Executive Summary

ANALYTICAL ASSESSMENT OF GROUND-WATER AVAILABILITY FOR COMMUNITIES AND RURAL WATER DISTRICTS IN COMANCHE COUNTY, SOUTHWESTERN OKLAHOMA

by

Douglas C. Kent

Jerry Overton

Ben Greeley

T. Boone Pickens

School of Geology

Oklahoma State University

ANALYTICAL ASSESSMENT OF GROUND-WATER AVAILABILITY FOR COMMUNITIES AND RURAL WATER DISTRICTS IN COMANCHE COUNTY, SOUTHWESTERN OKLAHOMA

AND

ADDENDUM:

DISTRIBUTION OF WELL YIELDS IN THE ARBUCKLE GROUP AQUIFER BASED ON LINEAMENT ANALYSIS

FINAL REPORT

TO THE

OKLAHOMA WATER RESOURCES BOARD

BY

DOUGLAS C. KENT
PRINCIPAL INVESTIGATOR

AND

BENJAMIN B. GREELEY
JERRY V. OVERTON

DEPARTMENT OF GEOLOGY
OKLAHOMA STATE UNIVERSITY

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INTRODUCTION

This is a final report to the Oklahoma Water Resources Board in partial fulfillment of contract No. 1-5-71325 through Oklahoma State University and the Geology Department.

A hydrogeologic analysis of Comanche County south of the Wichita Mountains, and including small portions of Cotton, Stevens, and Tillman Counties was conducted to estimate ground-water reserves capable of yielding adequate quality ground-water to supplement municipal and rural water district supplies within tolerable limits of nitrate and fluoride. Average well yields were determined and a summary of available ground water was prepared.

Studies by Stone (1981) and Green and Al-Shaieb (1981) have been made to assess the fluoride problem found in ground-water supplies in Comanche County and to identify alternative solutions to this problem. The primary conclusion from these reports was to utilize local ground-and surface-water supplies. Feasible ground-water resources include the alluvium and shallow portions of the Post Oak Aquifer. Ground water from the deeper Arbuckle Aquifer might be mixed with other sources in order to reduce the fluoride concentration. Havens (1983) confirmed the findings of Stone (1981) and Green and Al-Shaieb stating that little of the deep ground water is consumed by humans due to the high fluoride content.

The larger study area contains 1,440 square miles, mostly in Comanche County (Figure 1). Primary focus was restricted to the area south of the Wichita Mountains, an area of approximately 936 square miles. The Wichita Mountains to the north rise some 500 feet above the adjacent study area. Principal drainage is toward the south to the Red River by West Cache Creek, East Cache Creek, and Big Beaver Creek. Analysis was directed to the three aquifers found to be present within this latter area. These are the alluvium deposits along major creeks, the Post Oak Aquifer, and the Arbuckle Aquifer.

Data from the analysis will serve as input to a numerical model of the ground-water hydraulics in the Post Oak Aquifer to be described by Greeley (1985).

GEOLOGY

The geology in the study area consists of Cambrian igneous rocks in the Wichita Mountains, Ordovician and Cambrian limestone and dolomites adjacent to the mountains, and Permian red bed conglomerates, sandstones, and shales on the plains (Figure 2). The Lower Permian Post Oak Conglomerate, Hennessey Shale, and Garber Sandstone lie on the flanks of the Wichita Mountains. The Middle Permian El Reno Group of sandstones and shales and the

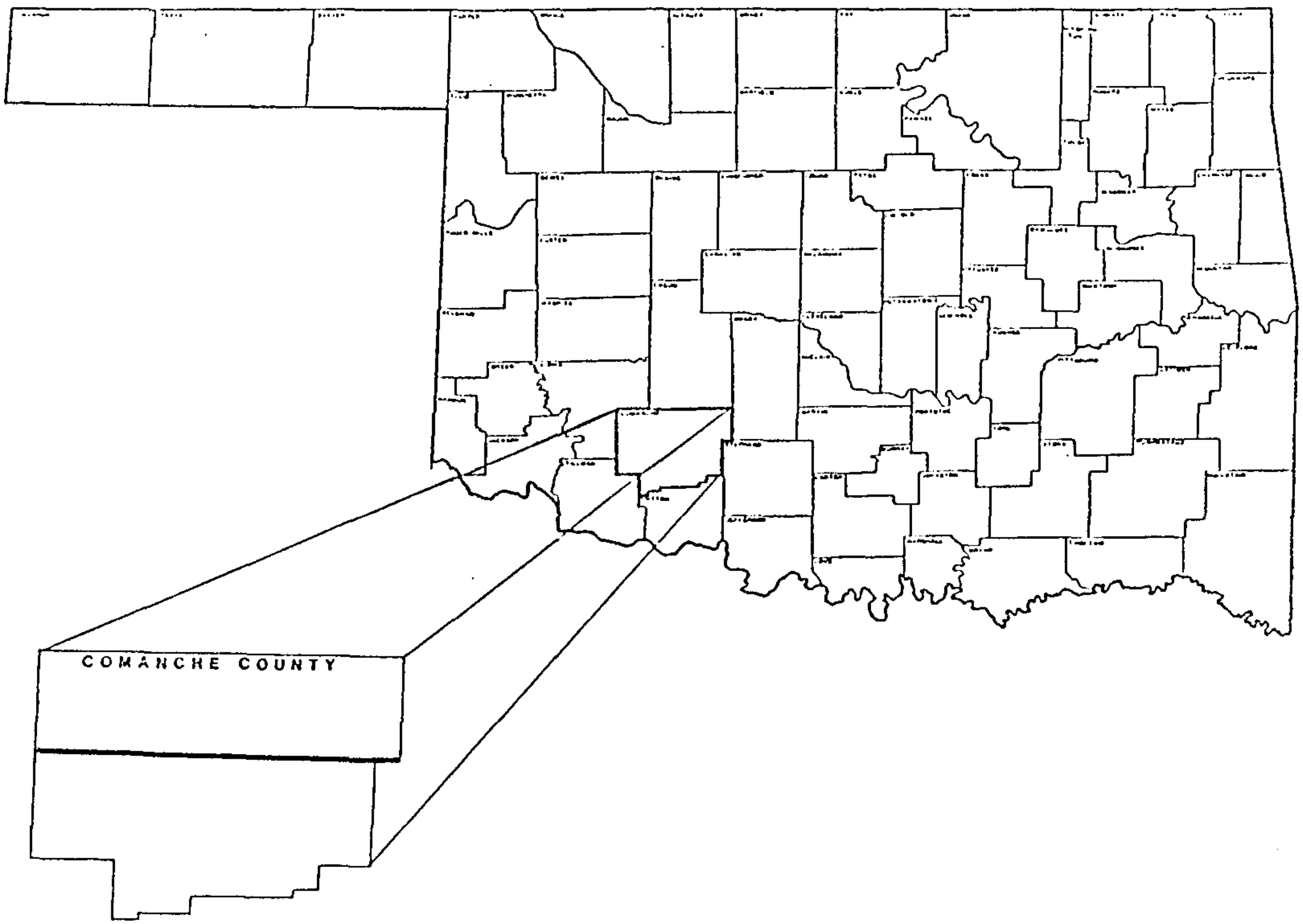
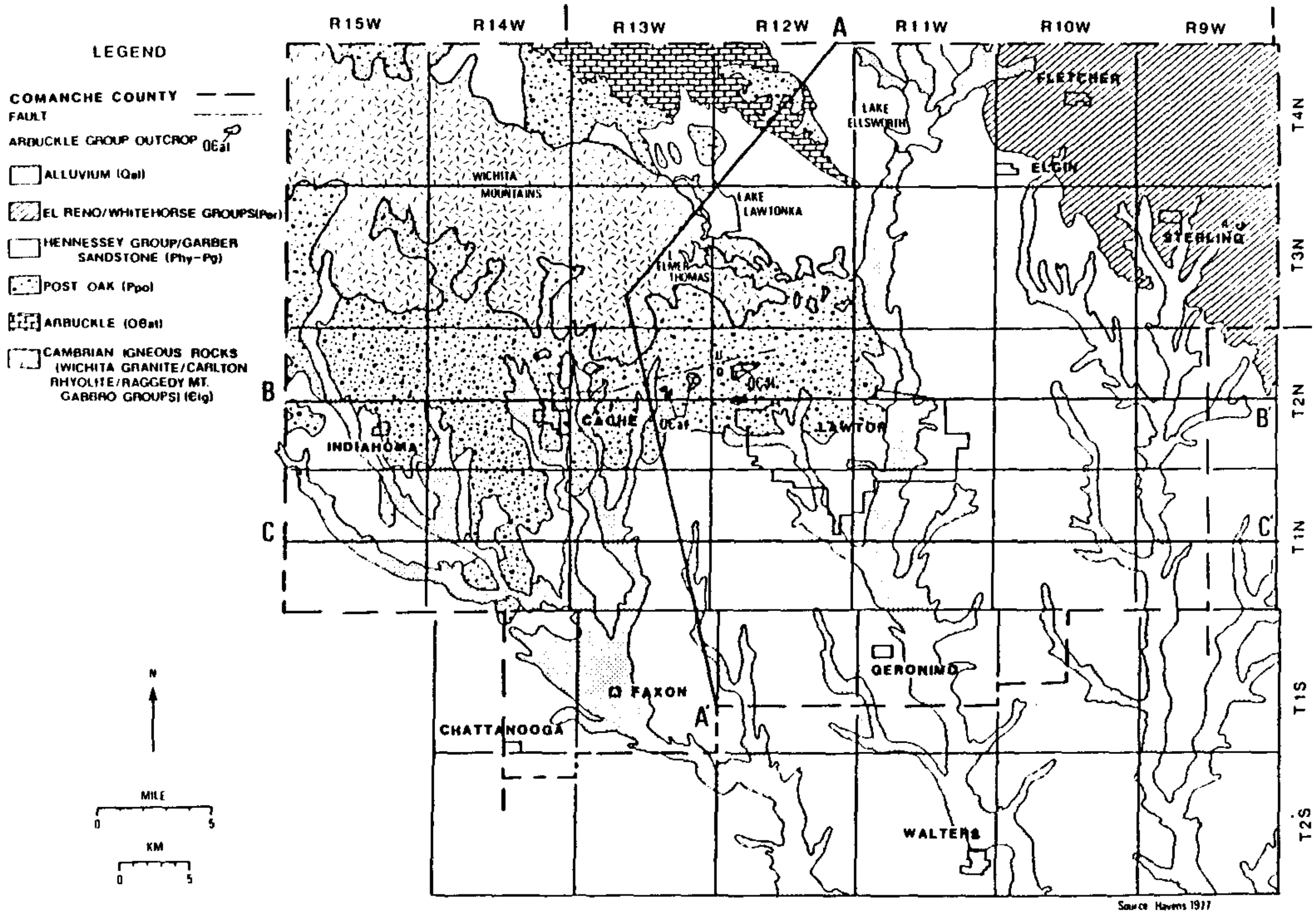


Figure 1. Location Map



GEOLOGIC MAP

Figure 2.

Upper Permian Whitehorse Group of sandstones and gypsum occur in the northeastern corner of the county (Havens, 1977). Within the creek valleys are Quaternary alluvial deposits of sand, gravel, and clay.

North-south cross-sections A-A' (Figure 3) and east-west cross-sections B-B' (Figure 4) and C-C' (Figure 5) show schematically the relationship of the formations in the subsurface. The Wichita Mountains are a block of igneous rocks bounded by steep faults. Overlying the igneous rocks are the Arbuckle Group of limestones and dolomites. These dip in the direction of the Anadarko Basin in the north and toward the Marietta Basin in the south. Overlying the Arbuckle Group in the north are the Permian Hennessey Shale, Garber Sandstone, and El Reno and Whitehorse Groups. The Permian Post Oak Conglomerate, Hennessey Shale, and Garber Sandstone lie on the Arbuckle to the south of the Wichita Mountains. These Permian formations are undifferentiable in the subsurface.

SOILS

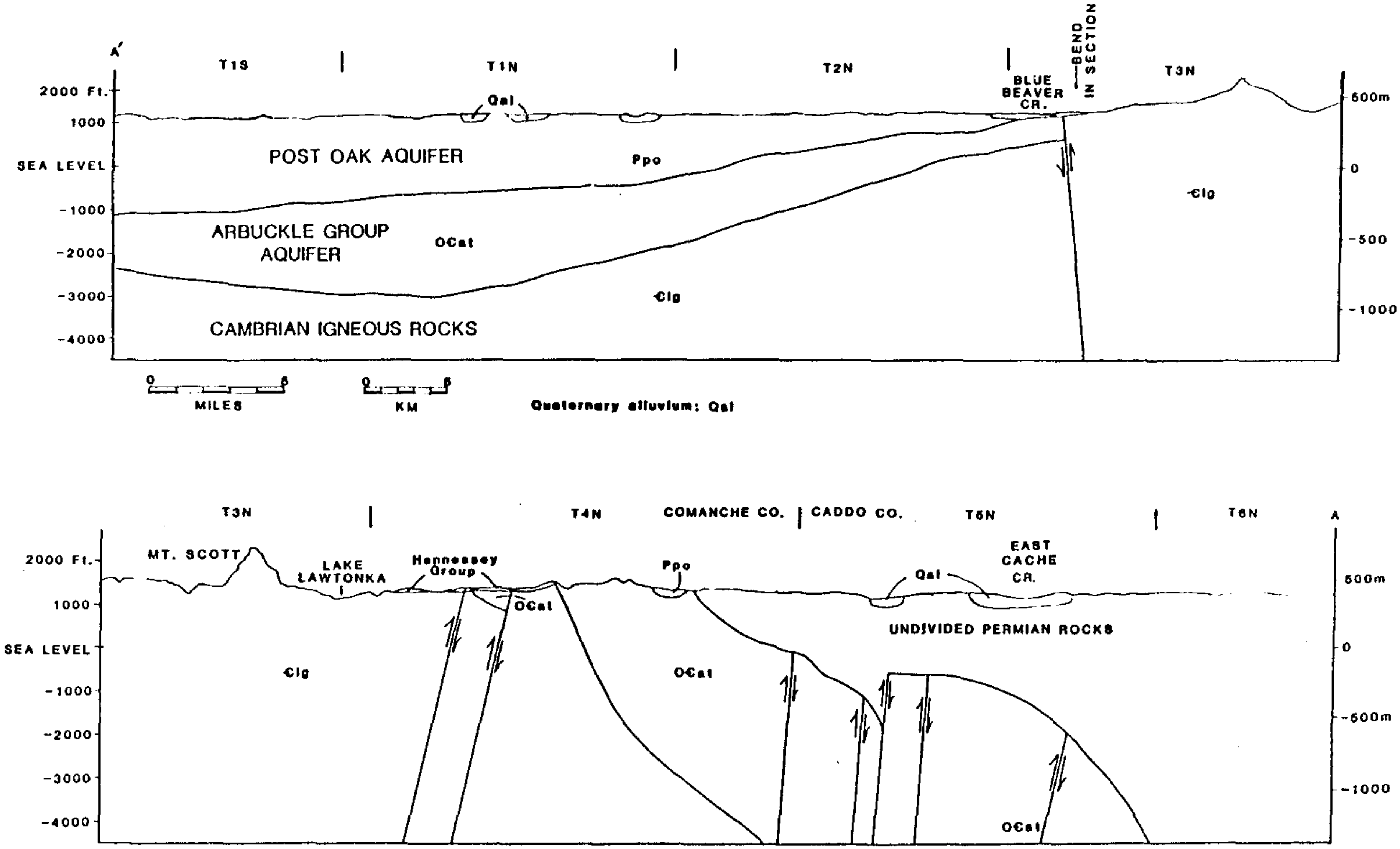
Distinctive soils have developed on the geological formations. The Foard-Tillman soil association covers 120,726 acres, or 18 percent of the county. These soils developed from limey Permian shales on uplands. The Zaneis-Lawton-Lucien association occupies 132,700 acres, or 19% of the county. These soils formed from granitic outwash and fine-grained sandstone. On flood plains is found the Port-Zevala-Lela association, which covers 76,800 acres, or 11% of the county. These soils are fine sandy limey clay loams (Mobley and Brinlee, 1967).

CLIMATE

Comanche County has a dry, subhumid, temperate, continental climate (Mobley and Brinlee, 1967). The average daily temperature is 36°F in January and 84°F in July (Pettyjohn and others, 1983). The mean annual precipitation is 29.18 inches (Figure 6) as determined from records for Lawton (National Oceanic and Atmospheric Administration, 1952-1981). Monthly precipitation is greatest in May with an average of 5.43 inches and is lowest in December (1.22 inches) and January (1.04 inches) (Figure 7). The high summer temperatures and low rainfall leads to an average annual evapotranspiration of 26 inches (Pettyjohn and others, 1983).

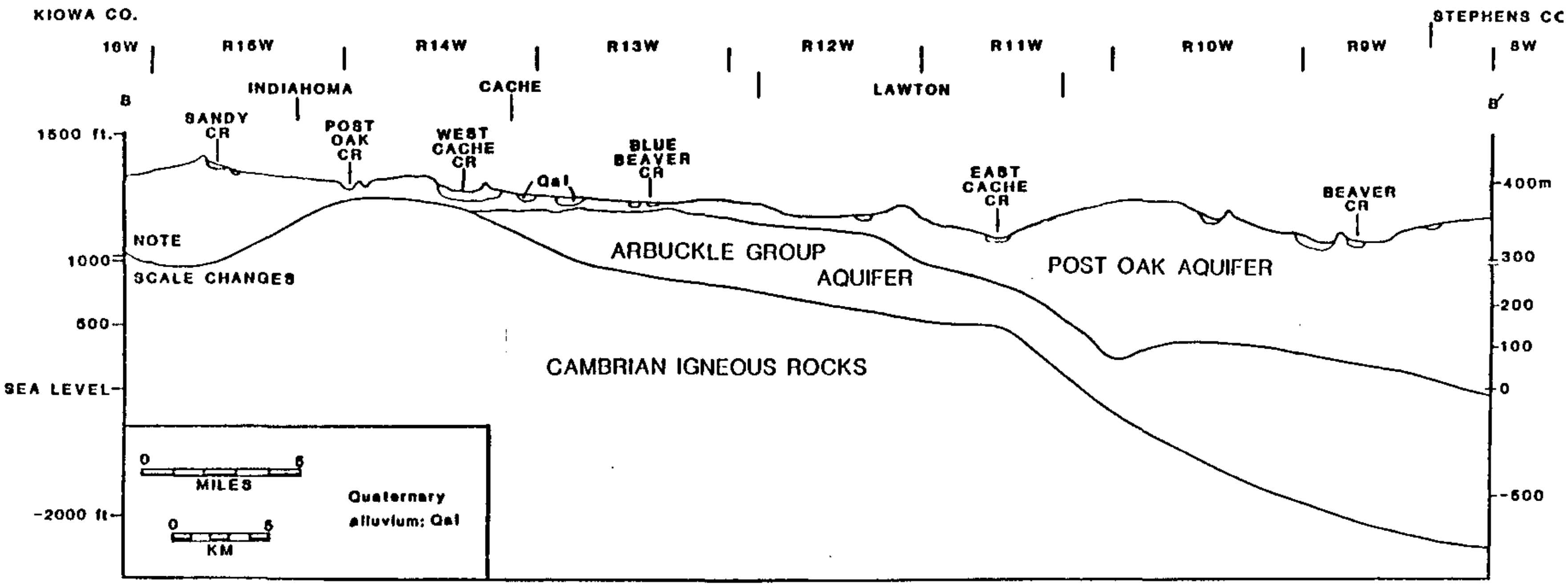
METHODOLOGY

Data were obtained from drillers' logs, field measurements, and previously published reports (Havens, 1977 and 1983; Uranium Resource Evaluation Project, 1978). The extent, thickness, saturated thickness, permeability, transmissivity, and yield of the aquifers in the study area were derived from these data.



Cross-section A-A'

Figure 3



Cross-section B-B'

Figure 4.

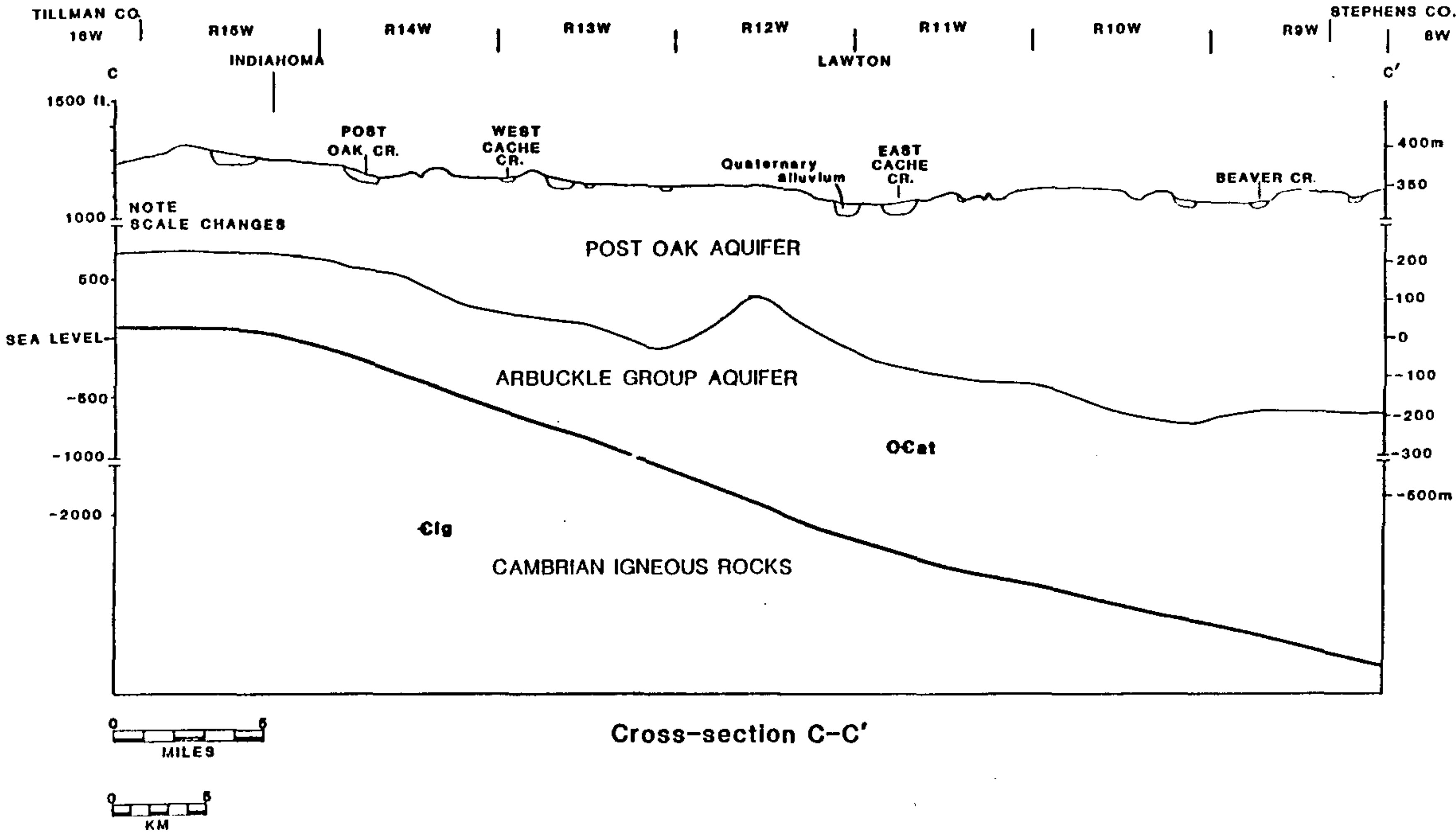
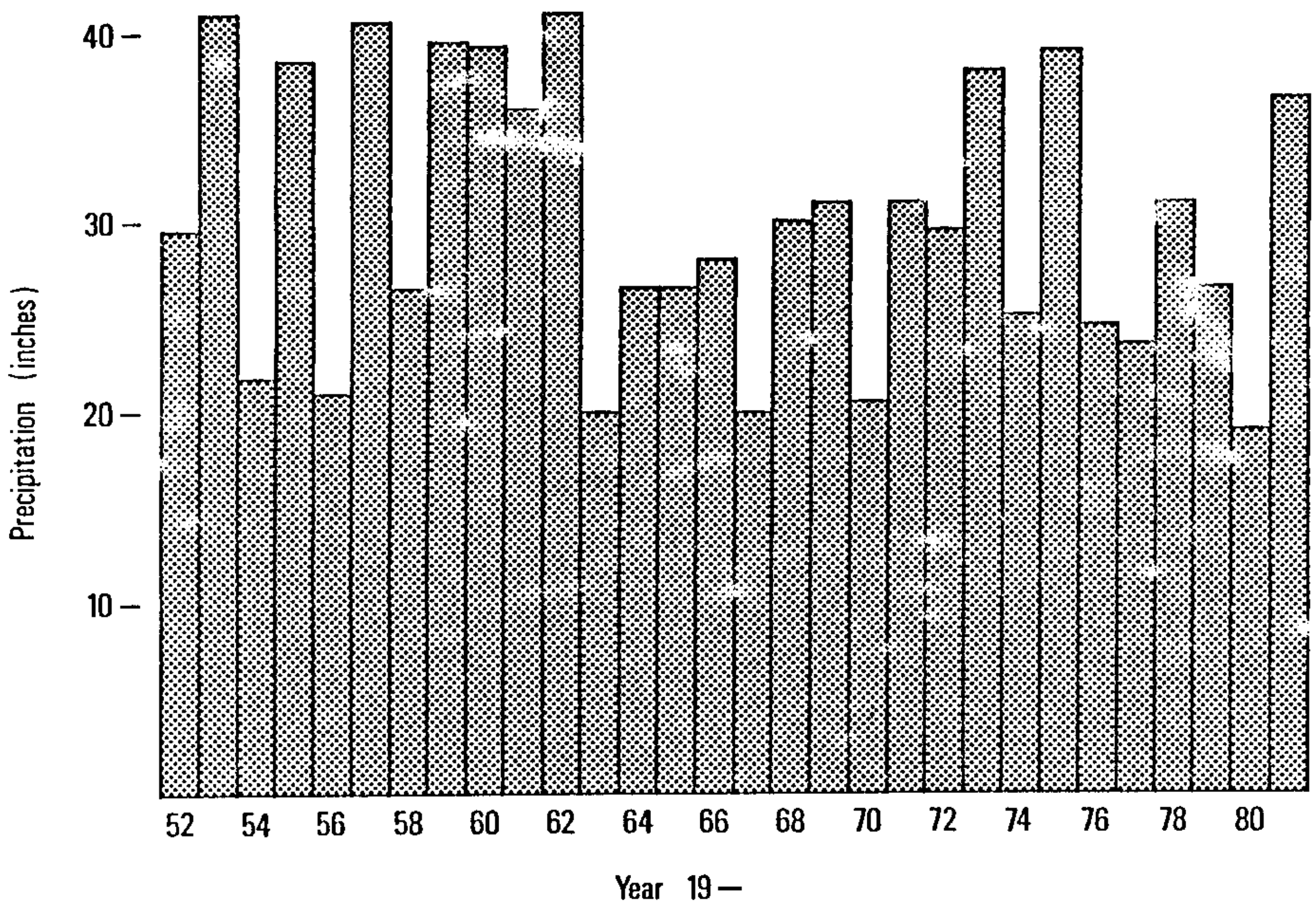
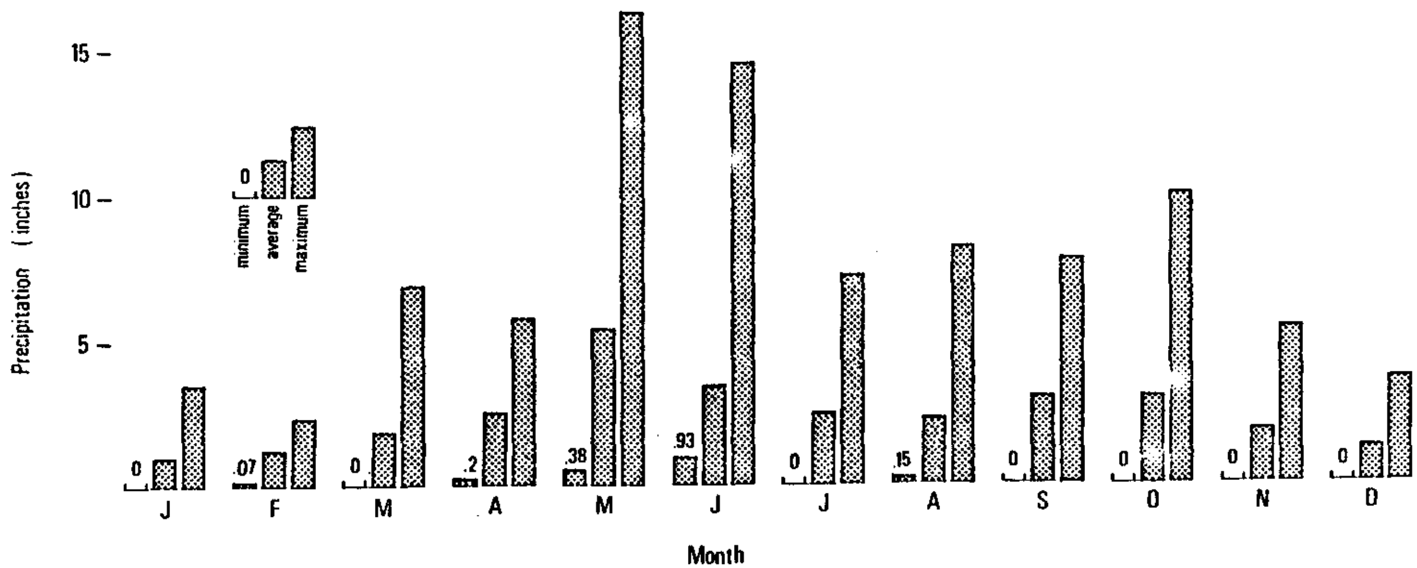

TILLMAN CO.
16W
R15W
R14W
R13W
R12W
R11W
R10W
R9W
STEPHENS CO.
8W
INDIAHOMA
LAWTON
C
C′
1500 ft.
1000
500
SEA LEVEL
-500
-1000
-2000
400m
350
200
100
0
-100
-200
-300
-600m
NOTE
SCALE CHANGES
POST
OAK CR.
WEST
CACHE
CR.
Quaternary
alluvium
EAST
CACHE
CR.
BEAVER CR.
POST OAK AQUIFER
ARBUCKLE GROUP AQUIFER
OCat
Ꞓig
CAMBRIAN IGNEOUS ROCKS
0
5
MILES
0
5
KM
Cross-section C-C′

Figure 5.



MEAN ANNUAL PRECIPITATION 1952 – 1981

Figure 6.



MONTHLY PRECIPITATION

Figure 7.

Well data were assigned to an aquifer according to location on the geologic map or soil survey and the well depth. The thickness of alluvium was determined from lithologic well logs; where these data were unavailable, the thickness of alluvium was assumed to be equal to the well depth. The thickness of the Post Oak Aquifer is the difference between land surface elevation and the elevation of the top of the Arbuckle Aquifer. These elevations were obtained from Havens (1983, Plate 1). The saturated thickness is denoted as the difference between well depth and static water level. The thickness of the Arbuckle Group is based on data from McDaniel (1959). Because the Arbuckle Aquifer is confined, its effective thickness was defined as the average well penetration into the aquifer.

Permeabilities were derived from well log data by using a relationship between grain size and permeability developed by Kent and others (1973) (Figure 8). Each layer in a well log was assigned a permeability value corresponding to its predominant grain size. The values were weighted according to the thickness of each layer and were summed to give a total permeability. The product of permeability and saturated thickness is transmissivity. This method is practical for only the alluvium and the Post Oak Aquifer.

Another approach for obtaining transmissivities, used here for these aquifers, is from pumping test data. The well yield per foot of drawdown is the specific capacity. Walton (1970) derived transmissivity from well yield, drawdown, well radius, duration of pumping, and storativity or specific yield. Average yields were determined from average values of transmissivity, well radius, pumping duration, storage or specific yield, and maximum drawdown. Water quality data were obtained from Havens (1983), Stone (1981), Hounslow and Back (1985a and b) and the U.S. Geological Survey's Water Data Storage and Retrieval System (WATSTORE). Drilling costs used in this report are based on current estimates by drillers and range from $5/ft. to $11/ft. and average $7/ft.

Data are presented in two forms within this study. The more general presentation uses a township-range grid for reference purposes. In an attempt to identify specific zones of high yield and chemical problem areas associated with nitrate and fluoride a grid of nine-square-mile nodes was incorporated (Figure 9). Average values of the data within each node were obtained.

AQUIFER CHARACTERISTICS

ALLUVIUM

Alluvium consists of the sands, gravels, and clays within creek valleys and comprises an unconfined aquifer (Figure 10). Terrace deposits are not considered in this report and are not shown.

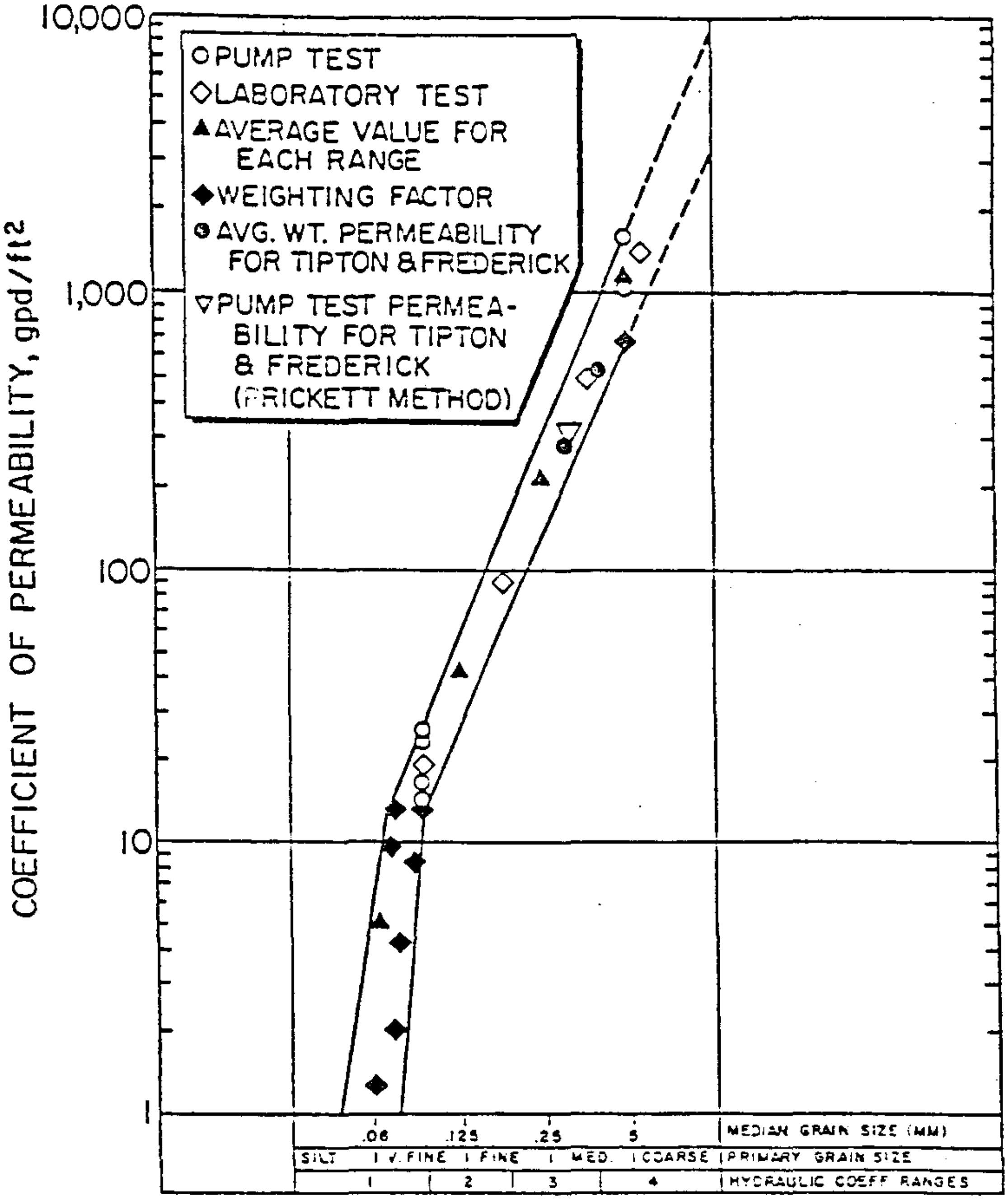
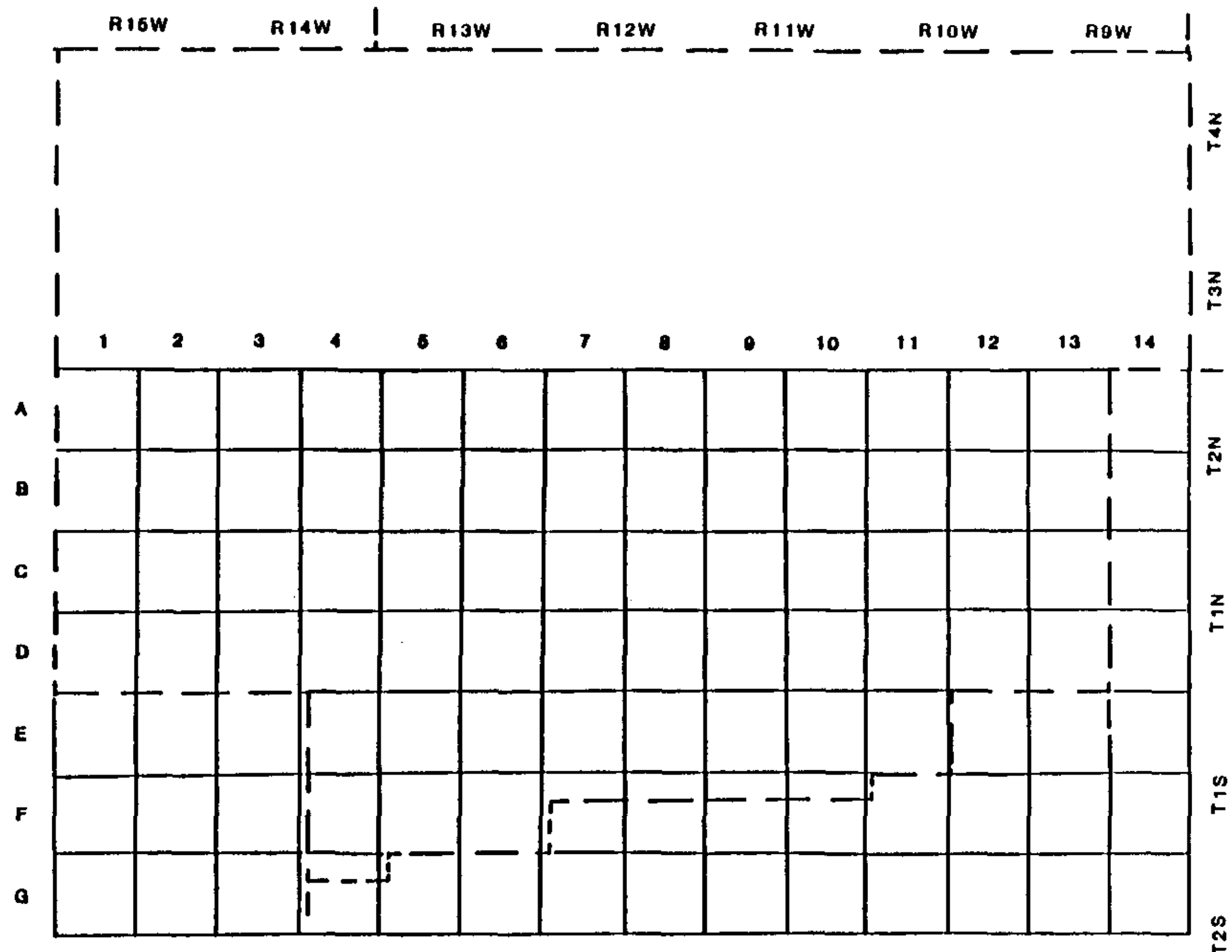
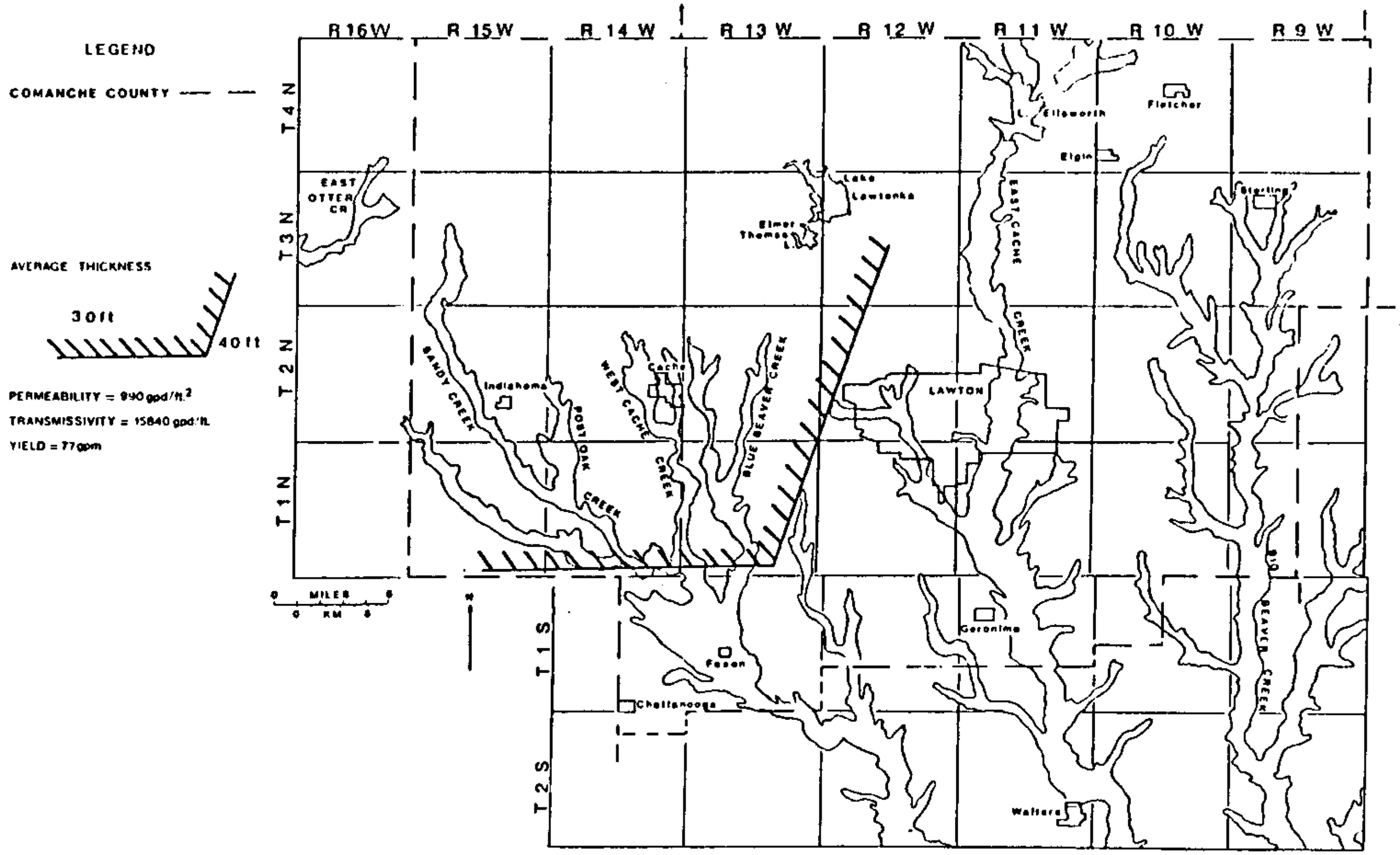


Figure 8. Coefficient of Permeability vs. Grain Size Envelope (Source: Kent and others, 1973).



REFERENCE GRID

Figure 9.



DISTRIBUTION OF ALLUVIUM AND REPORTED AVERAGE VALUES OF HYDROGEOLOGIC PROPERTIES

Figure 10.

Well-log data and the grain-size envelope (Figure 8) indicate an average permeability of 990 gpd/ft^2. The average saturated interval is 16 ft., and the average transmissivity is 15,840 gpd/ft. The specific yield was assumed to be two percent, a low value which would lead to an underestimation of the expected yield and a minimum figure to be used for water management purposes. The average well radius is 0.34 ft. (4.1 in.), and the average pumping duration is 1,200 min. (20 hrs.). The expected well yield is 77 gpm.

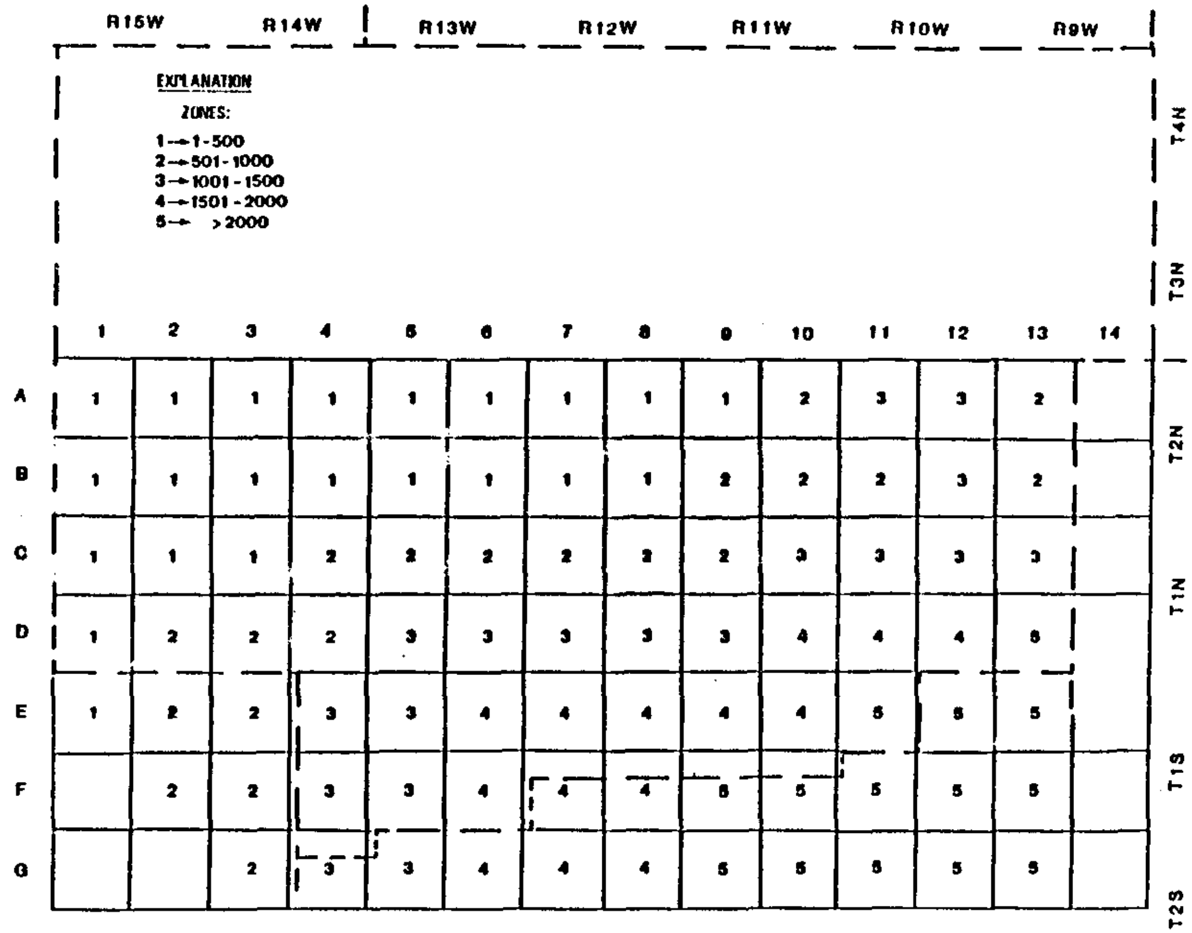
Where well-log data were unavailable, the thickness of alluvium was assumed to equal the well depth. Along East Otter Creek, Sandy Creek, Post Oak Creek, upper West Cache Creek, and Blue Beaver Creek the alluvium averages 30 feet in thickness, while along East Cache Creek, Big Beaver Creek, and the southern part of West Cache Creek the alluvium averages 40 feet in thickness (Figure 10). The approximate costs of drilling a production well are $210 in the 30-foot-thick zone and $280 in the 40-foot-thick zone.

POST OAK AQUIFER

The unconfined Post Oak Aquifer consists of conglomerates, sandstones, and shales eroded from the Wichita Mountains. Havens (1977 and 1983) considered the Post Oak Conglomerate, Hennessey Shale, and Garber Sandstone as separate aquifers because they can be mapped separately according to their geology. For this report they have been combined because they consist of rocks which cannot be differentiated in the subsurface and which exhibit similar hydraulic characteristics. The Wichita Formation and Oscar Formation are names sometimes applied to the deeper parts of the aquifer.

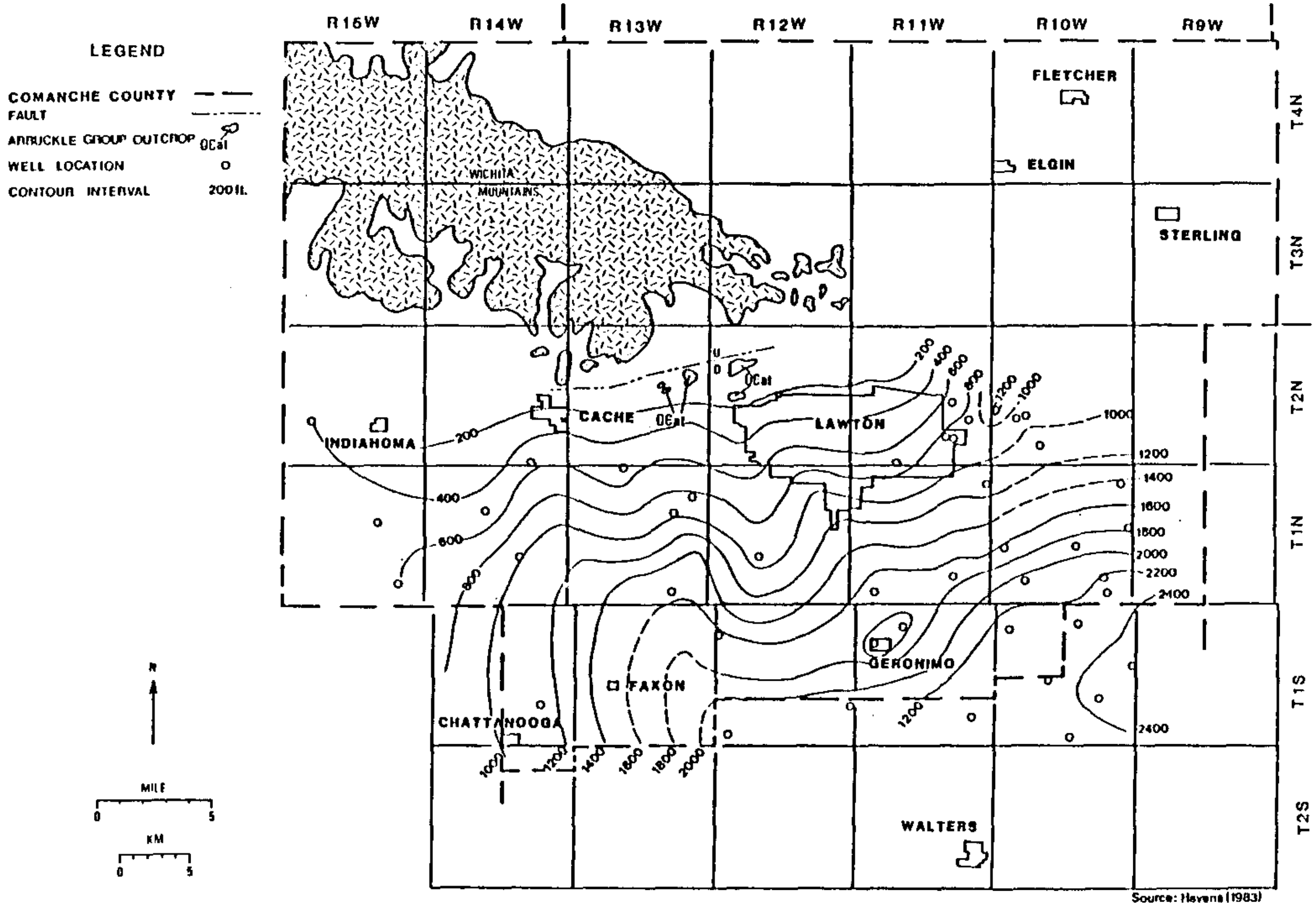
The total thickness of the Post Oak Aquifer is the difference between land surface elevation and the elevation of the top of the Arbuckle Group given by Havens (1983, Plate 1). Figure 11 shows the average total thickness per nine-square-mile node on the grid, and Figure 12 is a contour map of the thickness. The effective thickness of the Post Oak Aquifer was assumed to be equal to the average well depth of 50 feet.

In a study of the Post Oak Conglomerate, Stone (1977) mapped patterns of grain sizes and found evidence for ancient stream channels in areas of coarse mean grain size. These areas would have higher well yield created by higher permeability. Figure 13 is a map modified from Stone (1977) of the probable locations of these channels and their associated mean grain sizes of 0.5 and 0.7 mm. Based on this map the Post Oak Aquifer was separated into two zones of different permeability (Figure 14), transmissivity (Figure 15), and expected yield (Figures 16 and 17). From well-log data and the grain-size envelope (Figure 8) the permeability within the coarse-grained zone is found to be 800 gallons per day per square foot (gpd/ft^2). The average saturated interval for wells into the Post Oak is 20 feet; the transmissivity is, therefore, 16,000 gallons per day per foot



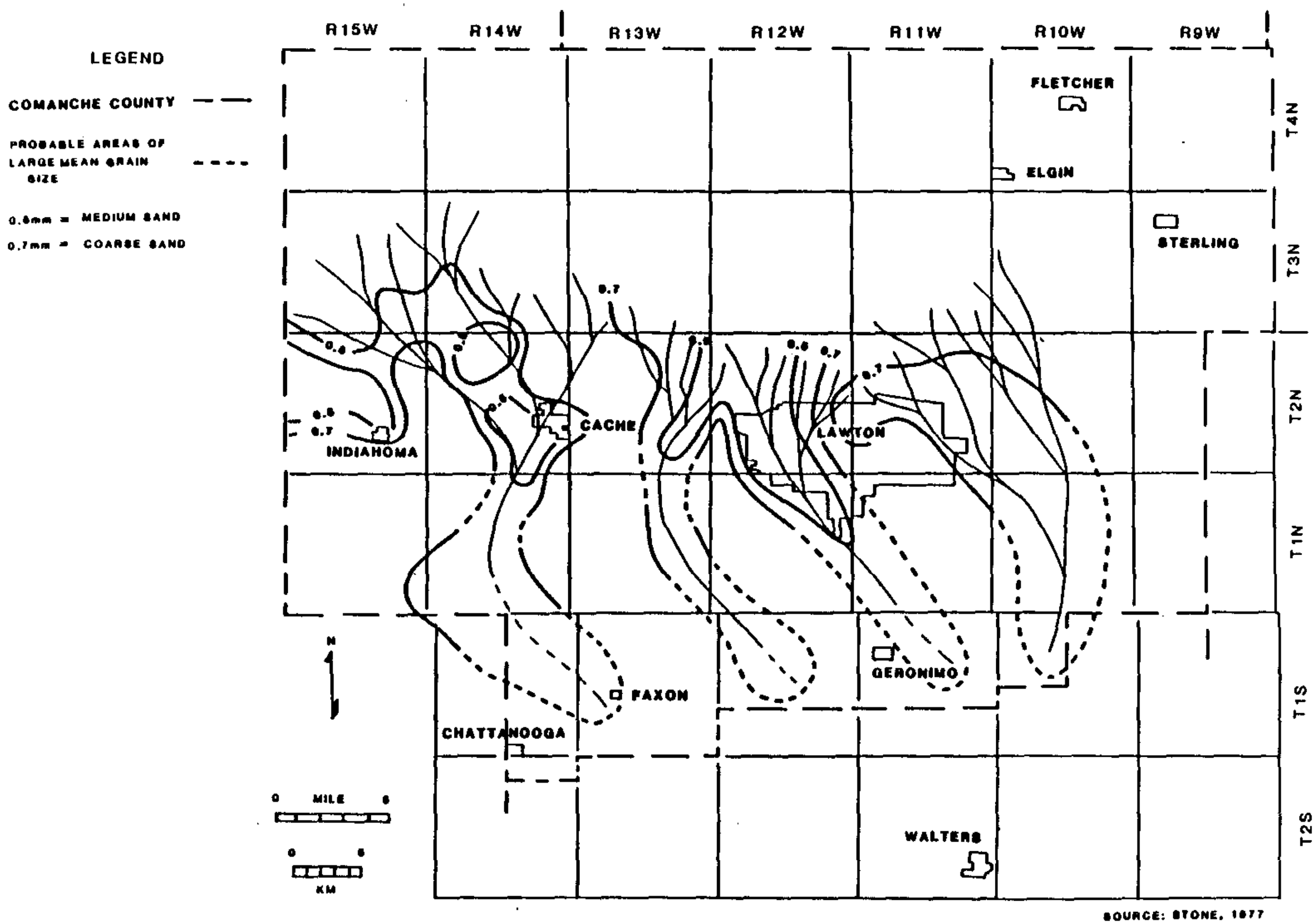
THICKNESS OF POST OAK

Figure 11.



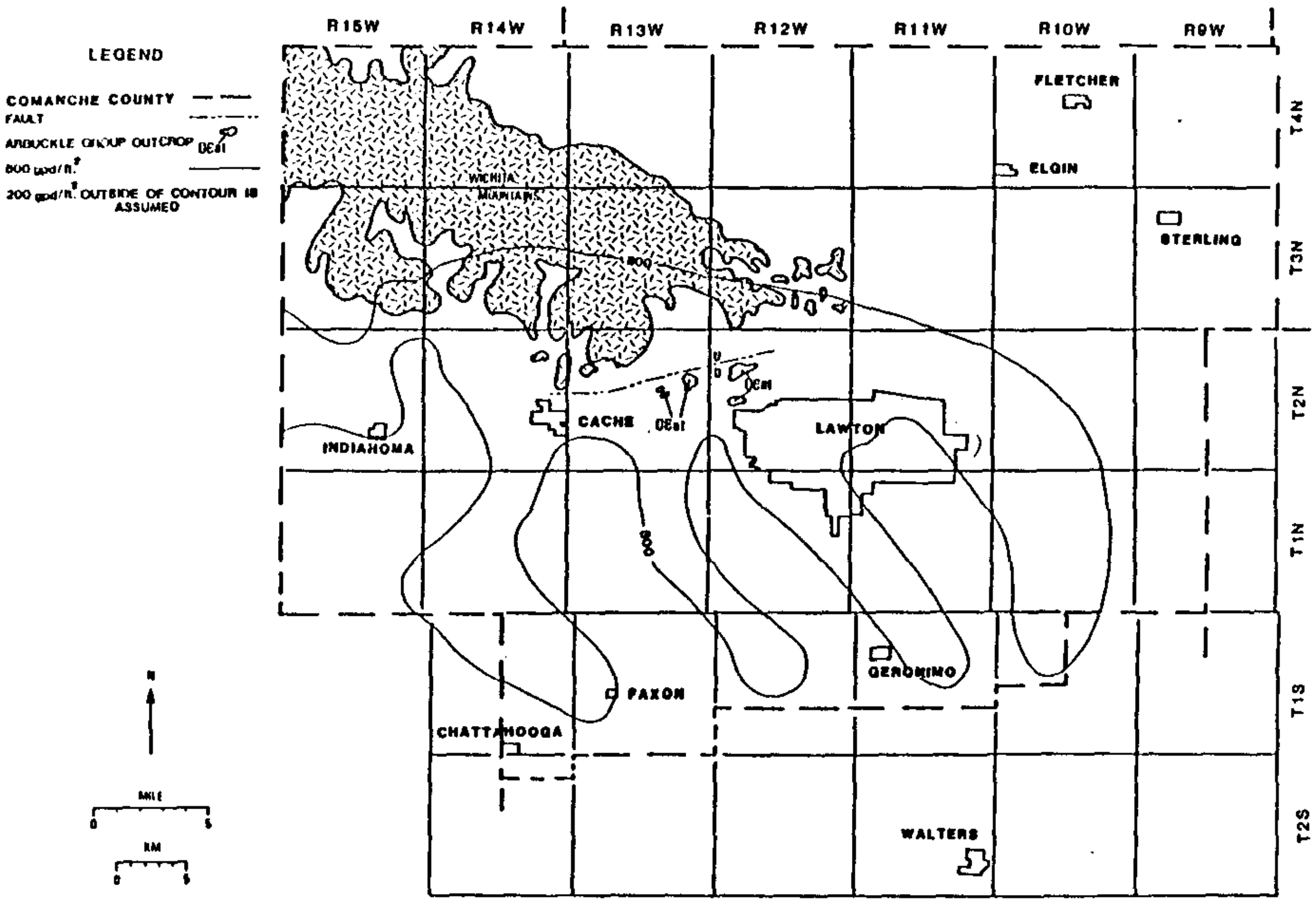
THICKNESS OF POST OAK AQUIFER

Figure 12.



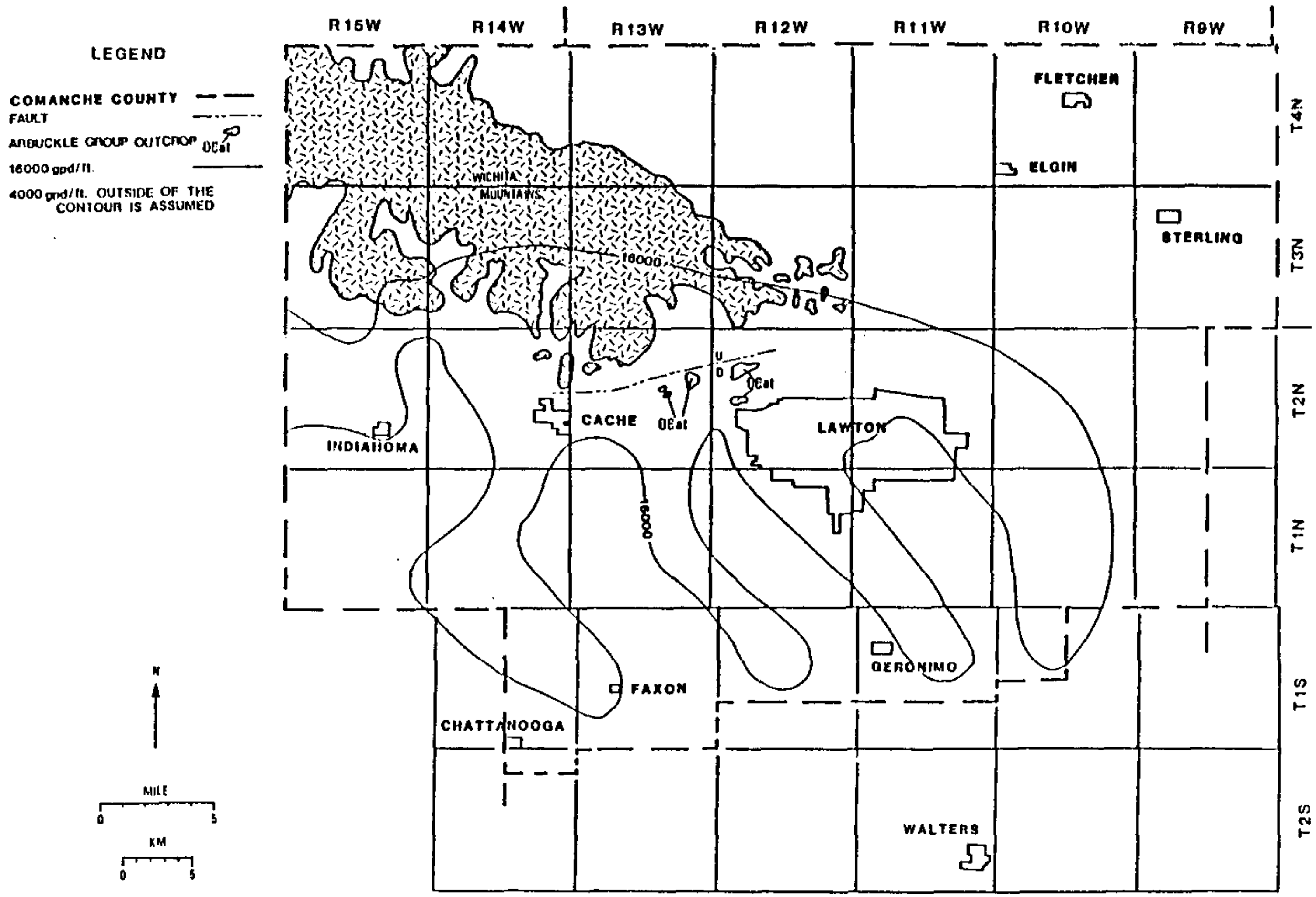
CHANNEL DEPOSITS WITHIN POST OAK AQUIFER

Figure 13.

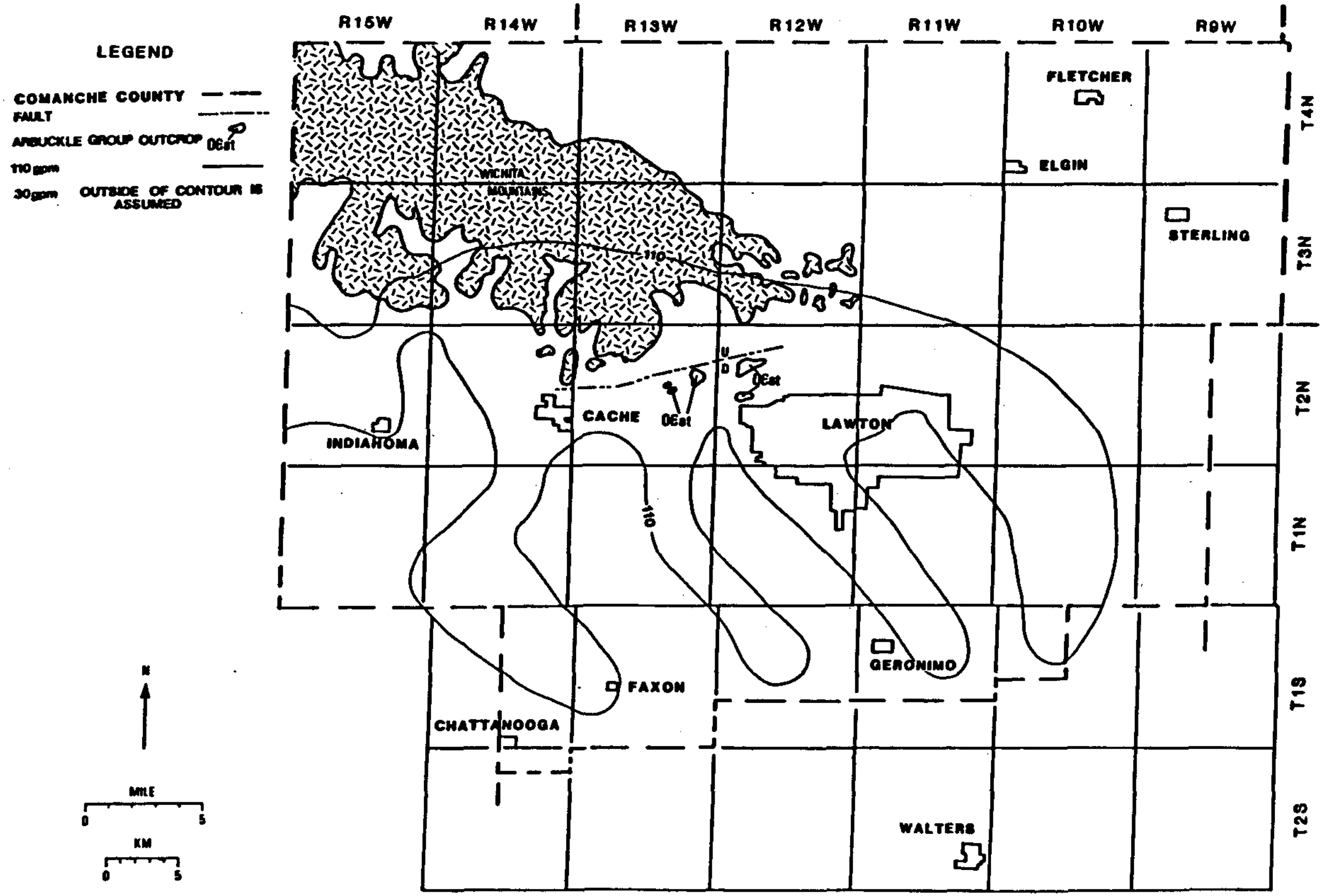


PERMEABILITY OF THE POST OAK AQUIFER

Figure 14.

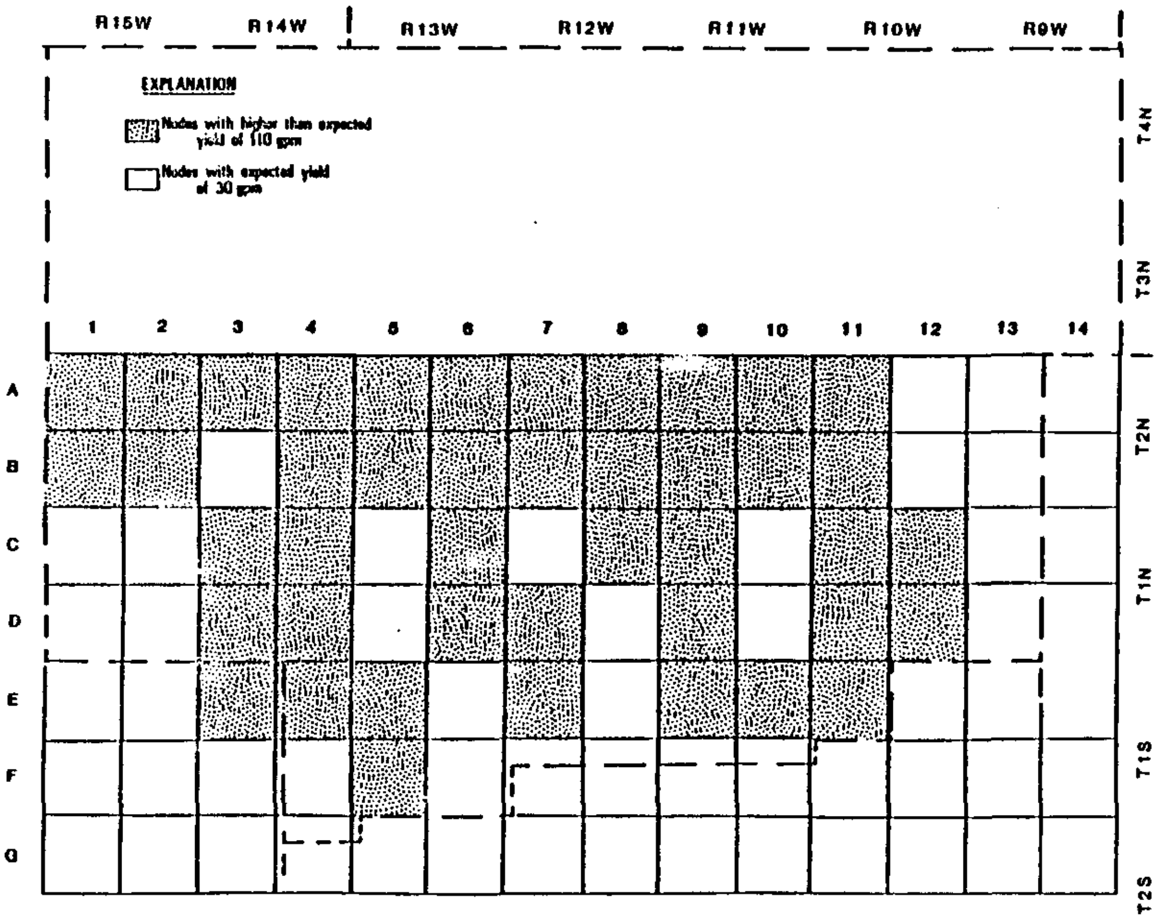


TRANSMISSIVITY OF THE POST OAK AQUIFER
Figure 15.



EXPECTED YIELD OF POST OAK AQUIFER

Figure 16



EXPECTED YIELD OF THE POST OAK AQUIFER

Figure 17.

(gpd/ft).

In addition to mean grain size as evidence of the existence of channels, total sand thickness also indicates channel areas. Figure 18 is a map of the total thickness of sand, gravel, and conglomerate layers within 50 feet of the surface. Ten-foot thick zones are identified through Indiahoma, Cache, and Lawton, with a possible channel east of Lawton.

The maximum theoretical drawdown is 70 percent of the saturated interval above a five-foot well screen (Johnson, 1966, p. 318); this results in a value of 11 feet. An underestimated specific yield of two percent was assumed; this compares with a value of five percent for sediments similar to those of the Post Oak Aquifer (Johnson, 1967). The average well radius is 0.35 ft (4 1/4 in.), and the average pumping duration is 660 minutes (11 hours). Walton's equation (1970, p. 315) provides a nominal average well yield of 110 gallons per minute (gpm) in the coarse-grained zone.

In the finer-grained zone the permeability is 200 gpd/ft^2, the transmissivity is 4,000 gpd/ft, and the expected well yield is 30 gpm.

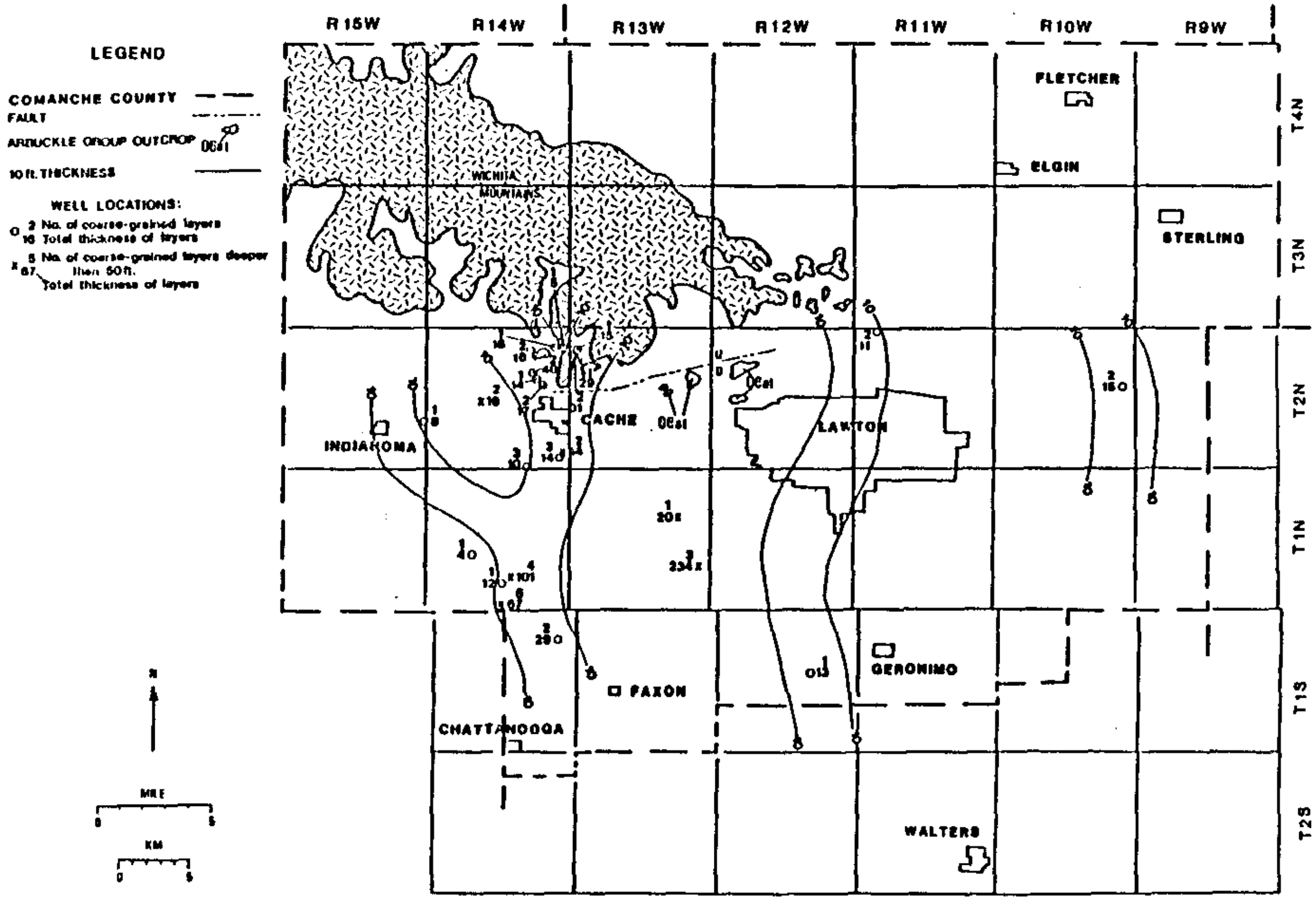
Information from water-well drillers in the region indicates an average drilling cost of $7.00 per foot. It would, therefore, cost $350 to drill to the average well depth of 50 feet in the Post Oak.

ARBUCKLE GROUP AQUIFER

South of the Wichita Mountains, the confined Arbuckle Group Aquifer lies below the Post Oak Aquifer and consists of limestones and dolomites. It is absent in the subsurface north of Indiahoma and Cache and southeast of Faxon and Chattanooga (McDaniel, 1959, Plate I) (Figures 19 and 20). Outcrops occur northwest of Lawton (Figure 2). The Limestone, or Slick, Hills region, where the Arbuckle Group crops out north of the mountains, is not considered in this report.

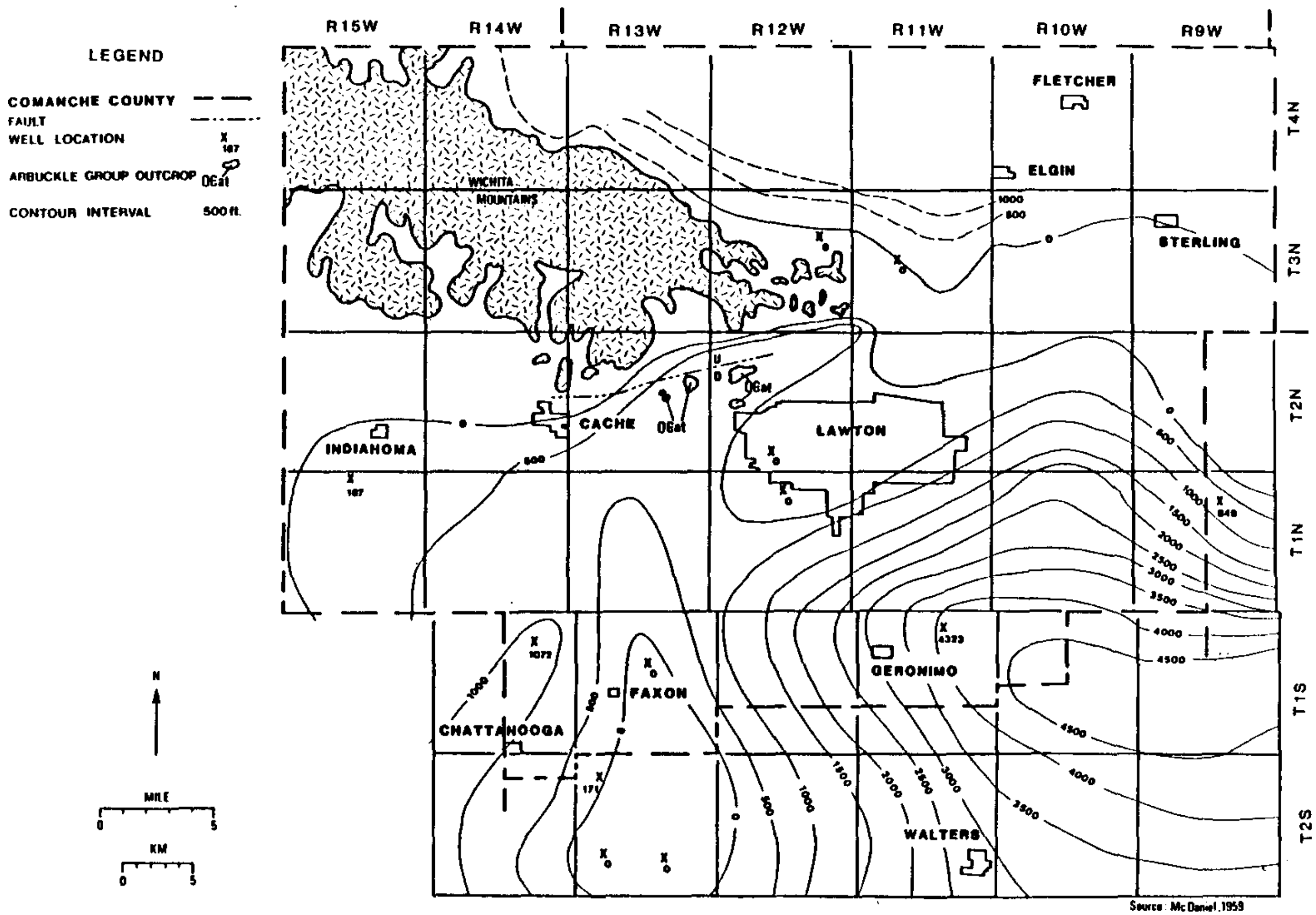
The depth of the Arbuckle Group below land surface, where the Arbuckle Group is present, is equal to the thickness of the Post Oak, which can be greater than 2,000 feet (Figures 11 and 12). The Arbuckle Group can also be more than 2,000 feet thick (Figures 19 and 20).

The grain-size envelope method for determining permeability is not applicable to this aquifer because ground water movement is through fractures and not between grains (Havens, 1983). Pumping test data indicate a transmissivity of 1,720 gpd/ft (Figure 21). The effective aquifer thickness was assumed equal to the average well penetration of 500 feet. The ratio of transmissivity to the effective thickness is the permeability; the value for this aquifer is 3.5 gpd/ft^2 (Figure 22).



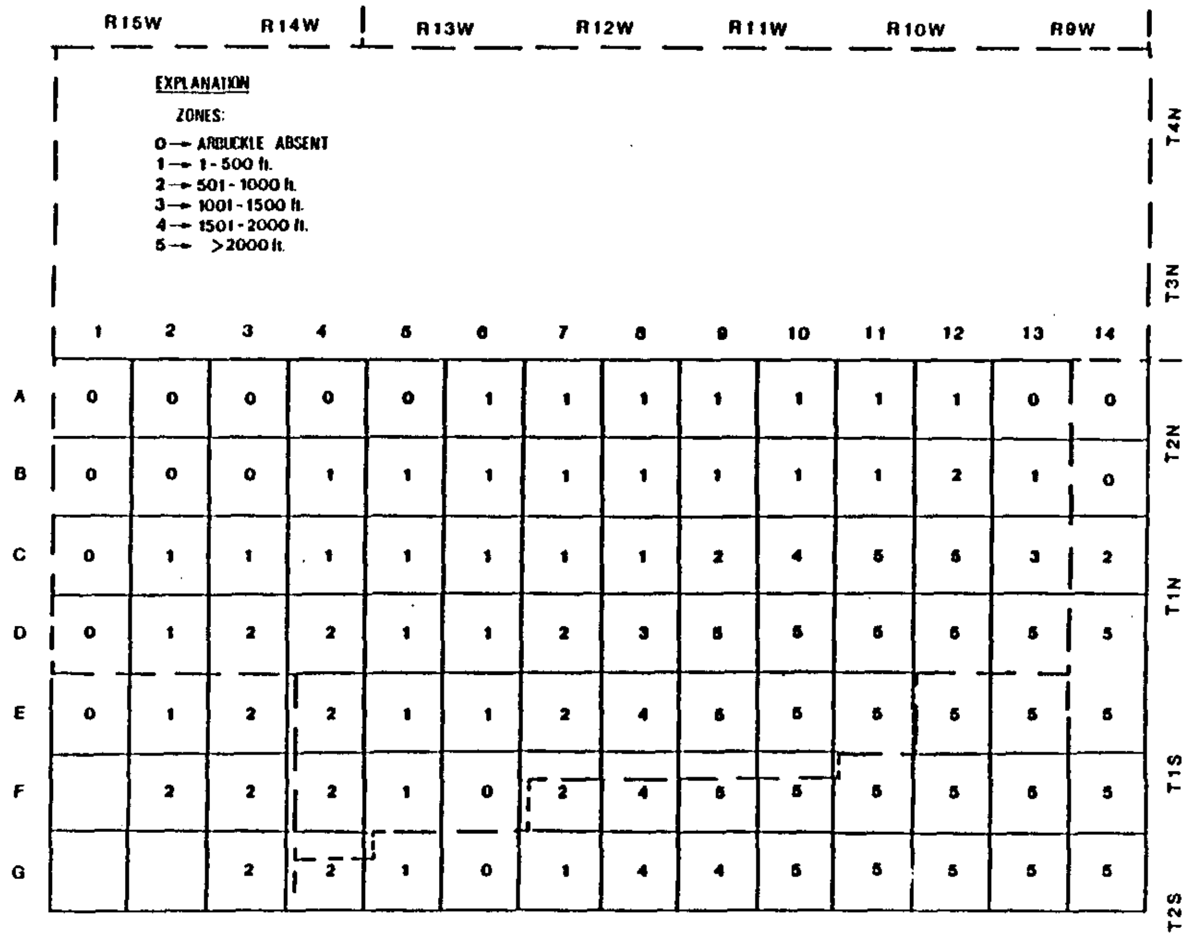
TOTAL SAND THICKNESS IN POST OAK AQUIFER WITHIN 50 FEET OF SURFACE

Figure 18.



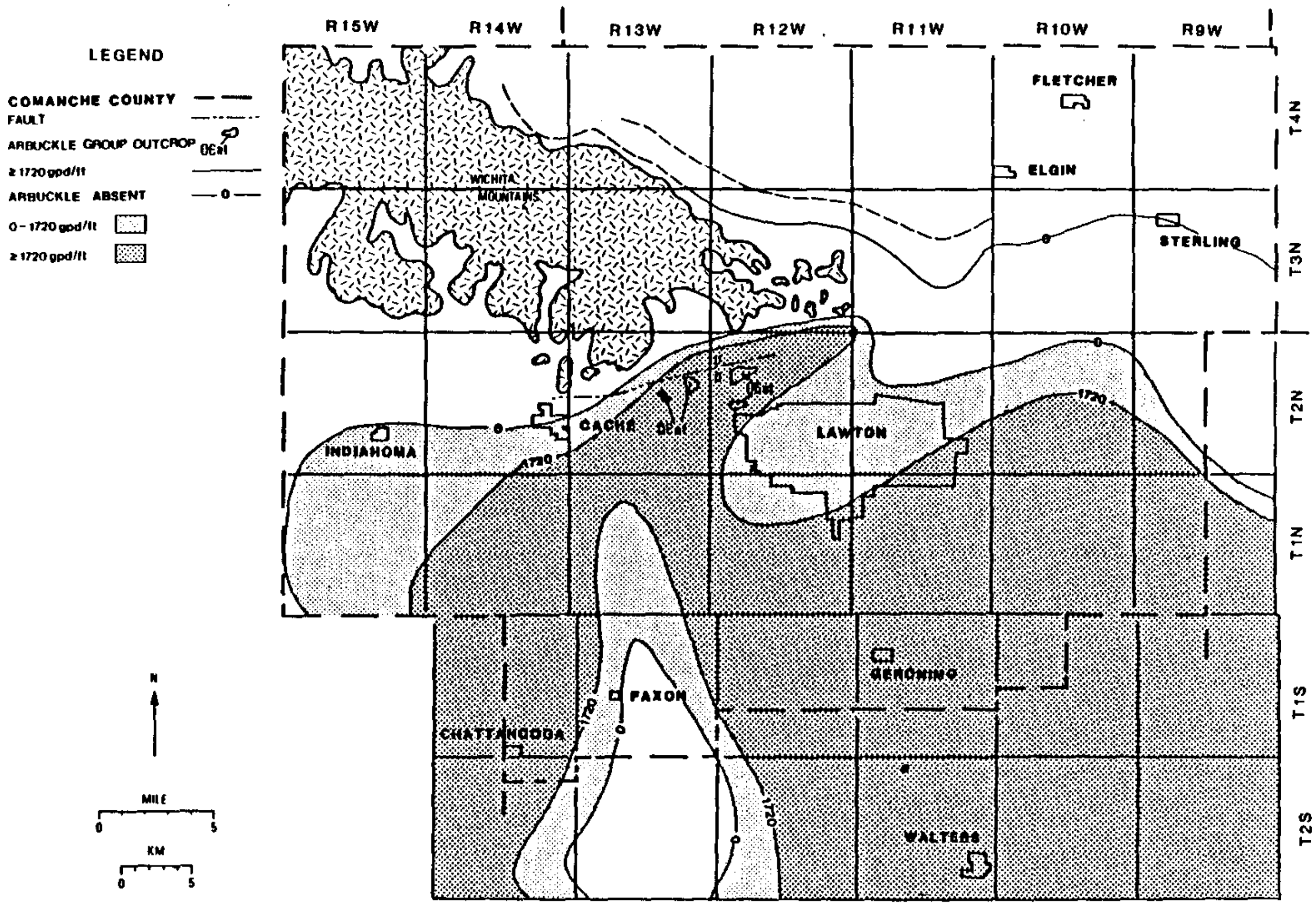
THICKNESS MAP OF ARBUCKLE GROUP SOUTH OF WICHITA MOUNTAINS

Figure 19.



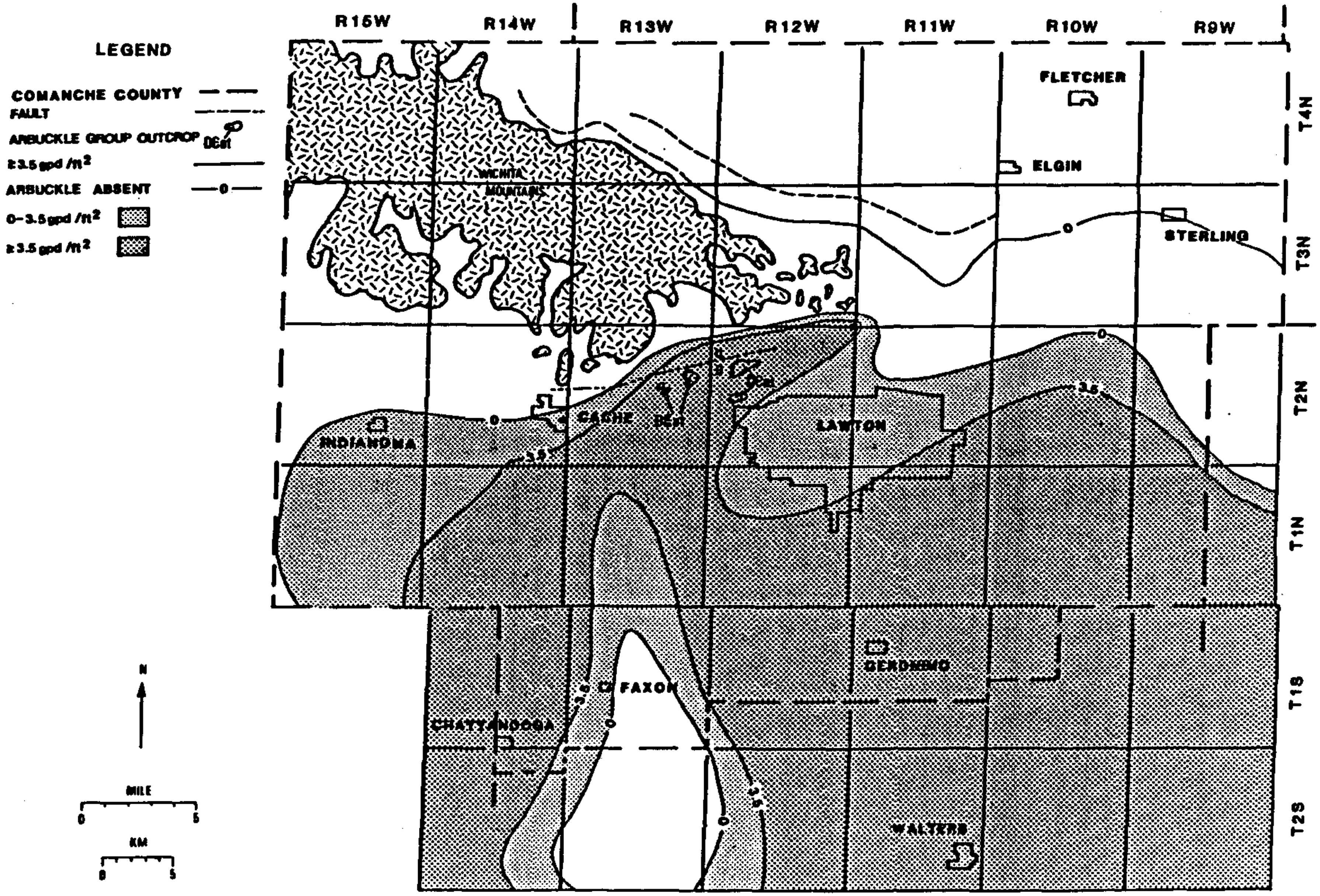
THICKNESS OF ARBUCKLE

Figure 20.



TRANSMISSIVITY OF THE ARBUCKLE AQUIFER

Figure 21.



PERMEABILITY OF ARBUCKLE AQUIFER

Figure 22

To calculate yield a storativity of 0.0001, a typical value as listed in Walton (1970, p. 315), was employed. The average well radius is 0.28 ft. (3 3/8 in.) and the average pumping duration is 5000 minutes (30 hours). The maximum drawdown was estimated to be 70 percent of the effective thickness, or 350 feet. The resulting expected yield is 270 gpm (Figures 23 and 24). Where the Arbuckle Group is less than 500 feet thick, the transmissivity, permeability, and yield are considered to be less than the calculated values.

In order to more realistically represent the drilling costs for the Arbuckle Group Aquifer, five-hundred feet were added to the Post Oak thickness. Estimated drilling costs range from $5,250 where this formation is close to the surface to over $17,500 where it lies more deeply buried.

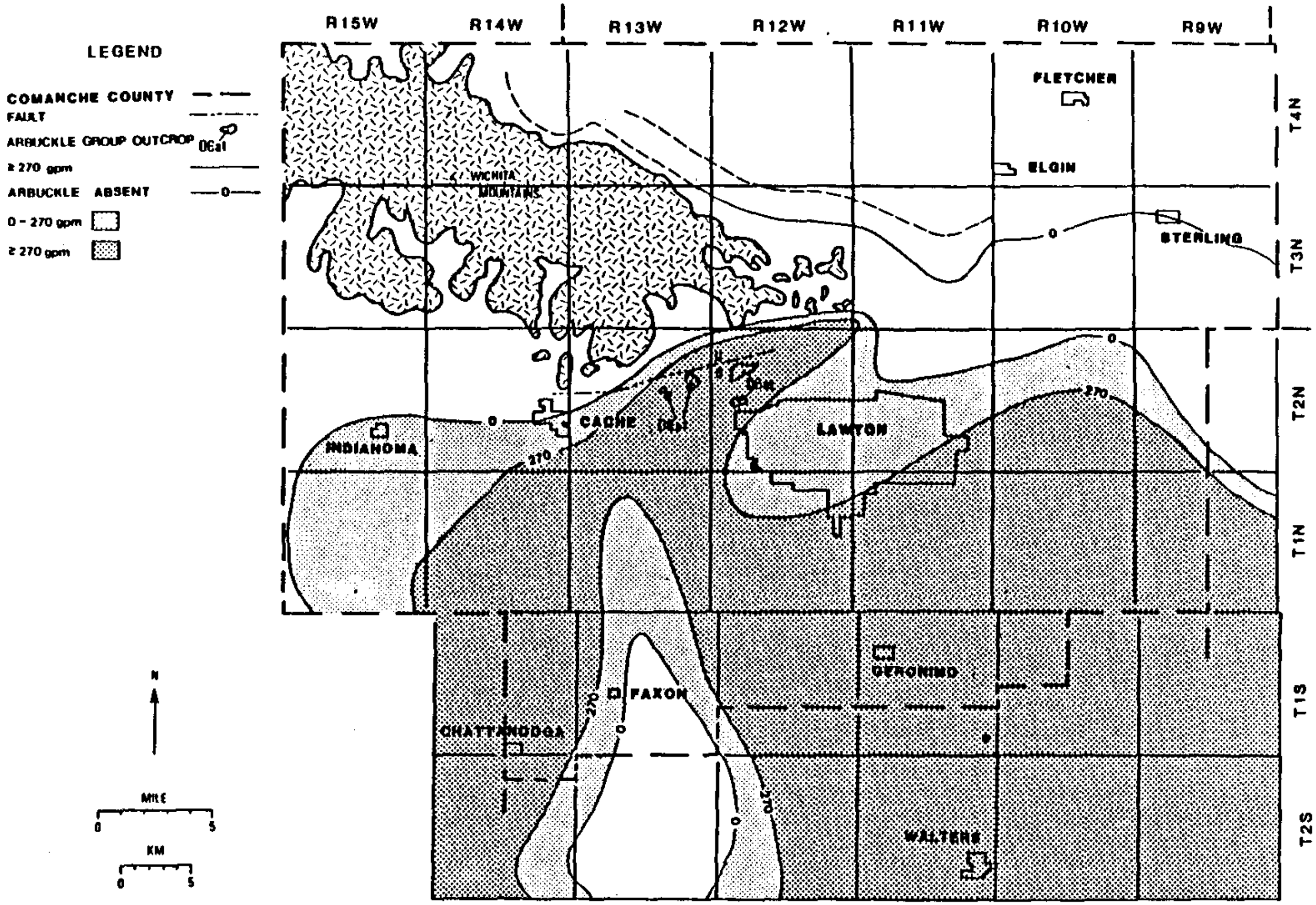
GROUND AND SURFACE WATER RELATIONSHIP

Most of the streams in Comanche County flow only during the wet season. In dry months the water table in the creek valleys lies below the bottom of the stream channel. Big Beaver Creek flows throughout the year, except during droughts, and is a gaining stream, with ground water sustaining the streamflow during periods of low flow (baseflow). Municipal effluent from Lawton and discharge from Lake Lawtonka and Lake Ellsworth sustain the flow of East Cache Creek (Hauth and others, 1984).

The surface-water quality during periods of low flow is similar to the regional ground-water quality. Data for Blue Beaver Creek (Hauth and others, 1984) show a background fluoride level of 0.3 to 0.5 milligrams per liter (mg/l) and a background nitrate level of 0.10 mg/l or less.

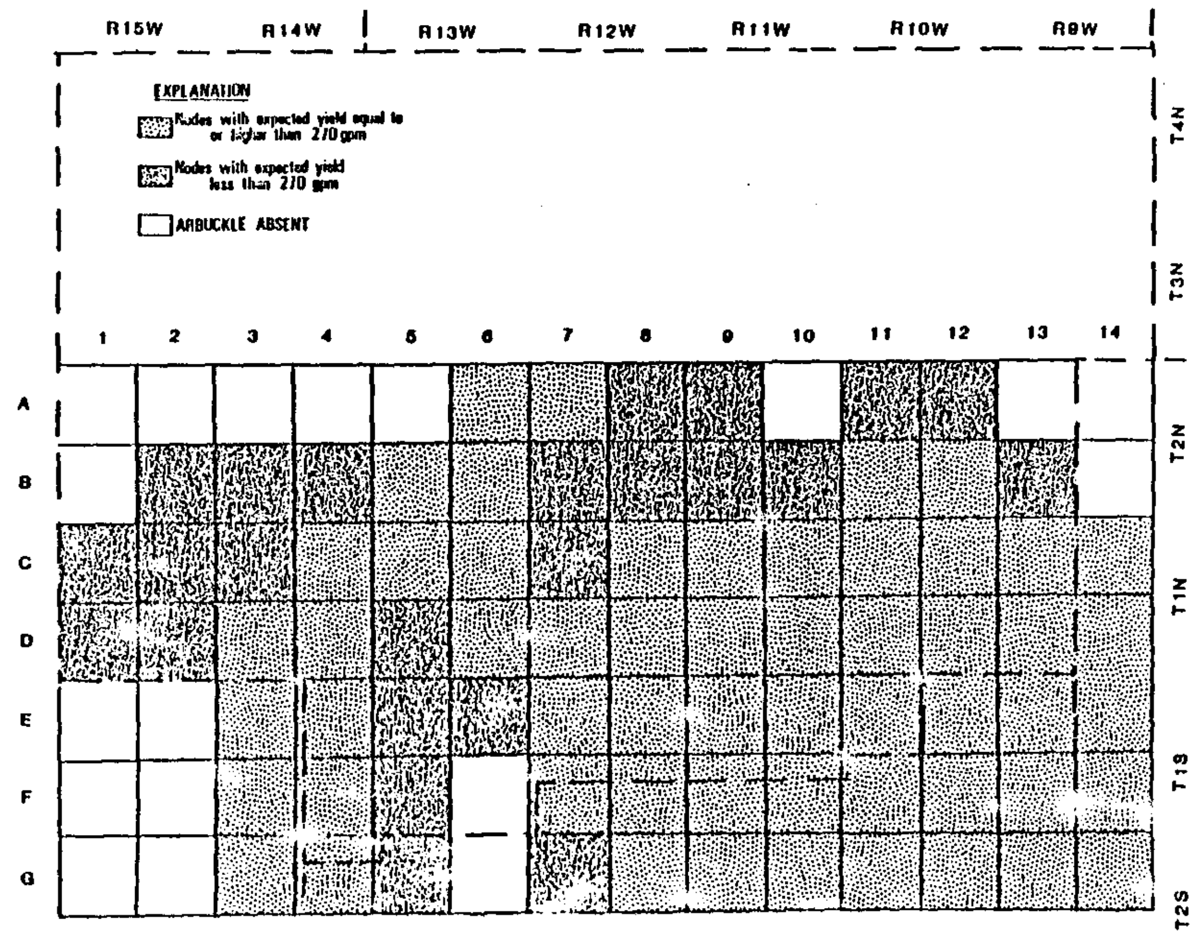
FLUORIDE AND NITRATE PROBLEMS

The Oklahoma water quality standards (Oklahoma Water Resources board, 1982) allow the maximum level of fluoride to be 1.6 milligrams per liter (mg/l) at 90^{o}F and the level of nitrate (NO_3-N) to be 10.0 mg/l. Ground-water quality data for the Post Oak Aquifer and alluvium from Hounslow and Back (1985a and b), Stone (1981) and WATSTORE indicate areas where these levels are probably exceeded (Figures 25,26,27 and 28). The complex geochemistry of the occurrence of fluoride in the Post Oak (Hounslow and Back, 1985a) implies that wells within a node could exhibit very different amounts of fluoride. A high nitrate level might be accompanied by pesticide contamination (Hounslow and Back, 1985b). For these reasons wells in those areas with favorable yield and drilling costs but with problematic water quality should be examined more extensively for contamination before development of ground-water supplies. Adverse quality in nodes containing both alluvium and the Post Oak Aquifer was



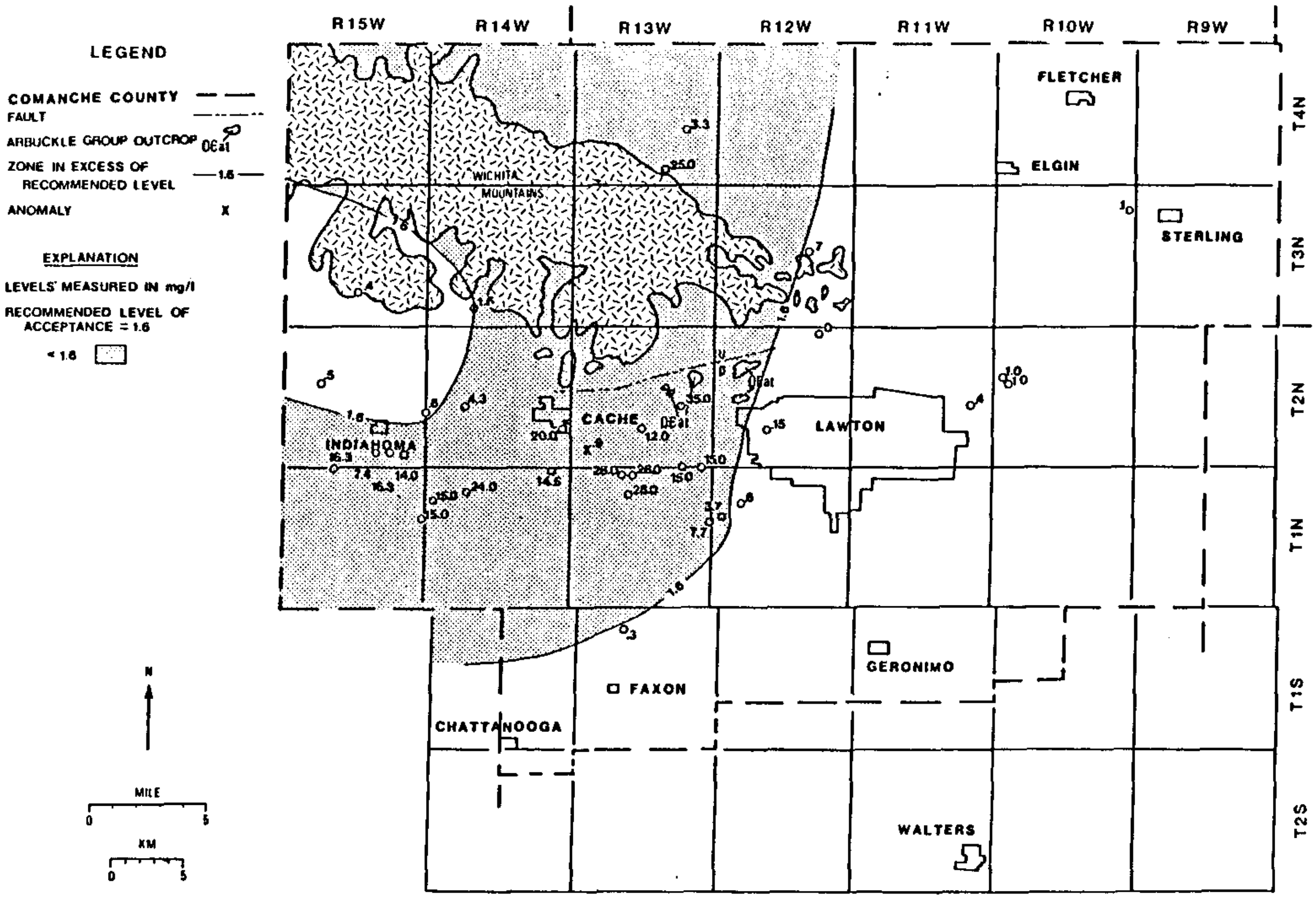
EXPECTED YIELD OF THE ARBUCKLE AQUIFER

Figure 23.



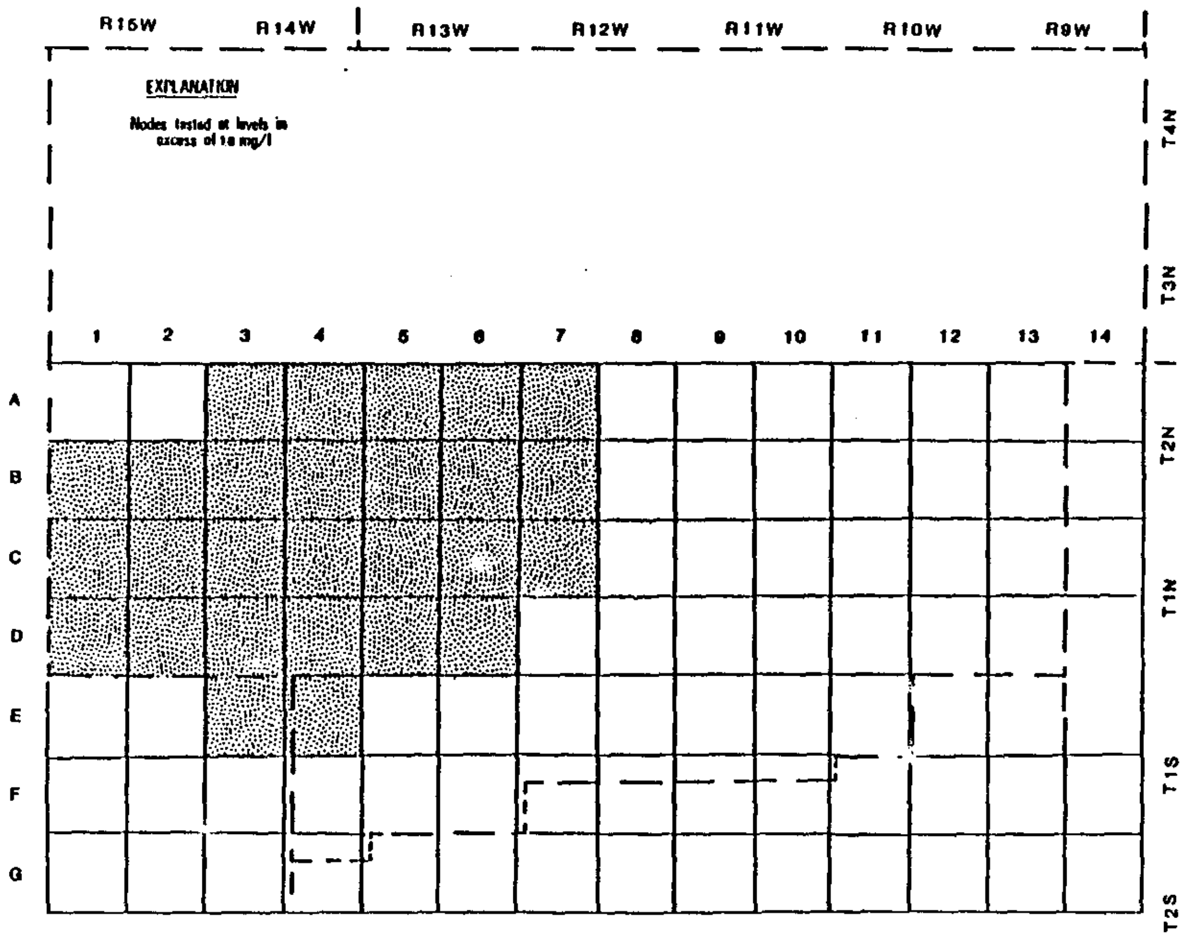
EXPECTED YIELD OF THE ARBUCKLE AQUIFER

Figure 24



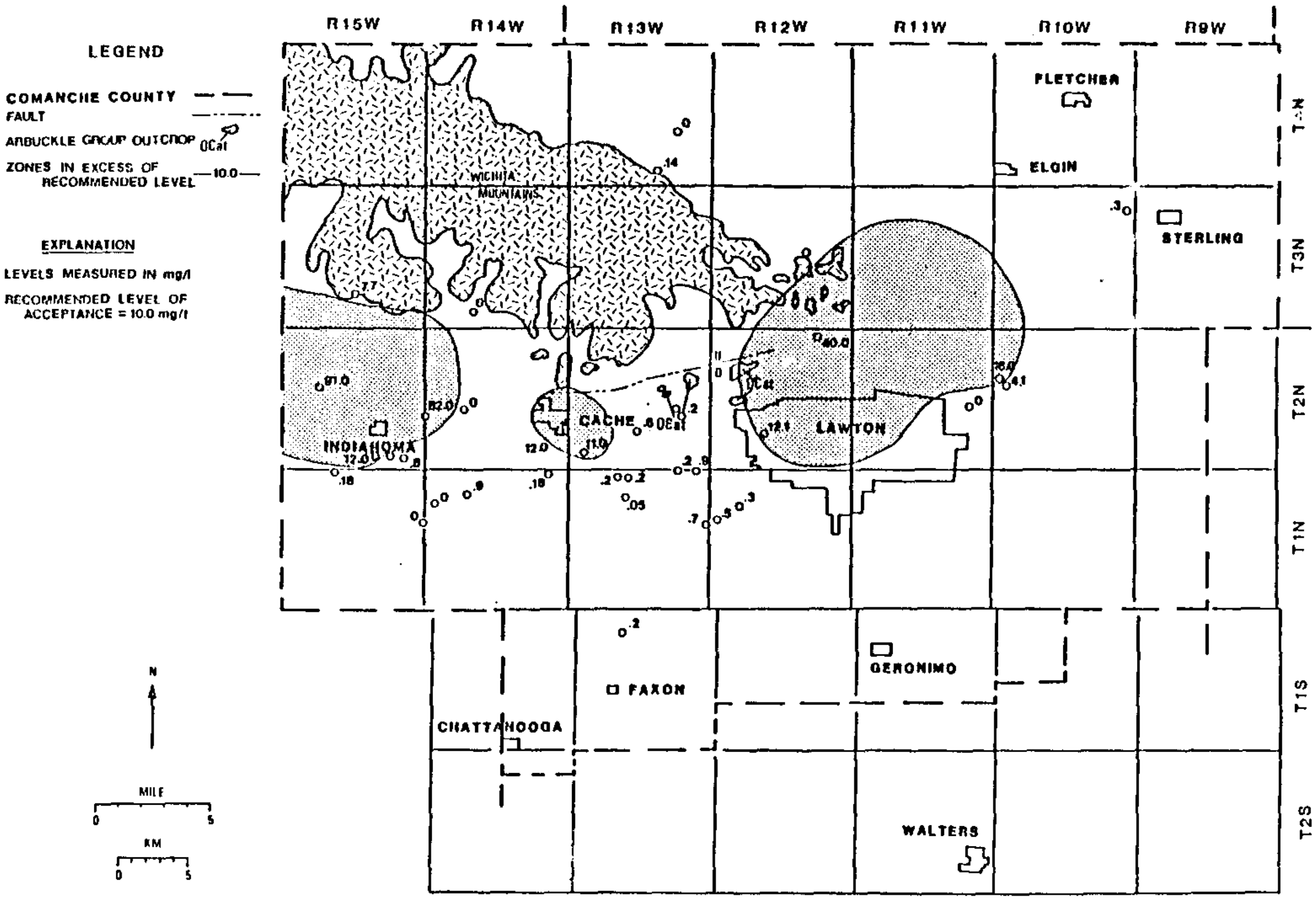
FLUORIDE: ZONES TESTED IN EXCESS OF RECOMMENDED LEVELS

Figure 25.



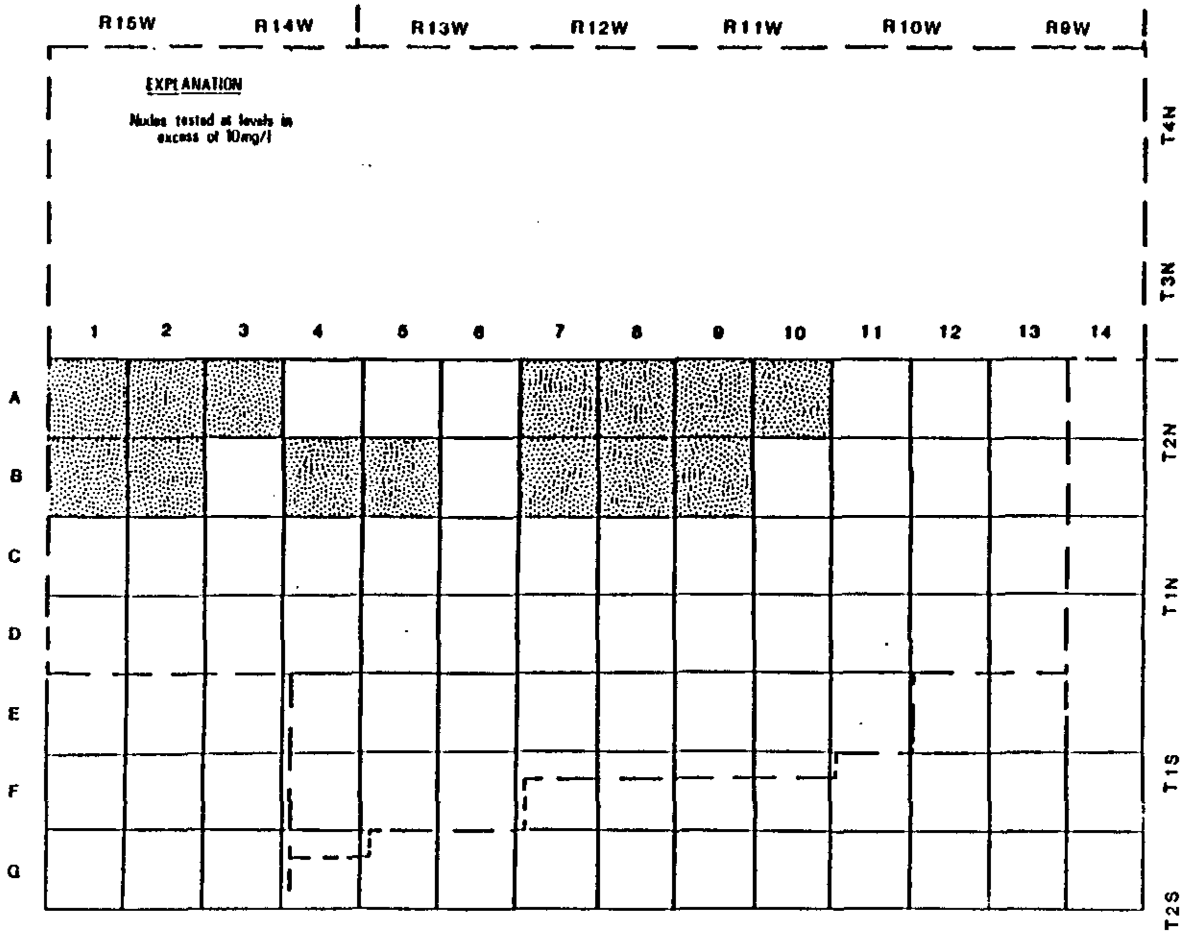
FLUORIDE: NODES TESTED IN EXCESS OF RECOMMENDED LEVEL AT 1.6 mg/l

Figure 26.



NITRATES (NO_3–N): ZONES TESTED IN EXCESS OF RECOMMENDED LEVELS

Figure 27.



NITRATES: NODES TESTED IN EXCESS OF RECOMMENDED LEVEL AT 10mg/l

Figure 28.

assumed to affect both aquifers.

According to data from Havens (1983) the fluoride level in the Arbuckle Aquifer ranges from 1.6 to 17.0 mg/l; the nitrate content is 0 to 8.3 mg/l. Hounslow and Back (1985a) claim that the presumed high fluoride level in the Arbuckle is due to poor well construction which allows contamination from high-fluoride Post Oak waters.

CONCLUSIONS

The three principal aquifers in Comanche County are the alluvium in creek valleys, the Post Oak Aquifer, and the Arbuckle Group Aquifer.

The Post Oak Aquifer consists of conglomerates, sandstones, and shales. This aquifer was separated into two zones of different permeability, transmissivity, and yield according to the areal distribution of grain sizes. The coarser-grained zone exhibits a permeability of 800 gpd/ft^2, a transmissivity of 16,000 gpd/ft, and would yield 110 gpm (Figure 29). The finer-grained zone has a permeability of 200 gpd/ft^2, a transmissivity of 4,000 gpd/ft, and would yield 30 gpm.

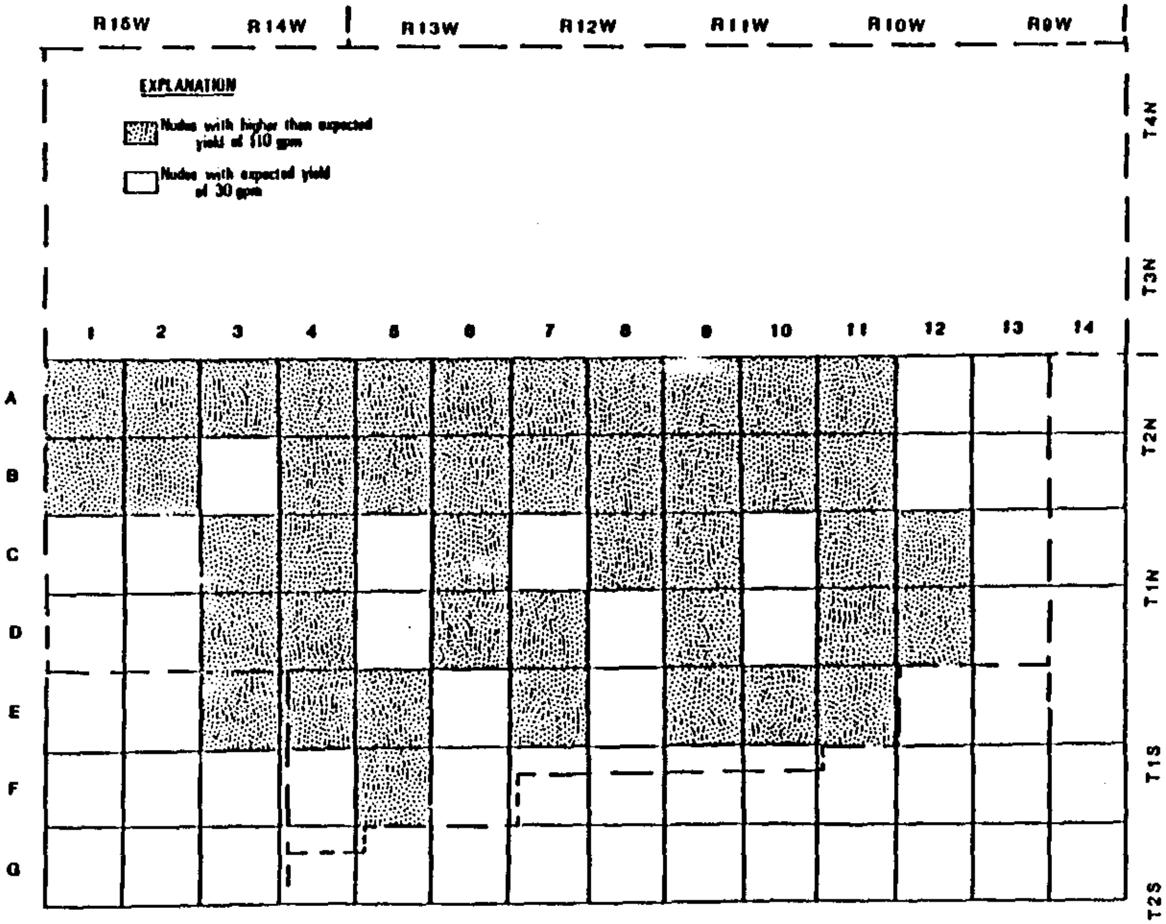
Alluvium consists of sands, gravels, and clays within creek valleys. The average permeability is 990 gpd/ft^2, the average transmissivity is 15,840 gpd/ft, and the average yield is 77 gpm (Figure 30).

The Arbuckle Group Aquifer lies below the Post Oak Aquifer and consists of limestones and dolomites. Its average permeability is 3.5 gpd/ft^2, with an average transmissivity of 1,720 gpd/ft, and the average well yield is 270 gpm (Figure 31).

Figure 32 is a map of the rural water distribution systems serving Comanche County showing the trunk lines longer than two miles. The smaller towns are supplied by their city well systems, except for Indiahoma which is temporarily on the CKT System. Comanche County Rural Water District (RWD) 3, Cotton County RWD 2, and the Geronimo Public Water Authority (PWA) may be connected.

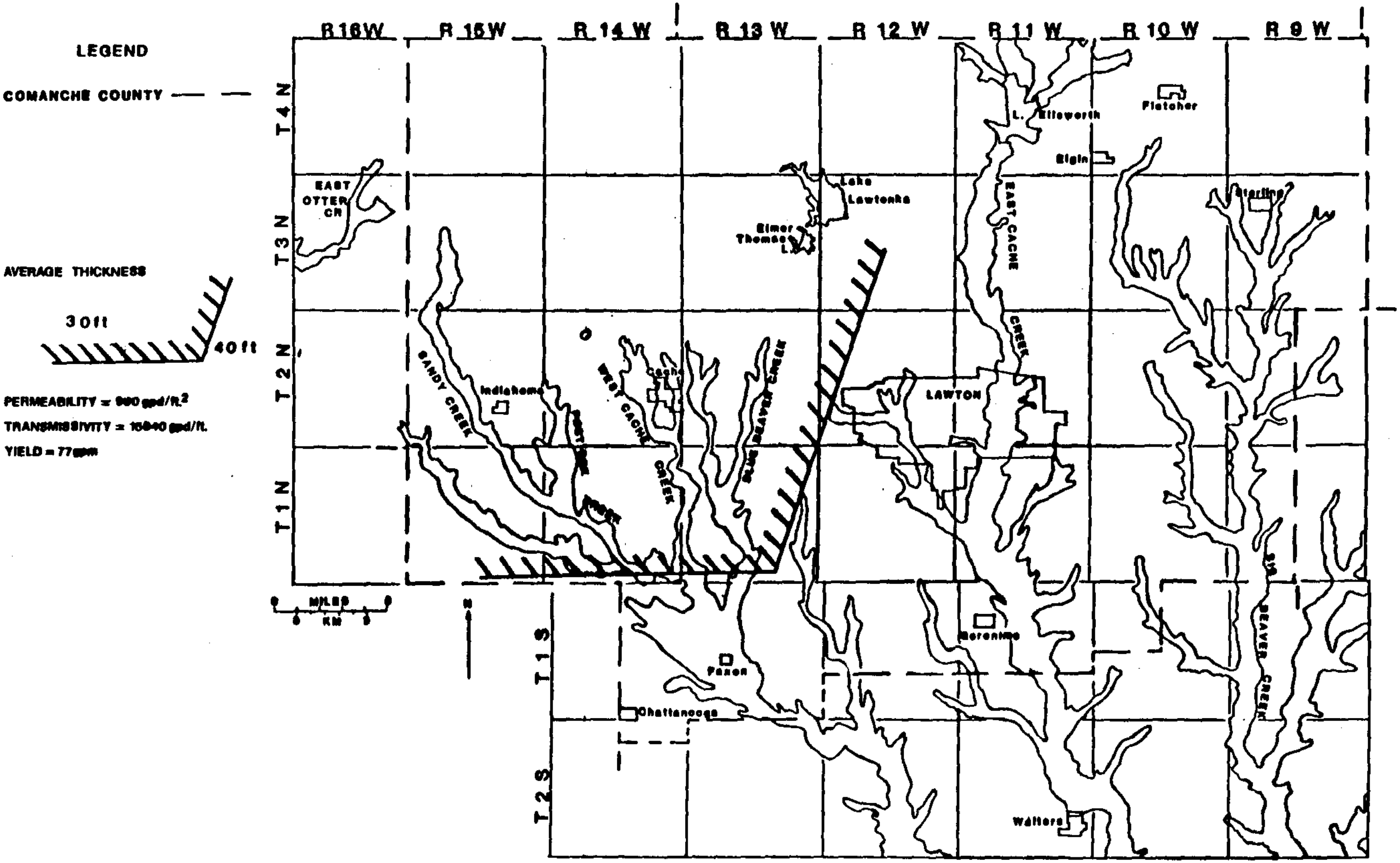
High fluoride levels in the Post Oak and alluvium occur in the west central portion of the study area between Indiahoma and Lawton (Figure 33). High nitrate levels occur just north of Indiahoma, southeast of Cache, and north of Lawton (Figure 34). In the Arbuckle Aquifer the fluoride content ranges from 1.6 to 17 mg/l, and the nitrate level ranges from 0 to 8.3 mg/l.

Table 1 summarizes the aquifer data for each nine-square-mile node of the reference grid; the nodes are grouped by their location in the rural water districts. Data for those nodes with the most favorable yield, drilling costs, and ground-water quality have been summarized in Tables 2 through 16. These are based on data presented above in Figures 29 through 34. A town or rural water district requiring additional ground-water supplies can compare areas of potential ground-water development which are close to the trunk lines of the water distribution systems. Within these favorable nodes the drilling costs, yields, and water quality of the aquifers can be compared.



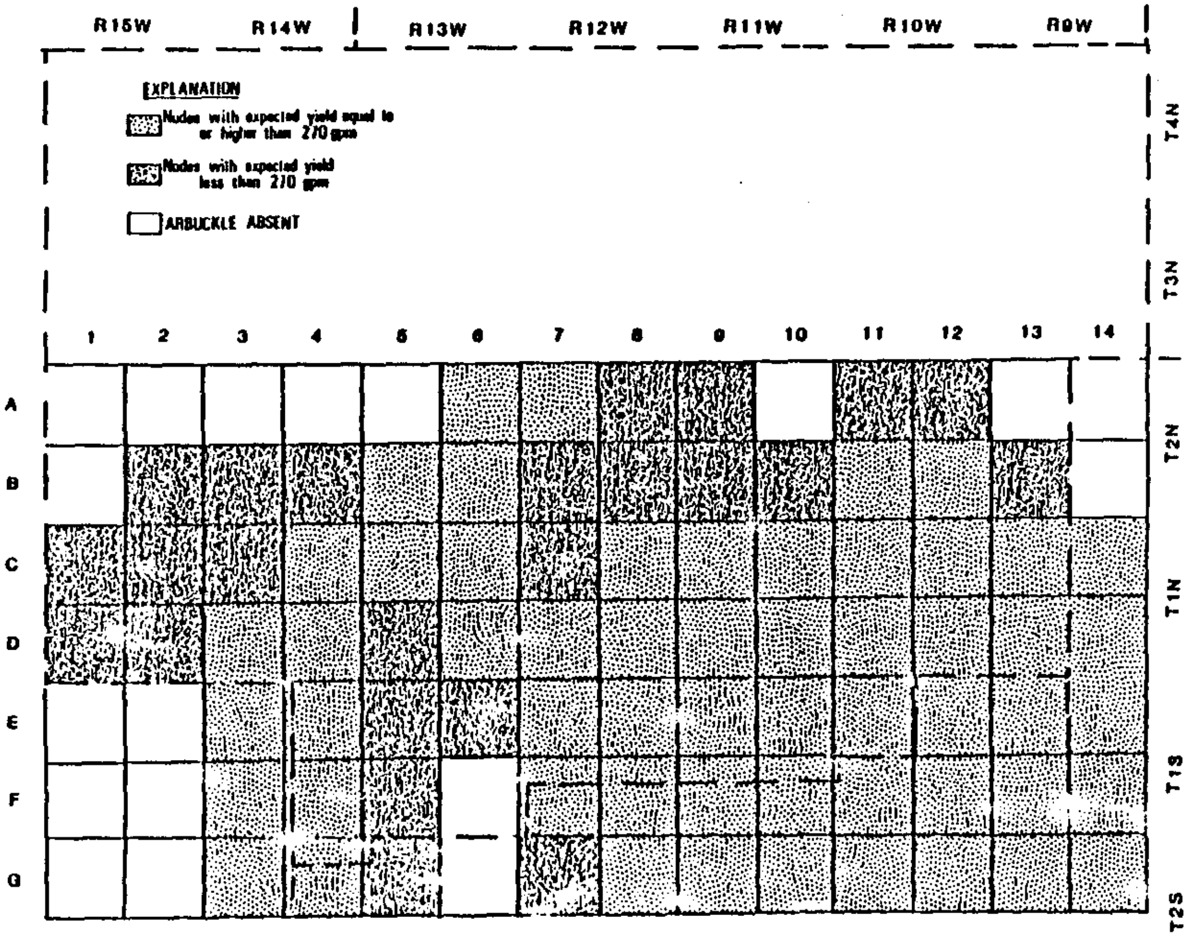
EXPECTED YIELD OF THE POST OAK AQUIFER

Figure 29.



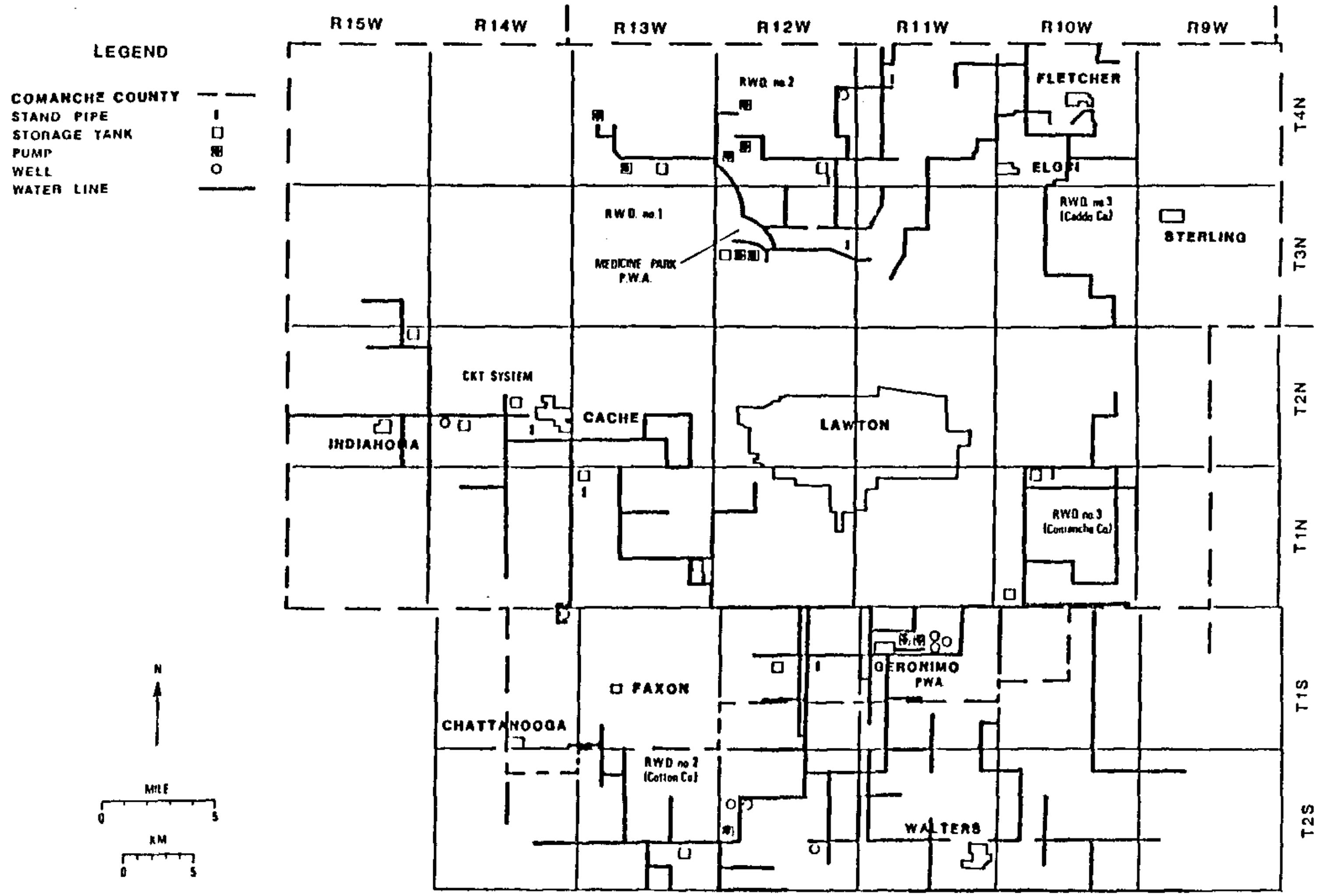
DISTRIBUTION OF ALLUVIUM AND REPORTED AVERAGE VALUES OF HYDROGEOLOGIC PROPERTIES

Figure 30.



EXPECTED YIELD OF THE ARBUCKLE AQUIFER

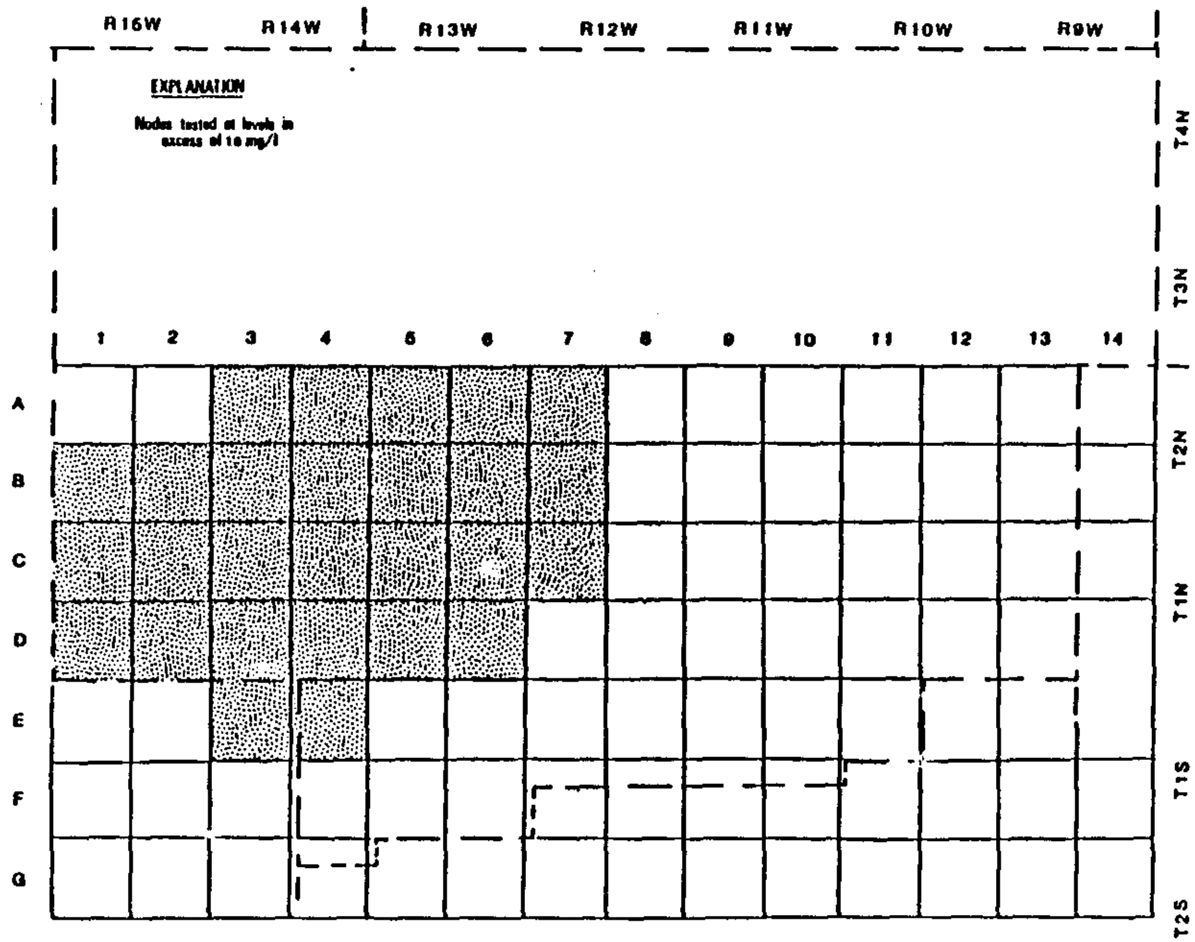
Figure 31.



Source: Oklahoma Water Resources Board, 1980

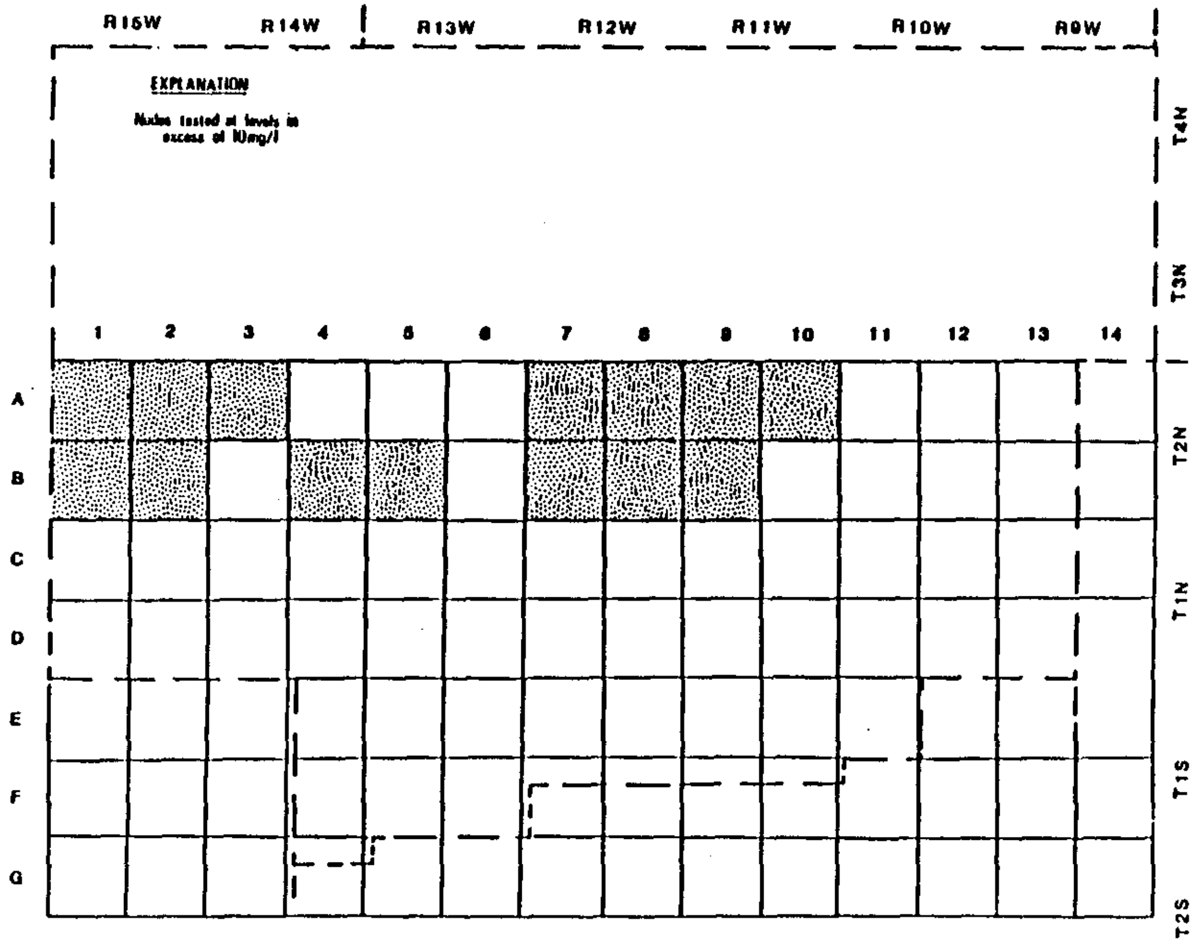
RURAL WATER DISTRICT MAIN TRUNK LINES

Figure 32.



FLUORIDE: NODES TESTED IN EXCESS OF RECOMMENDED LEVEL AT 1.6 mg/l

Figure 33.



NITRATES: NODES TESTED IN EXCESS OF RECOMMENDED LEVEL AT 10mg/l

Figure 34.

TABLE 1

AQUIFER CHARACTERISTICS

Node	POST OAK AQUIFER Avg Yield gpm	Depth to Water ft	Estimated Drilling Cost 1983$	Flouride mg/l	Nitrate mg/l	Permeability gpd/ft²	Transmissivity gpd/ft	Total Thickness ft	ALLUVIUM Average Yield gpm	Est. Drilling Cost 1983$	Flouride mg/l	Nitrate mg/l	Permeability gpd/ft²	Transmissivity gpd/ft	Average Thickness ft	ARBUCKLE Average Yield gpm	Depth to Arbuckle	Est. Drilling Cost 1983 $	Permeability	Transmissivity
CAT SERIES																				
A1	110	8	350		>10	800	16000	≤500	77	210	>1.6	>10	990	15840	30					
A2	110	8	350		>10	800	16000	≤500												
A3	110	8	350	>1.6	>10	800	16000	≤500												
A4	110	8	350	>1.6		800	16000	≤500	77	210	>1.6		990	15840	30					
A5	110	12	350	>1.6		800	16000	≤500	77	210	>1.6		990	15840	30					
A6	110	14	350	>1.6		800	16000	≤500								≥270	≤500	5250	≥3.5	≥1720
B1	110	10	350	>1.6	>10	800	16000	≤500	77	210	>1.6	>10	990	15840	30					
B2	110	11	350	>1.6	>10	800	16000	≤500	77	210	>1.6	>10	990	15840	30	<270	≤500		<3.5	<1720
B3	30	11	350	>1.6		200	4000	≤500	77	210	>1.6		990	15840	30	<270	≤500		<3.5	<1720
B4	110	8	350	>1.6	>10	800	16000	≤500	77	210	>1.6	>10	990	15840	30	<270	≤500	5250	<3.5	<1720
B5	110	13	350	>1.6	>10	800	16000	≤500	77	210	>1.6	>10	990	15840	30	≥270	≤500	5250	≥3.5	≥1720
B6	110	16	350	>1.6		800	16000	≤500								≥270	≤500	5250	≥3.5	≥1720
C1	30	12	350	>1.6		200	4000	≤500	77	210	>1.6		990	15840	30	<270	≤500	5250	<3.5	<1720
C2	30	16	350	>1.6		200	4000	≤500	77	210	>1.6		990	15840	30	<270	≤500	5250	<3.5	<1720
C3	110	17	350	>1.6		800	16000	≤500	77	210	>1.6		990	15840	30	<270	≤500	5250	<3.5	<1720
C4	110	12	350	>1.6		800	16000	≤1000								≥270	≤1000	5250	≥3.5	≥1720
*C5	30	12	350	>1.6		200	4000	≤1000	77	210	>1.6		990	15840	30	≥270	≤1000	5250	≥3.5	≥1720
D1	30	12	350	>1.6		200	4000	≤500								<270	≤500	5250	<3.5	<1720
D2	30	16	350	>1.6		200	4000	≤1000	77	210	>1.6		990	15840	30	<270	≤1000	8750	<3.5	<1720
D3	110	40	350	>1.6		800	16000	≤1000	77	210	>1.6		990	15840	30	≥270	≤1000	8750	≥3.5	≥1720
D4	110	12	350	>1.6		800	16000	≤1000	77	210	>1.6		990	15840	30	≥270	≤1000	8750	≥3.5	≥1720
*D5	110	12	350	>1.6		800	16000	≤1500	77	210	>1.6		990	15840	30	<270	≤1500	12250	<3.5	<1720
GERONIMO ZNE																				
*C5	30	12	350	>1.6		200	4000	≤1000	77	210	>1.6		990	15840	40	≥270	≤1000	8750	≥3.5	≥1720
C6	110	14	350	>1.6		800	16000	≤1000								≥270	≤1000	8750	≥3.5	≥1720
C7	30	14	350	>1.6		200	4000	≤1000								<270	≤1000	8750	<3.5	<1720
*D5	30	12	350	>1.6		200	4000	≤1500		210	>1.6		990	15840	40	<270	≤1500	12250	<3.5	<1720
D6	110	14	350	>1.6		800	16000	≤1500		280	>1.6		990	15840	40	≥270	≤1500	12250	≥3.5	≥1720
D7	110	13	350			800	16000	≤1500								≥270	≤1500	12250	≥3.5	≥1720
E6	30	15	350			200	4000	≤2000	77	280			990	15840	40	<270	≤2000	16750	<3.5	<1720
E7	30	15	350			200	4000	≤2000	77	280			990	15840	40	≥270	≤2000	16750	≥3.5	≥1720
E8	30	14	350			200	4000	≤2000								≥270	≤2000	16750	≥3.5	≥1720
E9	110	14	350			800	16000	≤2000	77	280			990	15840	40	≥270	≤2000	16750	≥3.5	≥1720
E10	110	12	350			800	16000	≤2000	77	280			990	15840	40	≥270	≤2000	16750	≥3.5	≥1720
COMANCHE COUNTY ZNE 1																				
B11	110	16	350			800	16000	≤1000								≥270	≤1000	8750	≥3.5	≥1720
B12	30	15	350			200	4000	≤1500	77	280			990	15840	40	≥270	≤1500	12250	≥3.5	≥1720
B13	30	16	350			200	4000	≤1000	77	280			990	15840	40	<270	≤1000	8750	<3.5	<1720
C11	110	14	350			800	16000	≤1500								≥270	≤1500	12250	≥3.5	≥1720
C12	110	14	350			800	16000	≤1500	77	280			990	15840	40	≥270	≤1500	12250	≥3.5	≥1720
C13	30	16	350			200	4000	≤1000	77	280			990	15840	40					
D11	110	12	350			800	16000	≤2000								≥270	≤2000	16750	≥3.5	≥1720
D12	110	14	350			800	16000	≤2000								≥270	≤2000	16750	≥3.5	≥1720
D13	30	14	350			200	4000	>2000	77	280			990	15840	40	≥270	>2000	>17500	≥3.5	≥1720
E11	110	12	350			800	16000	>2000								≥270	>2000	>17500	≥3.5	≥1720
E12	30	12	350			200	4000	>2000								≥270	>2000	>17500	≥3.5	≥1720
E13	30	12	350			200	4000	>2000	77	280			990	15840	40	≥270	>2000	>17500	≥3.5	≥1720
F12	30	12	350			200	4000	>2000	77	280			990	15840	40	≥270	>2000	>17500	≥3.5	≥1720
F13	30	12	350			200	4000	>2000	77	280			990	15840	40	≥270	>2000	>17500	≥3.5	≥1720
G12	30	13	350			200	4000	>2000								≥270	>2000	>17500	≥3.5	≥1720
G13	30	11	350			200	4000	>2000	77	280			990	15840	40	≥270	>2000	>17500	≥3.5	≥1720
COTTON CO. ZNE 2																				
F3	30	12	350			200	4000	≤1000								≥270	≤1000	8750	≥3.5	≥1720
F4	30	12	350			200	4000	≤1500		280			990	15840	40	≥270	≤1500	12250	≥3.5	≥1720
F5	110	14	350			800	16000	≤1500	77	280			990	15840	40	<270	≤1500	12250	<3.5	<1720
F6	30	15	350			200	4000	≤2000	77	280			990	15840	40					
F7	30	14	350			200	4000	≤2000	77							≥270	≤2000	16750	≥3.5	≥1720
F8	30	14	350			200	4000	≤2000		280			990	15840	40	≥270	≤2000	16750	≥3.5	≥1720
F9	30	12	350			200	4000	>2000	77	280			990	15840	40	≥270	>2000	>17500	≥3.5	≥1720
F10	30	12	350			200	4000	>2000	77							≥270	>2000	>17500	≥3.5	≥1720
F11	30	12	350			200	4000	>2000								≥270	>2000	>17500	≥3.5	≥1720
G3	30	14	350			200	4000	≤1000								≥270	≤1000	8750	≥3.5	≥1720
G4	30	14	350			200	4000	≤1500								≥270	≤1500	12250	≥3.5	≥1720
G5	30	14	350			200	4000	≤1500								<270	≤1500	12250	<3.5	<1720
G6	30	14	350			200	4000	≤2000		280			990	15840	40					
G7	110	14	350			200	4000	≤2000	77	280			990	15840	40	<270	≤2000	16750	<3.5	<1720
G8	110	14	350			200	4000	≤2000	77							≥270	≤2000	16750	>3.5	≥1720
G9	110	13	350			200	4000	>2000		280			990	15840	40	≥270	>2000	>17500	>3.5	≥1720
G10	110	13	350			200	4000	>2000	77							≥270	>2000	>17500	>3.5	≥1720
G11	110	12	350			200	4000	>2000								≥270	>2000	>17500	>3.5	≥1720
ALL OTHER																				
A7	110	21	350	>1.6	>10	800	16000	≤500												
A8	110	24	350		>10	800	16000	≤500		280		>10	990	15840	40	≥270	≤500	5250	≥3.5	≥1720
A9	110	14	350		>10	800	16000	≤500	77							<270	≤500	5250	<3.5	<1720
A10	110	16	350		>10	800	16000	≤1000								<270	≤500	5250	<3.5	<1720
A11	110	15	350			800	16000	≤1500		280			990	15840	40	<270	≤500	8750	<3.5	<1720
A12	30	12	350			200	4000	≤1500	77	280			990	15840	40	<270	≤1500	12250	<3.5	<1720
A13	30	14	350			200	4000	≤1000	77	280	>1.6	>10	990	15840	40	<270	≤1500	12250	<3.5	<1720
A14	30	14	350			200	4000	≤1000	77	280		>10	990	15840	40					
B7	110	19	350	>1.6	>10	800	16000	≤500	77	280		>10	990	15840	40	<270	≤500	12250	<3.5	<1720
B8	110	22	350		>10	800	16000	≤500	77							<270	≤500	12250	<3.5	<1720
B9	110	14	350		>10	800	16000	≤500	77	280			990	15840	40	<270	≤500	12250	<3.5	<1720
B10	110	15	350			800	16000	≤1000		280			990	15840	40	<270	≤1000	8750	<3.5	<1720
B14	30	13	350			200	4000	≤1500		280			990	15840	40					
C8	110	17	350			800	16000	≤1000	77	280			990	15840	40	≥270	≤1000	8750	≥3.5	≥1720
C9	110	14	350			800	16000	≤1000	77							≥270	≤1000	8750	≥3.5	≥1720
C10	30	15	350			200	4000	≤1500	77							≥270	≤1500	12250	≥3.5	≥1720
C14	30	13	350			200	4000	≤1500		280			990	15840	40	≥270	≤1500	12250	≥3.5	≥1720
D8	30	14	350			200	4000	≤1500								≥270	≤1500	12250	≥3.5	≥1720
D9	110	14	350			800	16000	≤1500	77	280			990	15840	40	≥270	≤1500	12250	≥3.5	≥1720
D10	30	13	350			200	4000	≤2000								≥270	≤2000	16750	≥3.5	≥1720
D14	30	12	350			200	4000	>2000	77							≥270		16750	≥3.5	≥1720
E1	30	12	350	1.6		200	4000	≤500		280	>1.6		990	15840	40					
E2	30	13	350	1.6		200	4000	≤1000		280			990	15840	40	<270	≤500	8750	<3.5	<1720
E3	110	13	350	>1.6		800	16000	≤1000		280			990	15840	40	≥270	≤1000	8750	≥3.5	≥1720
E4	30	13	350	>1.6		200	4000	≤1500	77							≥270	≤1500	12250	≥3.5	≥1720
E5	110	13	350			800	16000	≤1500	77							<270	≤1500	12250	<3.5	<1720
E14	30	12	350			200	4000	>2000	77	280			990	15840	40	≥270		16750	≥3.5	≥1720
F1	30	13	350	>1.6		200	4000	≤1000												
F2	30	13	350	>1.6		200	4000	≤1000								<270	≤500	8750	<3.5	<1720
F14	30	12	350			200	4000	>2000	77							≥270		16750	≥3.5	≥1720
G1	30	13	350			200	4000	≤1000												
G2	30	13	350			200	4000	≤1000								≥270		16750	≥3.5	≥1720
G14	30	12	350			200	4000	>2000												

* CAT & GERONIMO OVERLAP- NODE LISTED TWICE

TABLE 2

CKT SYSTEM: HIGH YIELD NODES, ALLUVIUM AQUIFER

		HIGHER THAN RECOMMENDED LIMITS		
NODE	EXPECTED AVERAGE YIELD, gpm	FLUORIDE, mg/l	NITRATE, mg/l	ESTIMATED COST AT $7.00/ft.
A1	77	>1.6	>10	$210.00
A4	77	>1.6		210.00
A5	77	>1.6		210.00
B1	77	>1.6	>10	210.00
B2	77	>1.6	>10	210.00
B3	77	>1.6		210.00
B4	77	>1.6	>10	210.00
B5	77	>1.6	>10	210.00
C1	77	>1.6		210.00
C2	77	>1.6		210.00
C3	77	>1.6		210.00
C5	77	>1.6		210.00
D2	77	>1.6		210.00
D4	77	>1.6		210.00
D5	77	>1.6		210.00

TABLE 3

CKT SYSTEM: HIGH YIELD NODES, POST OAK AQUIFER

NODE	EXPECTED YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS FLUORIDE, mg/l	NITRATE, mg/l	ESTIMATED COST AT $7.00/ft., AVG. OF 50 ft.
A1	110		>10	$350.00
A2	110		>10	350.00
A3	110	>1.6	>10	350.00
A4	110	>1.6		350.00
A5	110	>1.6		350.00
A6	110	>1.6		350.00
B1	110	>1.6	>10	350.00
B2	110	>1.6	>10	350.00
B4	110	>1.6	>10	350.00
B5	110	>1.6	>10	350.00
B6	110	>1.6		350.00
C3	110	>1.6		350.00
C4	110	>1.6		350.00
D3	110	>1.6		350.00
D4	110	>1.6		350.00
D5	110	>1.6		350.00

TABLE 4

CKT SYSTEM: HIGH YIELD NODES, ARBUCKLE AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGER THAN RECOMMENDED LIMITS* FLUORIDE, mg/l	NITRATE, mg/l	ESTIMATED COST AT $7.00/ft.
A6	>270	>1.6		$5,250.00
B5	>270	>1.6		5,250.00
B6	>270	>1.6		5,250.00
C4	>270	>1.6		5,250.00
C5	>270	>1.6		5,250.00
D3	>270	>1.6		5,250.00
D4	>270	>1.6		5,250.00

* SOURCE OF DATA: HAVENS, 1983

TABLE 5

GERONIMO P.W.A.: HIGH YIELD NODES, ALLUVIUM AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS FLUORIDE, mg/l	NITRATE, mg/l	ESTIMATED COST AT $7.00/ft.
C5	77	>1.6		$210.00
E6	77			280.00
E7	77			280.00
E9	77			280.00
E10	77			280.00

TABLE 6

GERONIMO PWA: HIGH YIELD NODES, POST OAK AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS		ESTIMATED COST AT $7.00/ft., AVERAGE OF 50 ft.
		FLUORIDE, mg/l	NITRATE, mg/l	
C6	110	>1.6		$350.00
D6	110	>1.6		350.00
D7	110			350.00
E9	110			350.00
E10	110			350.00
				350.00

TABLE 7

GERONIMO P.W.A.: HIGH YIELD NODES, ARBUCKLE AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS* FLUORIDE, mg/l	NITRATE, mg/l	ESTIMATED COST AT $7.00/ft.
C5	>270	>1.6		$8,750.00
C6	>270	>1.6		8,750.00
D6	>270	>1.6		12,250.00
D7	>270	>1.6		12,250.00
E7	>270	>1.6		16,750.00
E8	>270	>1.6		16,750.00
E9	>270	>1.6		16,750.00
E10	>270	>1.6		16,750.00

*SOURCE OF DATA; HAVENS, 1983

TABLE 8

COMANCHE CO. RWD 3: HIGH YIELD NODES, ALLUVIUM AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS FLUORIDE, mg/l	NITRATE, mg/l	ESTIMATED COST AT $7.00/ft.
B12	77			$280.00
B13	77			280.00
C12	77			280.00
C13	77	(ALL NODES WERE BELOW		280.00
D13	77	RECOMMENDED LIMITS)		280.00
E13	77			280.00
F12	77			280.00
F13	77			280.00
G13	77			280.00

TABLE 9

COMANCHE CO. RWD 3: HIGH YIELD NODES, POST OAK AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS FLUORIDE, mg/l	NITRATE, mg/l	ESTIMATED COST AT $7.00/ft. AVERAGE OF 50 ft.
B11	110			$350.00
C11	110			350.00
C12	110	(ALL NODES WERE BELOW RECOMMENDED LIMITS)		350.00
D11	110			350.00
D12	110			350.00
E11	110			350.00

TABLE 10

COMANCHE CO. RWD 3: HIGH YIELD NODES, ARBUCKLE AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS* FLUORIDE, mg/l	NITRATE, mg/l	ESTIMATED COST AT $7.00/ft.
B11	>270	>1.6		$8,750.00
B12	>270	>1.6		12,250.00
C11	>270	>1.6		12,250.00
C12	>270	>1.6		12,250.00
D11	>270	>1.6		16,750.00
D12	>270	>1.6		16,750.00
D13	>270	>1.6		17,500.00
E11	>270	>1.6		17,500.00
E12	>270	>1.6		17,500.00
E13	>270	>.16		17,500.00
F12	>270	>1.6		17,500.00
F13	>270	>1.6		17,500.00
G12	>270	>1.6		17,500.00
G13	>270	>1.6		17,500.00

*SOURCE OF DATA: HAVEN, 1983

TABLE 11

COTTON COUNTY RWD 2: HIGH YIELD NODES, ALLUVIUM AQUIFER

NODES	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS FLUORIDE, mg/l	NITRATE, mg/l	EXPECTED COST AT $7.00/ft.
F5	77			$280.00
F6	77			280.00
F7	77	(ALL NODES WERE BELOW		280.00
F9	77	RECOMMENDED LIMITS)		280.00
F10	77			280.00
G7	77			280.00
G8	77			280.00
G10	77			280.00

TABLE 12

COTTON COUNTY RWD 2: HIGH YIELD NODES, POST OAK AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS FLUORIDE, mg/l	NITRATE, mg/l	EXPECTED COST AT $7.00/ft. AVERAGE OF 50 ft.
F5	110			$350.00
G7	110	(ALL NODES WERE BELOW RECOMMENDED LIMITS)		350.00
G8	110			350.00
G9	110			350.00
G10	110			350.00
G11	110			350.00

TABLE 13

COTTON COUNTY RWD 2: HIGH YIELD NODES, ARBUCKLE AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS* FLUORIDE, mg/l	NITRATE, mg/l	EXPECTED COST AT $7.00/ft.
F3	>270	>1.6		$8,750.00
F4	>270	>1.6		12,250.00
F7	>270	>1.6		16,750.00
F8	>270	>1.6		16,750.00
F9	>270	>1.6		17,500.00
F10	>270	>1.6		17,500.00
F11	>270	>1.6		17,500.00
G3	>270	>1.6		8,750.00
G4	>270	>1.6		12,250.00
G8	>270	>1.6		16,750.00
G9	>270	>1.6		17,500.00
G10	>270	>1.6		17,500.00
G11	>270	>1.6		17,500.00

*SOURCE OF DATA: HAVENS, 1983

TABLE 14

NON-RURAL WATER DISTRICT: HIGH YIELD NODES, ALLUVIUM AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS FLUORIDE, mg/l	NITRATE, mg/l	EXPECTED COST AT $7.00 ft.
A13	77			$280.00
A9	77		>10	280.00
A12	77			280.00
A14	77			280.00
B7	77	>1.6	>10	280.00
B8	77		>10	280.00
B9	77		>10	280.00
C8	77			280.00
C9	77			280.00
C10	77			280.00
D9	77			280.00
D14	77			280.00
E4	77	>1.6		280.00
E5	77			280.00
E14	77			280.00
F14	77			280.00

TABLE 15

NON-RURAL WATER DISTRICT: HIGH YIELD NODES, POST OAK AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS FLUORIDE, mg/l	NITRATE, mg/l	EXPECTED COST AT $7.00/ft. AVERAGE OF 50 ft.
A7	110	>1.6	>10	$350.00
A8	110		>10	350.00
A9	110		>10	350.00
A10	110		>10	350.00
A11	110			350.00
B7	110	>1.6	>10	350.00
B8	110		>10	350.00
B9	110		>10	350.00
B10	110			350.00
C8	110			350.00
C9	110			350.00
D9	110			350.00
E3	110	>1.6		350.00
E5	110			350.00

TABLE 16

NON-RURAL WATER DESTRICT: HIGH YIELD NODES, ARBUCKLE AQUIFER

NODE	EXPECTED AVERAGE YIELD, gpm	HIGHER THAN RECOMMENDED LIMITS* FLUORIDE, mg/l	NITRATE, mg/l	EXPECTED COST AT $7.00/ft.
A7	>270	>1.6		$5,250.00
C8	>270	>1.6		8,750.00
C9	>270	>1.6		8,750.00
C10	>270	>1.6		12,250.00
C14	>270	>1.6		12,250.00
D8	>270	>1.6		12,250.00
D9	>270	>1.6		12,250.00
D10	>270	>1.6		16,750.00
D14	>270	>1.6		16,750.00
E3	>270	>1.6		8,750.00
E4	>270	>1.6		12,250.00
E14	>270	>1.6		16,750.00
F14	>270	>1.6		16,750.00
G14	>270	>1.6		16,750.00

*SOURCE OF DATA: HAVENS, 1983

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ADDENDUM

Distribution of Well Yields in the Arbuckle Group Aquifer Based on Lineament Analysis

The distribution of estimated well yield of the Arbuckle Group Aquifer was determined by analysis of aerial photographs. Two approaches were used: one was to assume that lineaments in the Post Oak and Permian sediments above the Arbuckle Group indicate fracture patterns in the underlying Arbuckle Aquifer. These lineaments consist of straight segments of stream valleys, segments of several stream valleys that are in alignment with one another, or non-cultivated vegetation in linear patterns. The other approach involved projection of fracture patterns occurring in the Wichita Mountains into the Arbuckle Group to the south. Fractures in the Wichita Granite Group were studied by Gilbert (1982). A lineament analysis and corresponding geological interpretation of Comanche County is discussed by Donovan and others (1986).

Both approaches required the measurement of lengths and orientations of lineaments on a mosaic of aerial photographs at a scale of one to 40,000, or one inch equals approximately one mile (U.S. Department of Agriculture, 1981). A map of the major lineaments in the Wichita Mountains and in the Permian sediments to the south is shown in Figure 1. Fracture lineaments in the Wichita Mountains range in length from 0.2 to 6.2 miles and have three dominant orientations: 60° to 90° west of north, 10° west to 10° east of north, and 80° to 90° east of north (Fig. 2). Lineaments of stream valleys and vegetation, most of which are south of the mountains, range in length from 0.3 to 11.4 miles with two dominant orientations: 20° to 30° west of north and zero to 10° east of north (Fig. 3). Most of these lineaments are between one and two miles long.

The fracture lineaments can be separated into two sets according to their time of formation (see Figs. 2 and 3). The east-west trending fracture lineaments formed earlier than the north-south trending set as shown by the lack of an east-west trend in the lineaments of the Post Oak Conglomerate and Permian sediments. Presumably both sets occur in the Arbuckle Group; however, assuming that the north-south set formed after deposition of the Post Oak Conglomerate, only the north-south set propagated upward through the Post Oak.

Assuming that permeability and well yield are controlled by the density of fractures, the amount of fracturing was studied by using two approaches. It was assumed in the first approach that a lineament might indicate only part of a fracture and that an area with many intersecting fractures would have a greater permeability. Therefore, the lineaments were extended across the area on an overlay map using both the east-west and north-south sets of lineaments; it is assumed that both sets occur in the Arbuckle Group. The schematic map shown in Figure 4 represents the extended lineaments, and the number of lineament intersections per node is shown in Figure 5. The bottom row is beyond the area of the overlay map. In order to establish a permeability value for each node, the average permeability of the Arbuckle Aquifer was determined from the well data. A value of

3.5 gpd/ft^2 was computed (see Kent and others, 1986, p. 33) and multiplied by the ratio of the number of intersections in a node to the mean number of intersections per node. An example of this calculation is shown in Figure 6; a map of the calculated permeability values for each node is shown in Figure 7. Well yield values were calculated for each node using a formula by Walton (1970, p. 315) which assumes an average effective aquifer thickness of 500 feet, a well radius of 0.28 feet, a pumping period of 5000 minutes, a drawdown of 350 feet, and a storativity of 0.0001. These values are derived from drillers' logs and pumping test data from this area. A sample well yield calculation is also shown in Figure 6; a map of the calculated yield values for each node is shown in Figure 8.

It was assumed in the second approach that the total length of fractures in an area controls the permeability. Only the lineaments in the Post Oak and Permian sediments were considered because the Wichita Mountain fracture lineaments are outside the study area, and the lineaments in the Post Oak indicate fracture patterns in the Arbuckle Group. The sum of lineament lengths per node is shown in Figure 9. The computation of the permeability for the node is similar to the procedure used in the first method. The permeability is the product of the average permeability as determined from well data and the ratio of the total lineament length in a node to the average total length per node. Well yield again was determined by Walton's formula. Sample calculations of permeability and well yield for a node are shown in Figure 10. Figure 11 is a map of the permeabilities for each node, and Figure 12 is a map of the well yield values for each node. Nodes without values are beyond the area of either the aerial photographs or the overlay map.

Well yield values derived from the two approaches (Figs. 8 and 12) were also averaged using an arithmetic mean and are shown in Figure 13. These values were compared with the average calculated yield according to production well test data shown in Figure 14 (Fig. 24 from Kent and others, 1986). The locations from both maps (Figs. 13 and 14) which correspond to a well yield of more than 270 gpm are plotted and shown on the map in Figure 15.

The methods of analysis used for the two approaches have been applied in conjunction with well yield data (Kent and others, 1986) to estimate the distribution of relative, average-expected well yields in the Arbuckle Group Aquifer as shown in Figures 13 and 15. These methods qualitatively locate areas of relatively higher well yields. The determination of actual aquifer well yields quantitatively for any one location requires actual production well test data for that location.

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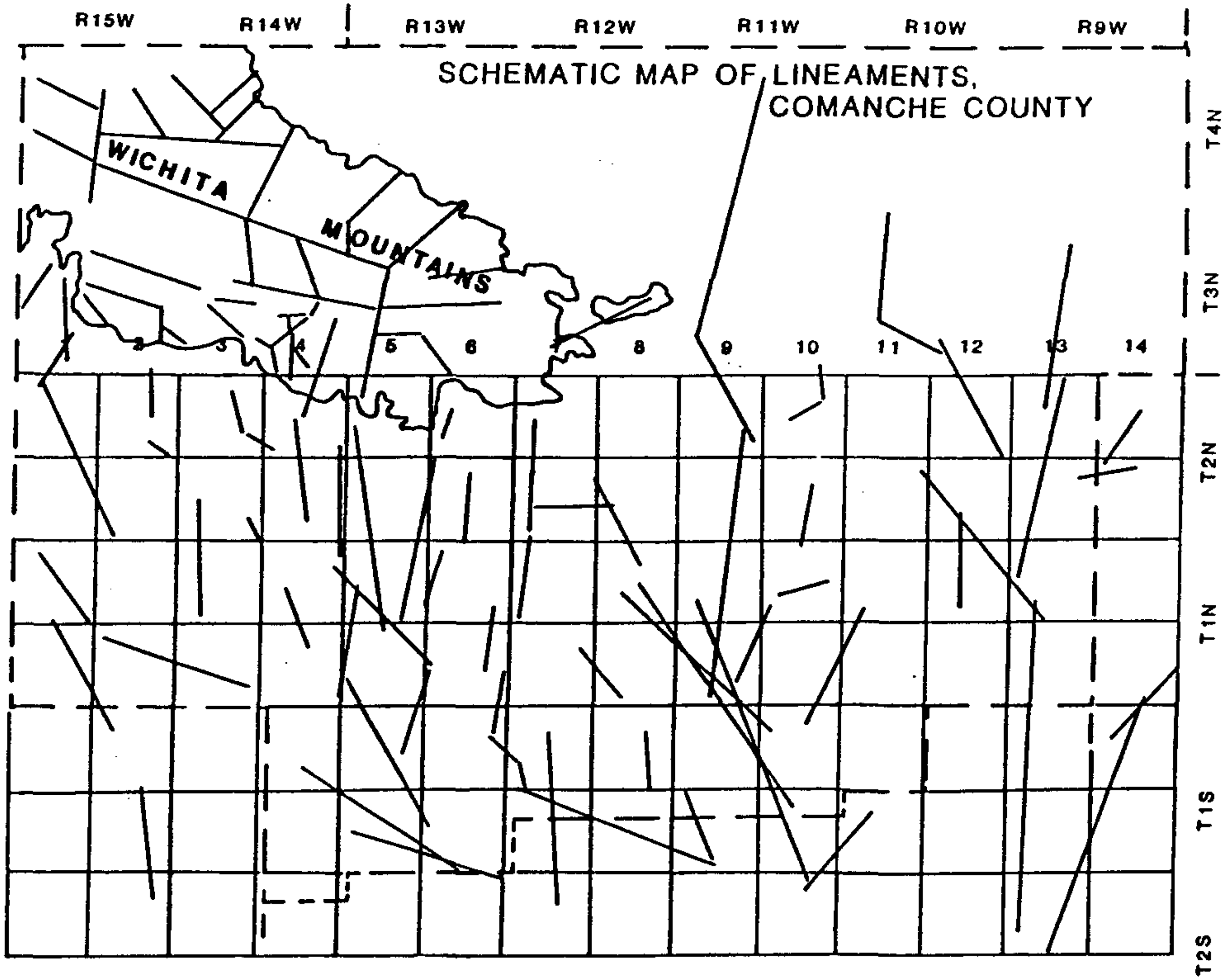

R15W
R14W
R13W
R12W
R11W
R10W
R9W
SCHEMATIC MAP OF LINEAMENTS,
COMANCHE COUNTY
WICHITA
MOUNTAINS
T4N
T3N
T2N
T1N
T1S
T2S
1
2
3
4
5
6
7
8
9
10
11
12
13
14
A
B
C
D
E
F
G

Figure 1

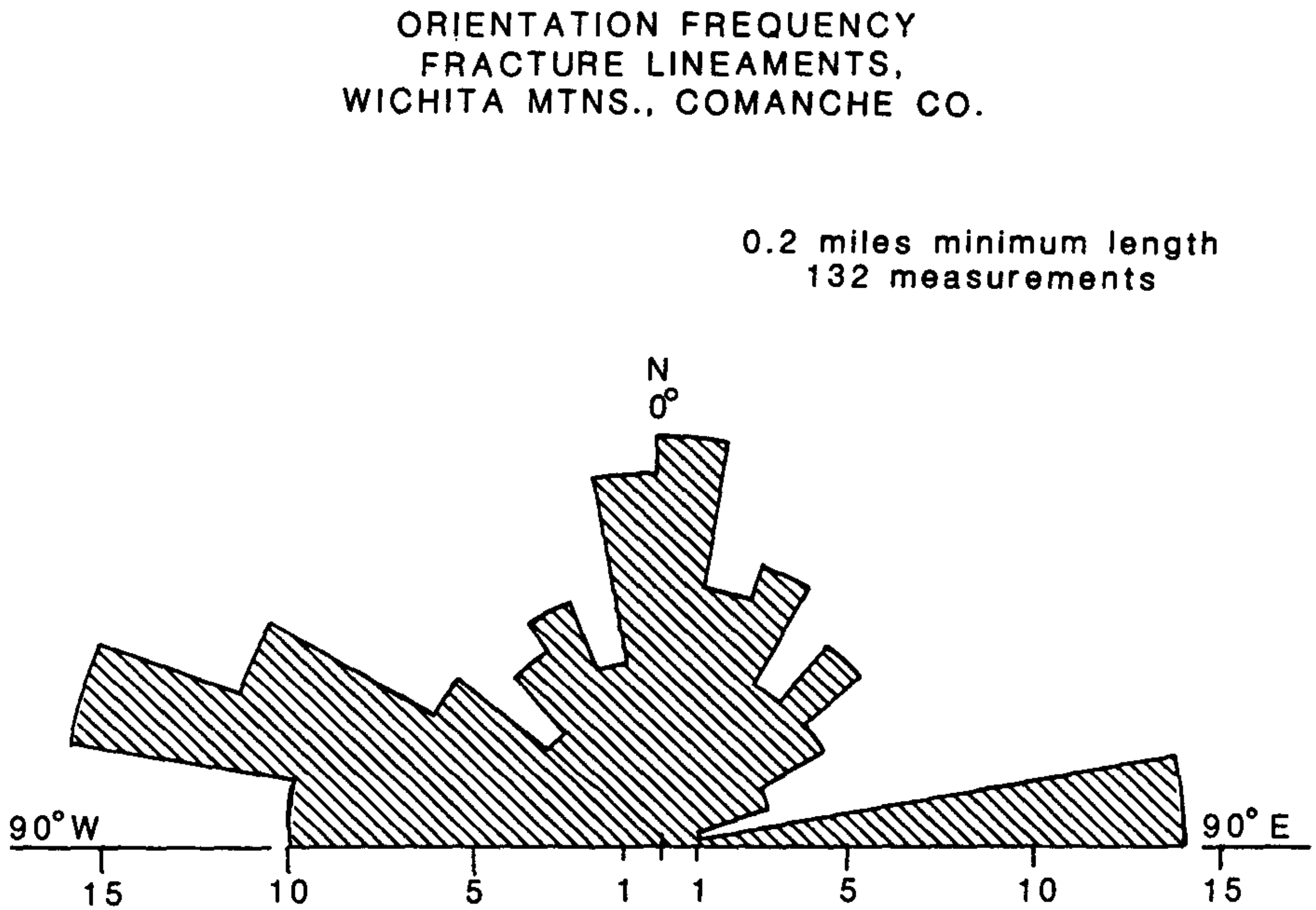

ORIENTATION FREQUENCY
FRACTURE LINEAMENTS,
WICHITA MTNS., COMANCHE CO.
0.2 miles minimum length
132 measurements
N
0°
90°W
90° E
15
10
5
1
1
5
10
15

Figure 2

ORIENTATION FREQUENCY
VALLEY AND VEGETATION LINEAMENTS,
SOUTH OF WICHITA MTNS., COMANCHE CO.

0.3 miles minimum length
115 measurements

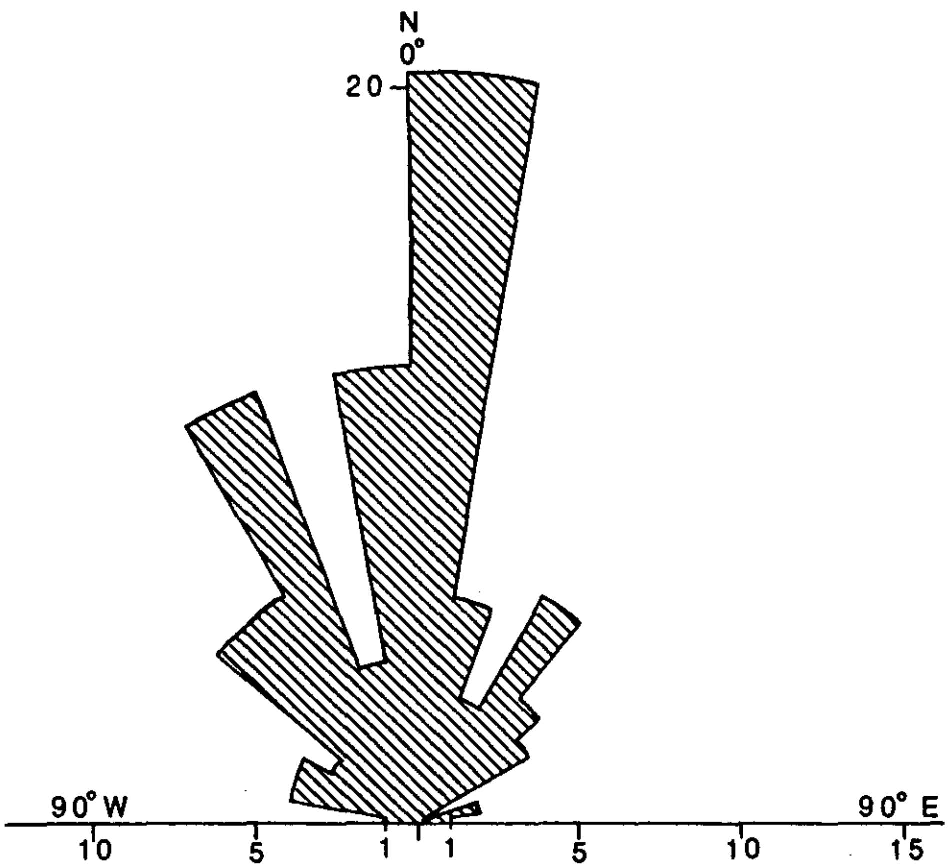


Figure 3

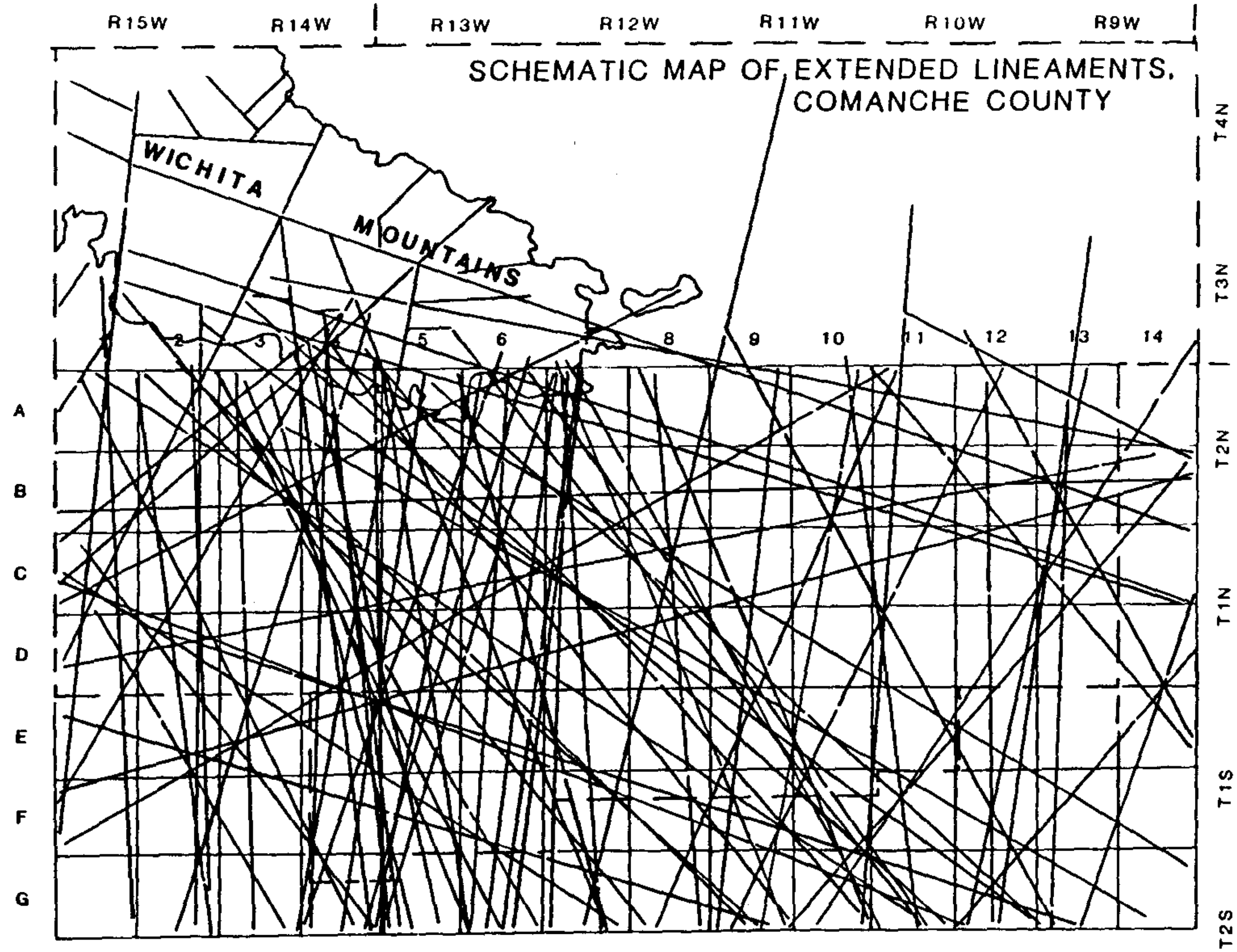

R15W
R14W
R13W
R12W
R11W
R10W
R9W
SCHEMATIC MAP OF EXTENDED LINEAMENTS,
COMANCHE COUNTY
WICHITA
MOUNTAINS
T4N
T3N
T2N
T1N
T1S
T2S
A
B
C
D
E
F
G
2
3
5
6
8
9
10
11
12
13
14

Figure 4

R15W R14W R13W R12W R11W R10W R9W

ARBUCKLE AQUIFER: NUMBER OF LINEAMENT INTERSECTIONS PER NODE, n

mean n=58

T4N T3N

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	116	80	125	246	157	153	103	36	58	22	32	61	30	8
B	101	96	98	121	103	138	99	46	34	16	35	34	40	54
C	38	106	91	125	64	75	73	35	18	12	36	17	56	55
D	50	37	115	120	74	96	97	16	45	42	16	52	28	21
E	19	60	94	85	79	55	44	6	40	53	32	31	22	27
F	13	39	47	59	106	67	17	43	32	16	12	24	33	23
G														

T2N T1N T1S T2S

Figure 5

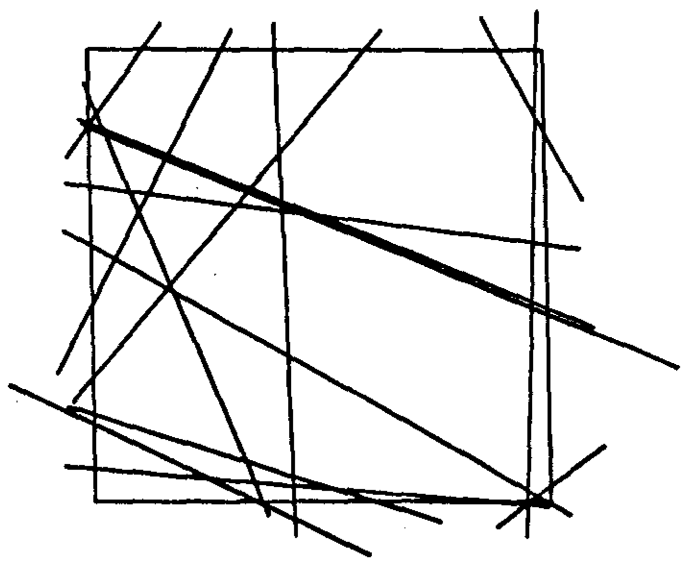
Figure 6

SAMPLE CALCULATIONS OF PERMEABILITY AND YIELD DERIVED FROM NUMBER OF LINEAMENT INTERSECTIONS FOR NODE B-12

Number of lineament intersections, n, = 34 ; mean n, $\bar{n}$, = 58

Mean Permeability, K, = 3.5 gpd/ft.^{2}

Permeability, K, = $\frac{n}{\bar{n}} \times K = \frac{34}{58} \times 3.5 = 2.03$ gpd/ft.^{2}



NODE B-12

Average effective aquifer thickness, b, = 500 ft.

Average well radius, r_w, = 0.28 ft.

Average pumping period, t, = 5000 min.

Average drawdown, s, = 350 ft.

Storativity, S, = 0.0001

$$\text{Yield, } Q, = \frac{Kbs}{264 \log\left(\frac{Kbt}{2693\, r_w^2\, S}\right) - 65.5}$$

$$= \frac{2.03\,(500)\,(350)}{264 \log\left(\frac{2.03\,(500)\,(5000)}{2693\,(0.28)^2\,(0.0001)}\right) - 65.5} = 165 \text{ gpm}$$

R15W R14W R13W R12W R11W R10W R9W

ARBUCKLE AQUIFER: PERMEABILITY, K, DERIVED FROM NUMBER OF LINEAMENT INTERSECTIONS, gpd/ft^2

$$K = \frac{n}{\text{mean } n} \times \text{mean } K$$

mean K = 3.5 gpd/ft^2

T4N T3N

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	6.94	4.79	7.48	14.72	9.39	9.15	6.16	2.15	3.47	1.32	1.91	3.65	1.79	0.48
B	6.04	5.74	5.86	7.24	6.16	8.26	5.92	2.75	2.03	0.96	2.09	2.03	2.39	3.23
C	2.27	6.34	5.44	7.48	3.83	4.49	4.37	2.09	1.08	0.72	2.15	1.02	3.35	3.29
D	2.99	2.21	6.88	7.18	4.43	5.74	5.80	0.96	2.69	2.51	0.96	3.11	1.68	1.26
E	1.14	3.59	5.62	5.09	4.73	3.29	2.63	0.36	2.39	3.17	1.91	1.85	1.32	1.62
F	0.78	2.33	2.81	3.53	6.34	4.01	1.02	2.57	1.91	0.96	0.72	1.44	1.97	1.38
G														

T2N T1N T1S T2S

Figure 7

R15W R14W R13W R12W R11W R10W R9W

ARBUCKLE AQUIFER: EXPECTED YIELD, Q, DERIVED FROM NUMBER OF LINEAMENT INTERSECTIONS, gpm

$$Q, \text{yield} = \frac{Kbs}{264 \log\left(\frac{Kbt}{2693 r_w^2 S}\right) - 65.5}$$

$b = 500$ ft. $s = 350$ ft.

$t = 5000$ min. $r_w = 0.28$ ft.

$S = 0.0001$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	531	373	570	1085	708	690	474	175	275	110	156	288	147	42.4
B	465	443	452	553	474	626	456	221	165	81.5	170	165	193	257
C	184	487	421	570	302	351	342	170	91.1	62.1	175	86.3	266	261
D	239	179	526	548	347	443	448	81.5	216	202	81.5	248	138	105
E	95.9	284	434	395	369	261	211	32.3	193	252	156	152	110	134
F	67.0	188	225	279	487	315	86.3	207	156	81.5	62.1	120	161	115
G														

T4N T3N T2N T1N T1S T2S

Figure 8

R15W R14W R13W R12W R11W R10W R9W

ARBUCKLE AQUIFER: SUM OF LINEAMENT LENGTHS PER NODE, L, miles

mean L = 2.97 miles

T4N

T3N

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	4.90	4.08	3.15	2.64	5.61	1.97	1.96	0.67	3.94	0.99	1.24	4.63	3.24	0.55
B	3.44	2.07	4.39	7.80	4.54	1.15	4.75	4.87	2.77	0.22	0.62	6.05	5.30	3.39
C	3.47	3.39	3.12	1.21	7.69	3.23	2.93	4.18	3.42	3.48	0.61	2.81	7.08	5.28
D	2.48	3.39	5.29	4.76	5.89	4.19	3.09	1.99	6.42	2.71	1.72	0.15	2.87	3.31
E	0.20	1.06	0.23	3.83	4.65	3.94	3.96		0.77	1.33	1.89	3.50		
F		1.83	0.82	0.50	4.56	3.02	3.11					1.84	1.03	
G			0.34	0.42		0.15								

T2N T1N T1S T2S

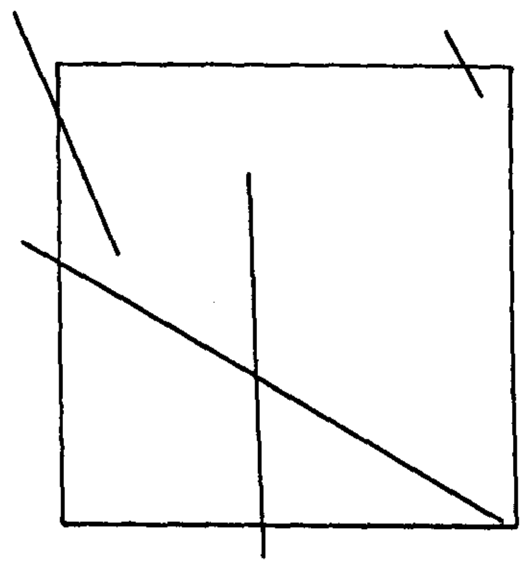
Figure 9

Figure 10

SAMPLE CALCULATIONS OF PERMEABILITY AND YIELD FOR NODE B-12 DERIVED FROM SUM OF LINEAMENT LENGTHS

Sum of lineament lengths, L, = 6.05 miles; mean sum, $\bar{L}$, = 2.97

Mean permeability, K, = 3.5 gpd/ft.^{2}



Permeability, K, $= \frac{L}{\bar{L}} \times \bar{K} = \frac{6.05}{2.97} \times 3.5 = 7.13$ gpd/ft.^{2}

Average effective aquifer thickness, b, = 500 ft.

Average well radius, r_w, = 0.28 ft.

Average pumping period, t, = 5000 min.

Average drawdown, s, = 350 ft.

Storativity, S, = 0.0001

$$\text{Yield, } Q, = \frac{Kbs}{264 \log \left(\frac{Kbt}{2693\, r_w^2\, S} \right) - 65.5}$$

$$= \frac{7.13\,(500)\,(350)}{264 \log \left(\frac{7.13\,(500)\,(5000)}{2693(0.28)^2(0.0001)} \right) - 65.5} = 545 \text{ gpm}$$

R15W R14W R13W R12W R11W R10W R9W

ARBUCKLE AQUIFER: PERMEABILITY, K, DERIVED FROM SUM OF LINEAMENT LENGTHS, gpd/ft^2

$K = \frac{L}{\text{mean } L} \times \text{mean } K$ mean L = 2.97 miles mean K = 3.5 gpd/ft^2

T4N T3N T2N T1N T1S T2S

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	5.77	4.81	3.71	3.11	6.61	2.32	2.31	0.79	4.64	1.17	1.46	5.46	3.82	0.65
B	4.05	2.44	5.17	9.19	5.35	1.36	5.60	5.74	3.26	0.26	0.73	7.13	6.25	3.99
C	4.09	3.99	3.68	1.43	9.06	3.81	3.45	4.93	4.03	4.10	0.72	3.31	8.34	6.22
D	2.92	3.99	6.23	5.61	6.94	4.94	3.64	2.34	7.57	3.19	2.03	0.18	3.38	3.90
E	0.24	1.25	0.27	4.51	5.48	4.64	4.67		0.91	1.57	2.23	4.12		
F		2.16	0.97	0.59	5.37	3.56	3.66					2.17	1.21	
G			0.40	0.50		0.18								

Figure 11

R15W R14W R13W R12W R11W R10W R9W

ARBUCKLE AQUIFER: EXPECTED YIELD, Q, DERIVED FROM SUM OF LINEAMENT LENGTHS, gpm

T4N

T3N

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	445	375	293	248	507	188	187	67.8	362	98.0	121	423	301	56.2
B	318	197	401	693	415	113	433	443	259	23.7	63.0	545	481	314
C	321	314	291	119	684	300	273	384	317	322	62.0	263	632	478
D	233	314	479	434	531	384	288	189	576	254	165	16.6	268	307
E	21.7	105	24.8	353	424	362	364	300	77.3	130	181	324	201	220
F	102	175	82.0	51.4	416	282	289	247	189	168	203	176	101	175
G	120	99.8	35.8	43.6	165	16.6	199	231	223	195	180	158	151	142

T2N

T1N

T1S

T2S

Figure 12

R15W R14W R13W R12W R11W R10W R9W

ARBUCKLE AQUIFER: AVERAGE EXPECTED YIELD, Q, ACCORDING TO LINEAMENT ANALYSIS

Nodes with expected yield equal to or greater than 270 gpm [+]

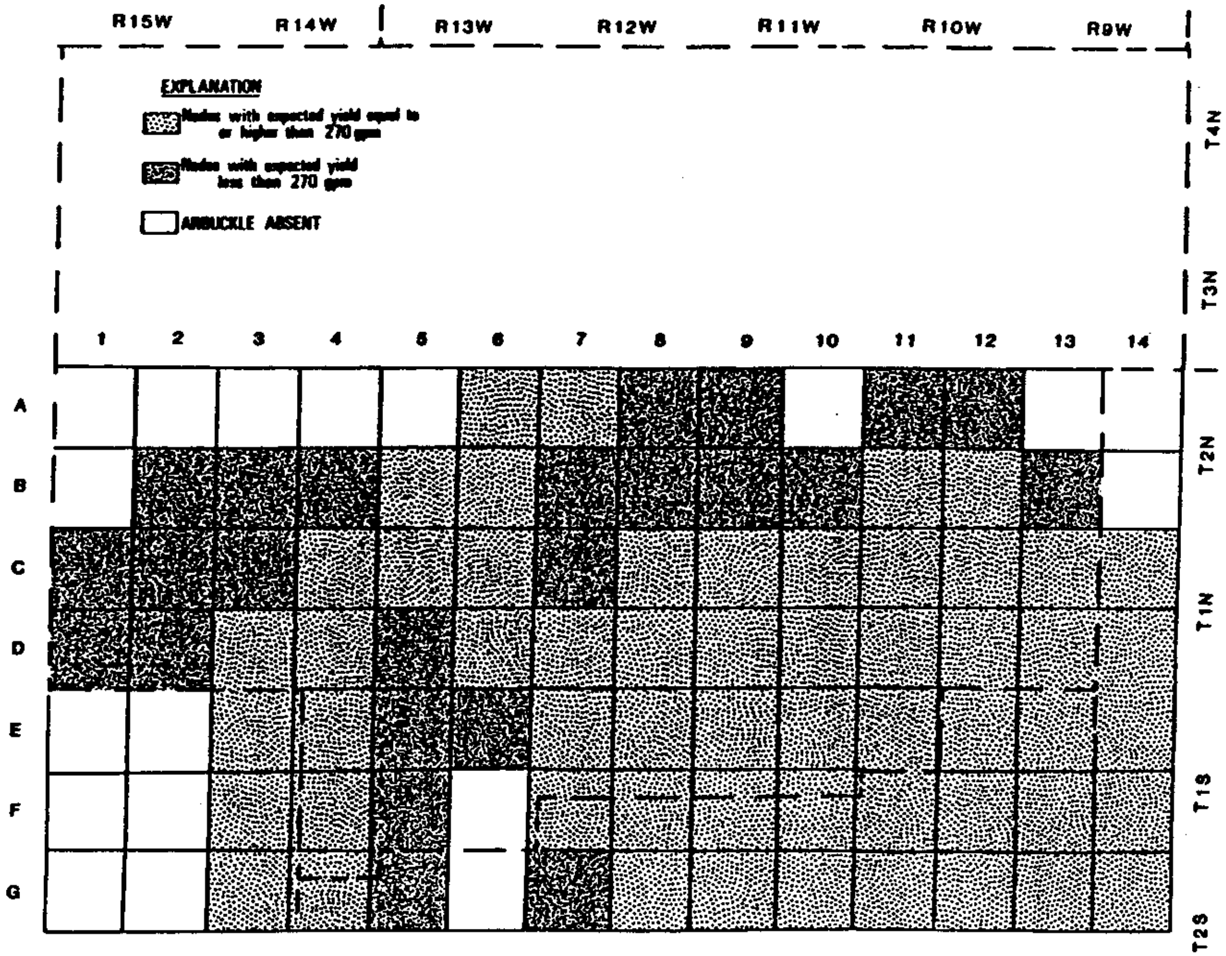
Nodes with expected yield less than 270 gpm [−]

ARBUCKLE GROUP ABSENT [ ]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A						+	+	−	+		−	+		
B		+	+	+	+	+	+	+	−	−	−	+	+	
C	−	+	+	+	+	+	+	+	−	−	−	−	+	+
D	−	−	+	+	+	+	+	−	+	−	−	−	−	−
E			−	+	+	+	+	−	−	−	−	−	−	−
F			−	−	+		+	+	−	−	−	−	−	−
G			−	−	−		−	−	−	−	−	−	−	−

T4N T3N T2N T1N T1S T2S

Figure 13



EXPECTED YIELD OF THE ARBUCKLE AQUIFER

Figure 14

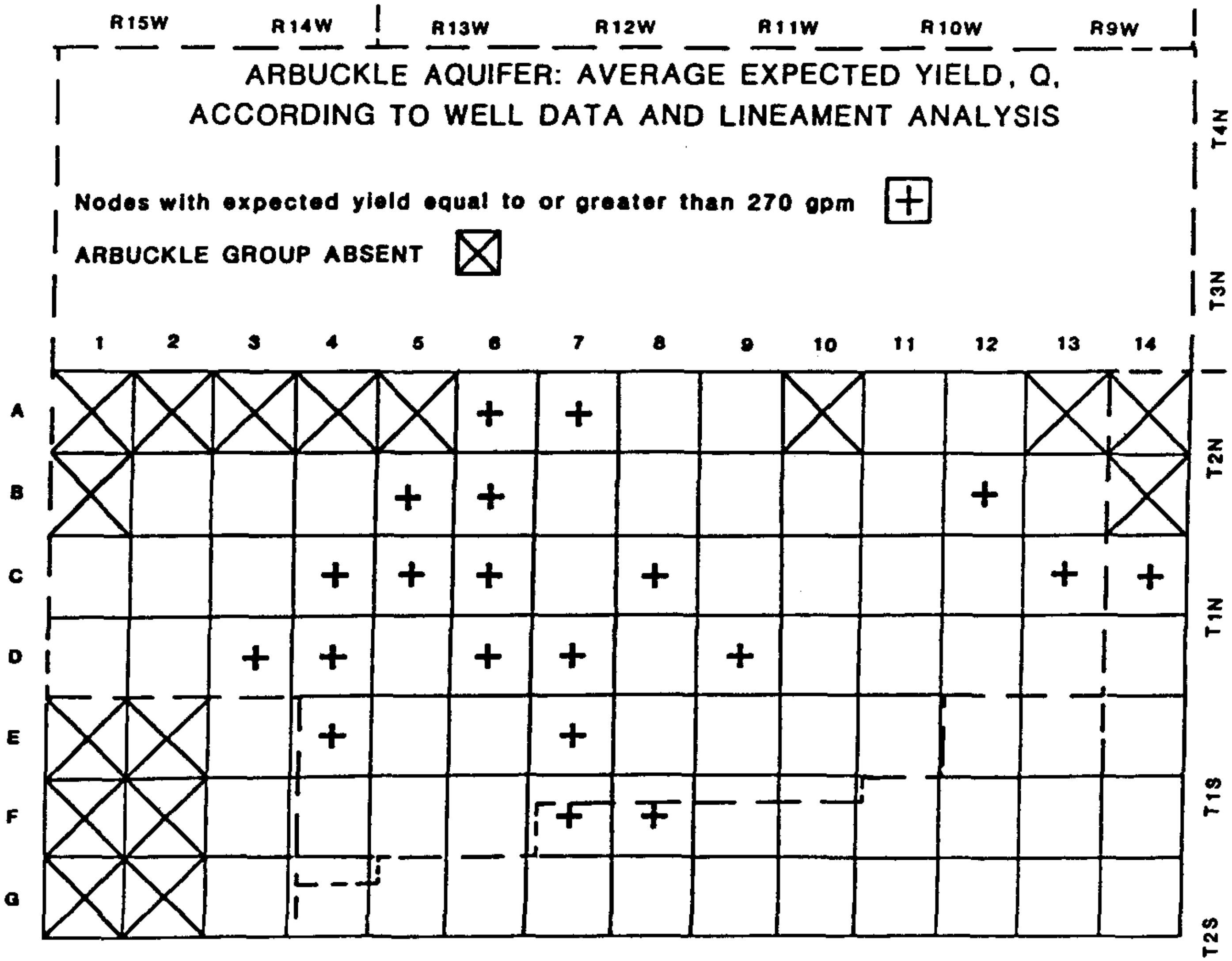

R15W
R14W
R13W
R12W
R11W
R10W
R9W
ARBUCKLE AQUIFER: AVERAGE EXPECTED YIELD, Q,
ACCORDING TO WELL DATA AND LINEAMENT ANALYSIS
Nodes with expected yield equal to or greater than 270 gpm
ARBUCKLE GROUP ABSENT
T4N
T3N
T2N
T1N
T1S
T2S
1
2
3
4
5
6
7
8
9
10
11
12
13
14
A
B
C
D
E
F
G

Figure 15