7 – 30
Sand, fine and medium	3 – 15
Sand, fine	1.5– 7
Sand, very fine and fine	.7– 3
Sand, very fine	.3– 1.5

The transmissivity of the alluvium and terrace deposits was estimated by carefully examining the well cuttings at each test-hole site and by assigning hydraulic conductivities from table 3 to the different types of materials. Areas where the transmissivity was estimated to be between 5,000 and 15,000 gpd per ft are indicated on plate 1. These areas are the most favorable for development of moderate quantities of ground water (10–30 gpm).

GROUND-WATER HYDROLOGY

OCCURRENCE AND MOVEMENT

Ground water in the Verdigris River valley is derived chiefly from rainfall seeping downward from the land surface. Below the water table, all pore space in the material is filled with water. If all the material penetrated by a well is permeable, the water will stand in the well at about the level of the water table. If the overlying material is semipermeable, the water will be confined under pressure, so that the static level in the well will be above the base of the confining material. The imaginary surface that coincides with the static water level in wells that tap a confined aquifer is called the potentiometric surface. Unconfined, or water-table, conditions exist in most of the report area. However, in parts of the area, water in the alluvium is confined by a relatively thick layer of clay, silt, and very fine sand (pl. 1).

After percolating downward to the zone of saturation, the water moves under the influence of gravity or potentiometric head to areas of discharge such as streams, springs, and pumping wells. Water moves down the slope of the hydraulic gradient, from points of high to points of low hydraulic head, and approximately at right angles to the contour lines on the potentiometric map (pl. 2). The rate of movement in the alluvium under natural conditions probably is only a few tens of feet per year.

FLUCTUATION OF THE POTENTIOMETRIC SURFACE

Water levels in most wells fluctuate continuously, primarily as a result of changes in the amount of water in storage in the aquifer. Changes in storage are caused by differences in the rates of ground-water recharge and discharge.

Water-level fluctuations in the Verdigris valley can be separated into short term, seasonal, and long term. Short-term fluctuations occur within a few hours or days after a change in the recharge or discharge relationship, or they occur in response to changes in pressure or load on the aquifer. Fluctuations of water levels in response to temporary changes in river stage and changes in atmospheric pressure are examples of short-term fluctuations.

Seasonal fluctuations of water levels are caused by variations in recharge or discharge during different seasons of the year. Water levels generally rise during the winter and are highest in the early spring, when recharge by spring rains is greater than discharge by evapotranspiration and seepage. Conversely, water levels decline rapidly during summer, when discharge by evapotranspiration and seepage is greater than recharge by rainfall. Typical seasonal water-level fluctuations in alluvium, ranging from 1 to 5 feet, for the period 1959–67 are shown by the hydrographs of wells 18N–16E–13bcc1 and 19N–16E–20aaa1 (fig. 3).

Long-term fluctuations in water levels reflect cumulative differences in recharge and discharge during a longer period of time. Water levels rise in years of above-normal precipitation and decline in years of below-normal precipitation. According to U.S. Weather Bureau records, the cumulative deficiency of precipitation from normal during the 3-year period 1962–64 at Muskogee was 29.39 inches. The deficiency in precipitation, and therefore the diminution of recharge to the aquifer, is reflected by consistent declines in water levels for the same period of time, as indicated by the hydrograph of well 17N–17E–35aab1 (fig. 3). Long-term fluctuations of water levels in the alluvium typically are about 10 feet for the period of record (fig. 3). In the terrace deposits, typical water-level fluctuations generally are less than 5 feet, as shown by the hydrograph of a representative well—18N–17E–29cbc1 (fig. 3).

RECHARGE AND DISCHARGE

Ground-water recharge is the addition of water to a ground-water reservoir. The ground-water reservoir in the alluvium is recharged principally by infiltration of rainfall and to a lesser extent by underflow from adjacent terrace deposits and bedrock and by influent seepage from the river during extreme high flow.

The flood plain receives an average annual precipitation ranging from about 38 inches at the weather station near Claremore to 42 inches at the station near Muskogee. A part of the precipitation infiltrates to the aquifer and is added to the water in storage. The amount of precipitation absorbed by the soil depends in part upon the character of the surface materials. Much of the surface of the alluvium is composed of clay, silt, and very fine sand, which absorb and transmit water very slowly. The seasonal distribution of rainfall is a major factor in ground-water recharge. Generally, precipitation during late fall, winter, and early spring will produce maximum ground-water recharge, because evaporation and plant transpiration are least effective during this time.

Influent seepage from the river generally occurs during periods of high river stage, when the water surface of the river temporarily is higher than the adjoining water table. Normally, the potentiometric surface slopes toward the river, as shown in profile (pl. 1); but during high stage, the

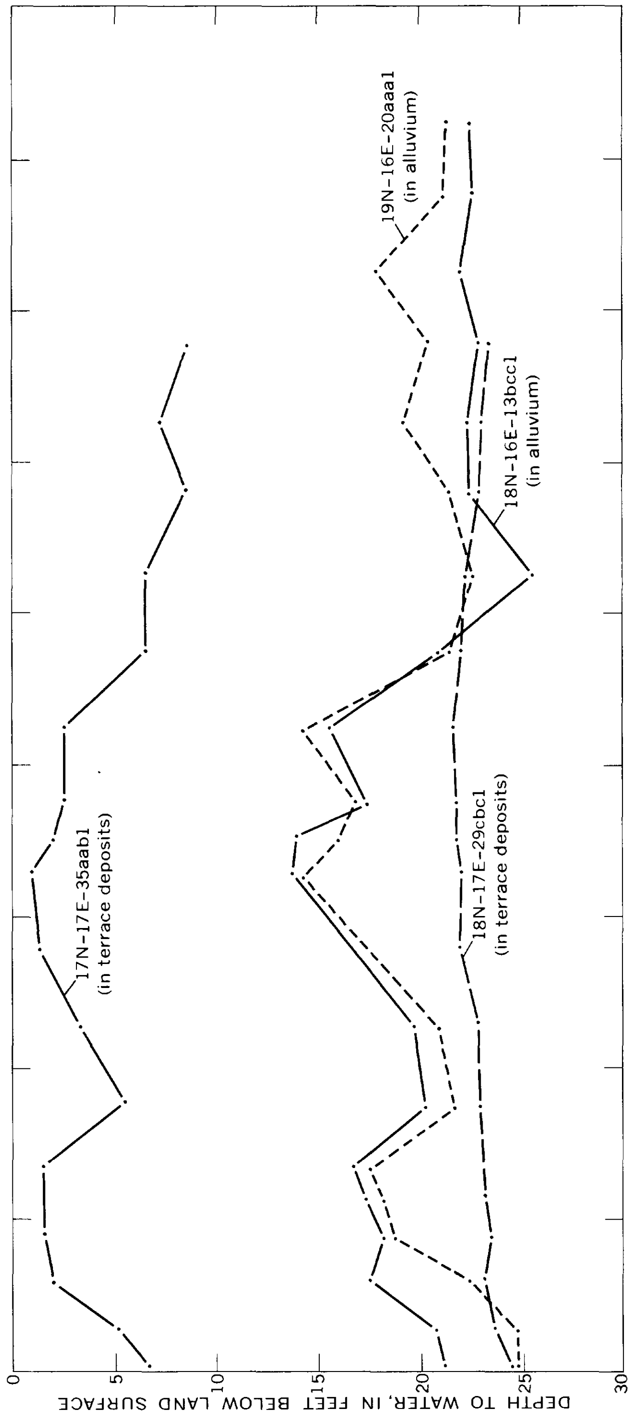

FIGURE 3.—Hydrographs of wells in alluvium and in terrace deposits along the Verdigris River.

slope of the potentiometric surface near the river is temporarily reversed as water enters the aquifer. This is illustrated in T. 19 N., R. 16 E., by the shape of the potentiometric surface after an unusually high stage of the Verdigris River (fig. 4). The potentiometric surface soon readjusts to a slope toward the river as the river returns to normal stage.

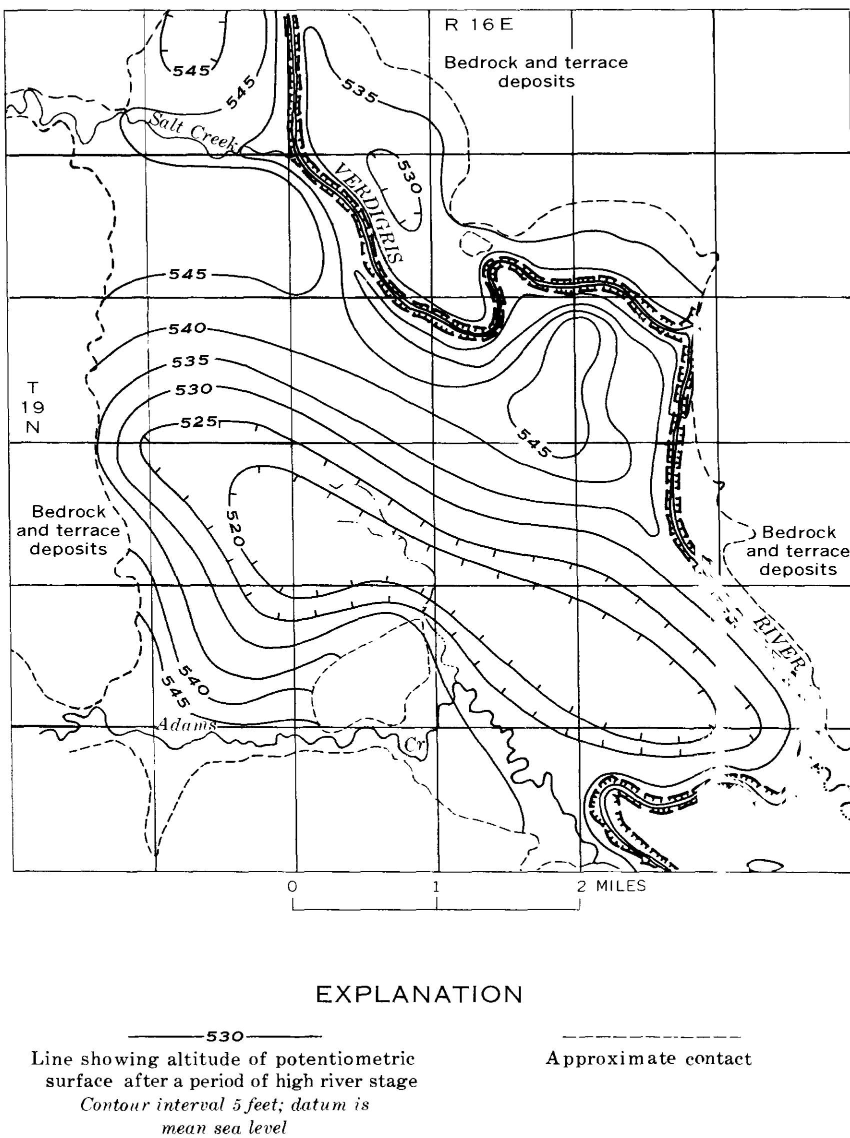

FIGURE 4.—Potentiometric map showing effects of high river stage on ground water in alluvium in T. 19 N., R. 16 E.

Probably the greatest amount of ground water in the alluvium is discharged by seepage into the channels of the Verdigris River and its main tributaries during periods of normal and low flow.

Ground water in the alluvium and in the adjacent terrace deposits is discharged mostly by seepage into streams and by evapotranspiration into the atmosphere. Only a small part of the total is discharged from the aquifer by springs and wells.

Evapotranspiration is the loss of water to the atmosphere by evaporation from the surface of both land and water and by transpiration from plants. In this region of moderately heavy rainfall, dense vegetation, and large areas of poorly drained land, large quantities of water are discharged to the atmosphere by evapotranspiration before and after the water reaches the potentiometric surface. In places where the potentiometric surface and capillary fringe are at or near the land surface, ground water is readily discharged into the atmosphere by evapotranspiration. Even where the potentiometric surface is between 10 and 20 feet below land surface, probably some discharge of ground water by evapotranspiration takes place, because water can be lifted tens of feet by capillary action where fine-grained material overlies the water table.

Springs are few and are not an important means of ground-water discharge. Most springs are seeps near the base of terrace deposits, where the underlying material is composed of clay or silt or where the potentiometric surface intersects the land surface, such as in deep ravines or gullies.

Small amounts of water for domestic and livestock use can be obtained from dug, drilled, or driven wells in almost all parts of the area. Yields of domestic and stock wells reported by landowners ranged from 1 to 5 gpm; however, these figures may represent the maximum demand of the landowner, rather than the maximum yield available from a properly constructed well at a particular location.

CHEMICAL QUALITY OF GROUND WATER

Ground water in the alluvium generally is of the calcium, magnesium bicarbonate type, variable in dissolved-solids content, and hard (table 4). At a few places, the concentrations of sulfate, chloride, and nitrate are high. However, the quality of most of the water in the alluvium and in the terrace deposits is suitable for domestic and stock use.

The chemical quality of water from the alluvium is summarized by listing the maximum, minimum, and modal concentrations of the principal constituents from table 4. The maximum values in table 5 for sodium, sulfate, chloride, and nitrate in general represent temporary and localized conditions which may be caused by seepage from bedrock or from adjacent formations or by contaminated seepage from the land surface. The modal values represent the concentrations that occur most often.

TABLE 4.—*Chemical analyses of water from selected wells in the Verdigris River valley*

[Results in milligrams per liter, except as indicated]

Well number (pl. 2)	Date of collection	Temperature (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Percent alkalinity	Sodium-adsorption-ratio	Specific conductance (micromhos at 25°C)	pH
Wagoner County																				
16N-18E-11bcc1	10-13-59	----	20	10	[1] 177	----	402	12	60	46	0.5	----	569	92	0	81	73	8.0	876	8.5
14aba1	8-27-59	----	17	9.1	[1] 182	----	390	12	65	48	1.2	----	548	80	0	83	71	8.8	876	8.5
	5-6-60	14	55	6.8	[1] 173	----	516	0	52	46	.1	----	599	165	0	70	78	5.9	983	7.7
15aaa1	8-13-59	----	26	8.5	[1] 33	----	140	0	29	19	.7	----	197	100	0	42	67	1.4	330	7.9
	5-6-60	15	52	16	[1] 55	----	230	0	72	36	.1	----	356	196	8	38	60	1.7	621	7.4
15bba1	8-13-59	----	88	24	[1] 31	----	372	0	25	40	.0	----	414	320	15	17	79	.8	692	8.2
16abb1	8-13-59	----	22	6.1	[1] 43	----	140	0	21	26	.0	----	220	80	0	54	66	2.1	360	8.0
22aab1	12-3-59	----	48	7.8	[1] 42	----	202	0	25	36	.8	----	290	152	0	37	68	1.5	472	7.8
33cad1	10-9-58	----	64	14	22	2.6	264	0	40	1.3	.6	----	315	230	14	17	83	.6	522	8.2
16N-19E-33bcc1	11-19-58	----	21	9.1	26	.6	123	0	15	14	.0	0.37	180	90	0	38	75	1.2	277	8.0
17N-17E-9ccc1	8-13-59	----	56	11	[1] 14	----	204	0	6.2	29	.7	----	250	184	17	14	78	.5	402	8.1
10cbc1	8-13-59	----	30	8.0	[1] 30	----	110	0	33	34	.7	----	200	108	18	38	52	1.3	344	7.9
17acc1	8-13-59	----	32	4.9	[1] 63	----	212	0	20	30	.0	----	254	100	0	58	73	2.7	432	8.1
	3-30-60	----	62	11	[1] 83	----	396	8	13	20	----	----	400	200	0	47	----	2.5	684	8.4
19ada1	8-13-59	----	37	14	[1] 17	----	168	0	7.4	31	.0	----	210	152	14	19	73	.6	344	8.0
27ada1	--------	----	85	26	[1] 56	----	328	0	92	51	5.2	----	505	320	51	27	61	1.4	821	8.0
27dab1	12-3-59	----	18	3.6	[1] 17	----	60	0	8.6	26	1.8	----	131	60	11	38	51	.9	210	7.2

18N-16E-12abb1	12- 3-59	----	31	20	[1] 201	----	372	0	214	48	1.0	----	709	160	0	73	51	6.9	1,110	7.9
19N-16E-4bba1	12- 3-59	----	17	4.3	[1] 17	----	64	0	26	11	1.2	----	137	60	8	38	55	.9	180	7.4
5aaa1	8-13-59	----	50	13	[1] 30	----	224	0	27	24	.1	----	275	180	0	27	75	1.0	470	8.2
	12- 3-59	----	44	11	[1] 15	----	128	0	53	21	.2	----	244	156	51	18	55	.5	376	7.8
5aba1	8-13-59	----	21	15	[1] 58	----	252	0	21	8.8	.0	----	264	116	0	52	86	2.3	441	8.2
5baa1	8-13-59	----	35	17	[1] 21	----	196	0	1.6	28	.0	----	211	156	0	23	80	.7	380	8.2
5bba1	8-13-59	----	146	43	[1] 164	----	272	0	519	94	.5	----	1,140	540	317	40	25	3.1	1,560	8.2
5ccc1	10-29-58	----	62	18	----	2.3	344	8	----	44	.1	----	----	230	0	----	----	----	802	8.3
22bbb1	12- 3-59	----	38	10	[1] 37	----	248	0	.00	9.9	1.3	----	235	138	0	37	93	1.4	407	8.1
30aaa1	10-29-58	----	46	18	110	.8	200	0	214	31	.1	----	563	190	26	56	79	3.5	856	8.0
Rogers County																				
20N-15E-17aaa1	12- 3-59	----	86	15	[1] 9.9	----	322	0	1.2	18	7.6	----	358	275	11	7	89	0.3	548	8.0
20N-16E-33cdc1	8-13-59	----	40	16	[1] 84	----	376	0	19	14	.0	----	370	164	0	53	89	2.9	626	7.9

[1] Includes sodium and potassium.

TABLE 5.—*Maximum, minimum, and modal concentrations of chemical constituents in the water from the alluvium of the Verdigris River valley between Muskogee and Catoosa*

[Results in milligrams per liter, except as indicated]

Constituent	Maximum	Minimum	Mode
Sodium (Na)	201	9.9	46
Bicarbonate (HCO_3)	516	60	250
Sulfate (SO_4)	519	.00	20
Chloride (Cl)	94	1.3	30
Nitrate (NO_3)	7.6	.0	.5
Hardness as $CaCO_3$	540	60	160
Dissolved solids	1,140	131	270
Specific conductance (micromhos at 25°C)	1,560	180	450

A comparison of the modal values in table 5 with the modal values of water in the Arkansas River alluvium between Fort Smith, Ark., and Muskogee (Tanaka and Hollowell, 1966, p. 38) shows that the water in the Verdigris River alluvium between Muskogee and Catoosa is of better quality. The dissolved-solids content of water in the two areas is similar, but the modal hardness of water in the alluvium of the Verdigris River is 160 mg/l (milligrams per liter), compared with 225 mg/l for water in the alluvium of the Arkansas River.

To the average user of water, the chief factors in regard to the chemical content are the taste and hardness of the water. Mineral constituents in water, within reasonable limits, add to the potability of water because they are responsible for its taste. If there were no chemicals dissolved in water, it would have the flat taste of distilled water. Hardness of water is caused mainly by the dissolved minerals calcium and magnesium, mostly in the form of bicarbonates or sulfates. Harder water requires more soap to produce a lather than does softer water. Water that has a total hardness of less than 50 mg/l generally is rated as soft. Hardness between 50 and 150 mg/l does not seriously interfere with most household uses of water. When the hardness exceeds 150 mg/l, treatment for its removal is generally desirable for most uses.

The U.S. Public Health Service drinking water standards (1962) state that the following chemical substances should not be present in a water supply in excess of the listed concentrations if, in the judgement of the reporting agency and certifying authority, other suitable supplies are or can be made available.

Substance	*Milligrams per liter*
Total dissolved solids	500
Chloride	250
Sulfate	250
Nitrate	45

Generally, ground water in the Verdigris River valley is of good quality (table 4). It adequately meets the U.S. Public Health Service's drinking water standards and, because of the moderate to low sodium and dissolved-solids content, is within the general "excellent to good" classification for irrigation use (Wilcox, 1948).

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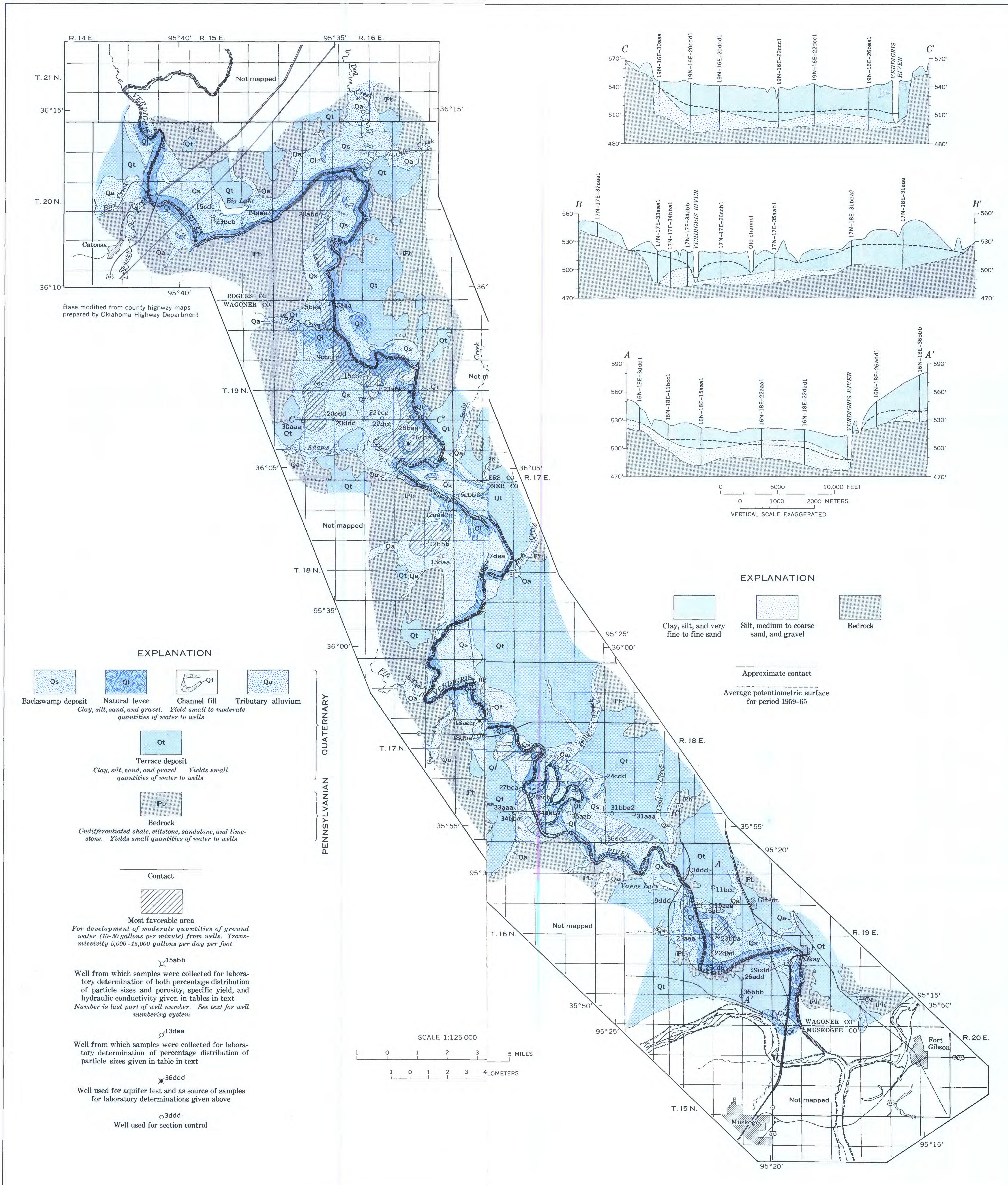

GEOLOGIC MAP OF THE VERDIGRIS RIVEVALLEY BETWEEN MUSKOGEE AND CATOOSA, OKLAHOMA, SHOWING AREAS FAVORAE FOR DEVELOPMENT OF GROUND WATER

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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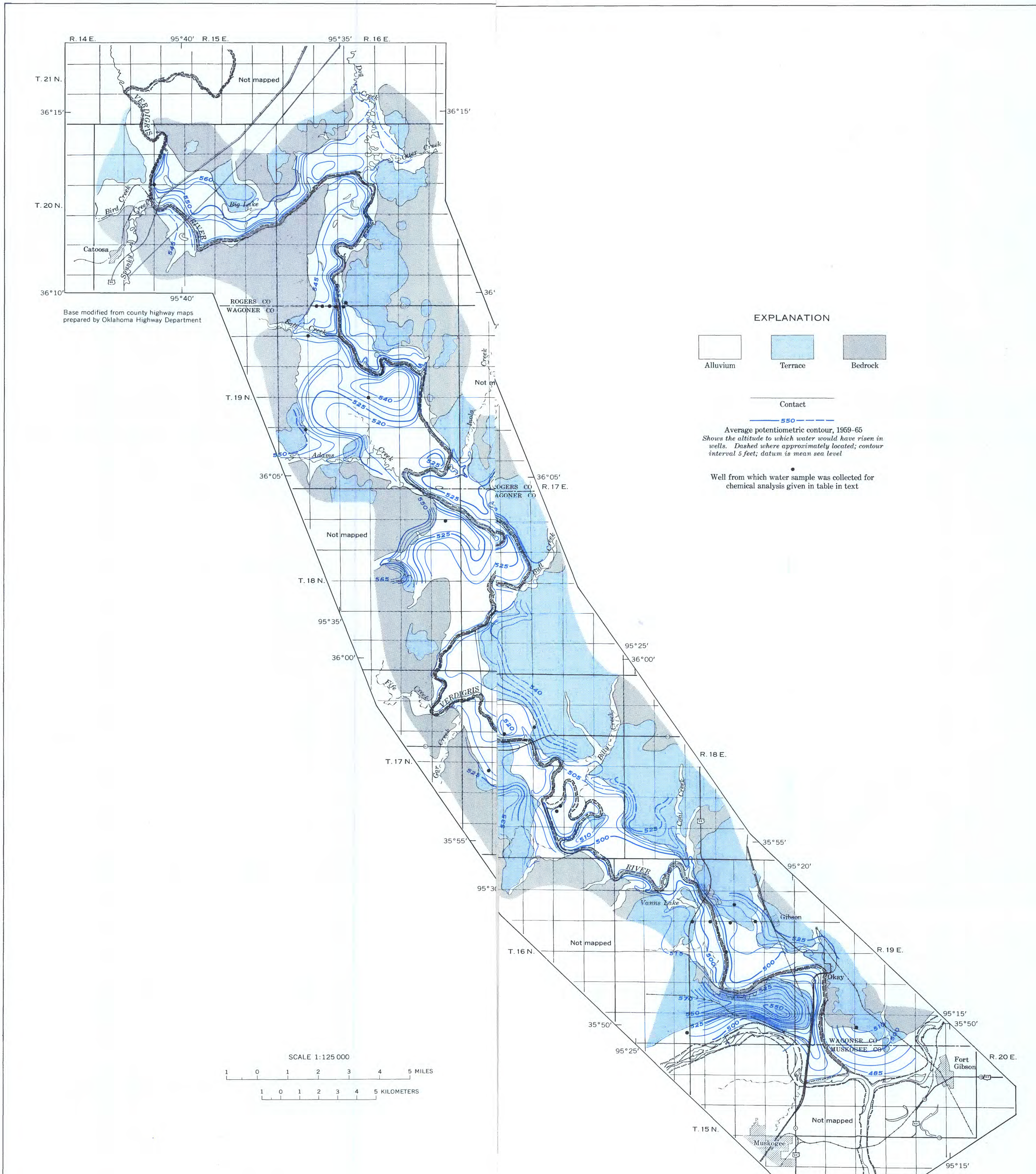
WATER-SUPPLY PAPER 1999-A
PLATE 2



POTENTIOMETRIC MAP OF THE VERDIGRIS RIVER VALLEY BETWEEN MUSKOGEE AND CATOOSA, OKLAHOMA

442-485 O - 72 (In pocket)