A RECONNAISSANCE STUDY OF SALTWATER CONTAMINATION IN THE EL DORADO AQUIFER, UNION COUNTY, ARKANSAS

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4012

Prepared in cooperation with the

ARKANSAS GEOLOGICAL COMMISSION

and

ARKANSAS DEPARTMENT OF POLLUTION CONTROL AND ECOLOGY

Little Rock, Arkansas
1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
gallon per minute (gal/min)	0.003785	cubic meter per minute (m^3/min
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
micromho per centimeter at 25°C (μmho/cm at 25°C)	1.000	microsiemens per centimeter at 25°C (μS/cm at 25°C)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. The NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

The El Dorado aquifer (lower part of the Sparta Sand) is the basal freshwater unit in Union County and the major source for municipal and industrial water supplies. Since 1960, chloride concentration in water from the aquifer has increased in the vicinity of El Dorado, the center of greatest withdrawal. The aquifer is approximately 300 feet thick and is confined by the Cane River Formation below and the middle confining unit of the Sparta Sand above. These Tertiary rocks dip gently east-southeast in Union County and are affected locally by a graben to the south and east of El Dorado.

From the onset of development in the 1920's the center of greatest withdrawal from the El Dorado aquifer has remained at El Dorado. Pumpage has increased from less than 0.5 million gallons per day in 1921 to 16 million gallons per day in 1982, reaching a high of 19 million gallons per day in 1965. In response to the withdrawal, the potentiometric surface at El Dorado has been lowered more than 300 feet, increasing the hydraulic gradient toward the center of pumping.

Chloride concentrations generally increase in the El Dorado aquifer to the east-southeast, conforming to the dip of the rocks and the original direction of water movement. North and west of the graben, chloride concentrations range from 25 to 150 milligrams per liter. Wells with the highest concentrations are located at or near the west end of the graben. Estimates based on interpretation of electric logs for two wells in the graben indicate chloride equivalents may be as high as 2,500 milligrams per liter in the El Dorado aquifer.

Analyses of water from aquifers above the El Dorado aquifer preclude surface brines as a source of this contamination. Saltwater-bearing formations below the El Dorado aquifer are eliminated as sources of contamination on the basis of geochemical analyses and hydrostatic pressures. Geologic, hydrologic, and chemical data indicate that the primary source of chloride is the El Dorado aquifer within the graben.

INTRODUCTION

Purpose and Scope of Study

Water managers of an oil refinery at El Dorado have noted steady increases of chloride concentration in water from the refinery wells during the last 20 years. By 1974, water from several of the wells showed chloride increases of 200 milligrams per liter (mg/L) or more. The chloride increase to date (1982) has caused the company to discontinue use of two wells and to reduce pumping from three of five currently producing water wells at the refinery as the refinery process has a chloride tolerance of about 100 mg/L.

The Sparta Sand is practically the only source of freshwater for industrial and municipal use in El Dorado and for rural water associations in Union County. Concern with possible widespread chloride concentration increase and migration of the high chloride water in the Sparta Sand led to this study of the problem by the U.S. Geological Survey in cooperation with the Arkansas Geological Commission and the Arkansas Department of Pollution Control and Ecology.

Objectives of the study included (1) determination of the magnitude and extent of the saltwater contamination of the Sparta Sand, and (2) definition of the possible sources and avenues of the contamination. The study was started in April 1982.

The area of study generally was limited to Union County with focus on the area around El Dorado. Activities included review of available geologic, hydrologic, and chemical data, and collection of additional data to establish or eliminate plausible sources and avenues of saltwater contamination in the El Dorado aquifer. The data were examined specifically for clues to any (1) lateral migration of high concentrations of chloride which are known to exist naturally in the Sparta Sand in the southeastern part of Union County, (2) vertical migration of brine to the aquifer from known brine-bearing formations below, and (3) vertical migration of brine to the aquifer from any contaminated formations above it, or (4) vertical migration from surface impoundments of brine.

Acknowledgments

The study benefited greatly from data provided by industries, municipalities, well drillers, rural water associations and owners of home wells. Data provided by the Arkansas Department of Health were also very useful. The study was further aided by consultation with many individuals associated with the development of water, petroleum, and brine in the area. The authors wish to express their thanks specifically to the following:

Larry Adams (Monsanto Company)
Walter Alderson (private citizen)
Victor Baldridge (Phillips Petroleum Company)
Sidney Campbell (Murphy Oil Corporation)
Jack Godwin (El Dorado Water Utilities)
John Gray (petroleum geologist)
Larry Moree (Great Lakes Chemical Corporation)
William Pender (Pender Well Drilling Company)
Larry Shoop (Layne Arkansas)
James Tennyson (Tennyson Oil Company)
William Wright (Arkansas Oil and Gas Commission)
James Warnock (TOSCO Corporation)

DESCRIPTION OF THE STUDY AREA

The study area, Union County (fig. 1), is in the Ouachita River basin of the West Gulf Coastal Plain. The Ouachita River forms the eastern boundary of the county. The area is characterized in most places by a sandy, gently rolling terrain with a vegetal cover of pine forests and pastures. The flood plain of Ouachita River provides a substantial flat area of hardwood-forested wetlands.

The land surface generally slopes north-northeast and south-southeast from a central ridge extending from the western edge of Union County to the flood plain of the Ouachita River. This ridge forms the principal drainage divide in the area. North of the ridge, drainage is largely to Smackover Creek, a tributary to the Ouachita River. South of the divide, drainage is largely to tributaries that are confluent with the Ouachita River in Louisiana. Altitudes along the divide range from about 300 feet above sea level near the western boundary of Union County to about 120 feet at the floodplain of the Ouachita River. El Dorado is on the divide at an altitude of about 250 feet, and near the geographic center of the study area.

Normal annual precipitation at El Dorado is 49.41 inches. Normal monthly precipitation is not uniformly distributed throughout the year, ranging from a minimum of 2.93 inches in June to a maximum of 5.90 inches in April. Short periods of deficient precipitation occur in most years. Normal annual temperature at El Dorado is 17.6°C (63.7°F). Normal monthly temperatures range from a low of 6.9°C (44.5°F) in January to a high of 27.8°C (82.1°F) in July (National Oceanic and Atmospheric Administration, 1981).

GEOLOGIC FRAMEWORK

Oil-test wells in the study area have penetrated about 10,000 feet of sediments, ranging from the Quaternary System to near the base of the Jurassic System. A geologic column is shown in table 1. Excluding relatively superficial Quaternary sediments in stream bottomlands, the column is made up of about 2,400 feet of Tertiary strata, 1,300 feet of Upper Cretaceous strata, 2,100 feet of Lower Cretaceous strata, and 4,000 of Jurassic strata. The strata generally occur in interbedded sequences of sand and clay in the Tertiary; marl, sand, and chalk in the Upper Cretaceous; limestone, shale, sand, and sandstone in the Lower Cretaceous; and sandstone, shale, anhydrite, limestone, and rock salt in the Jurassic.

Further description of the Cretaceous and older formations will concern only the chemistry and hydrostatic pressure of the brine they contain. For more information about the geology of these units and their relation to the production of petroleum and brine in the area, the following references are recommended: Spooner (1935), Fancher and Mackay (1946), and Imlay (1949).

The discussion to follow of the Tertiary units uses the group nomenclature of Haley (1976) for the Midway, Wilcox, and Claiborne. The formation nomenclature within the Claiborne Group is that of Hosman (1982), except for the treatment of the basal formation of the Claiborne, the Carrizo Sand. The Carrizo Sand is discontinuous in parts of Union County and, where present, is treated as the uppermost part of the Wilcox because the Carrizo Sand and the Wilcox sands are hydraulically connected and constitute a single

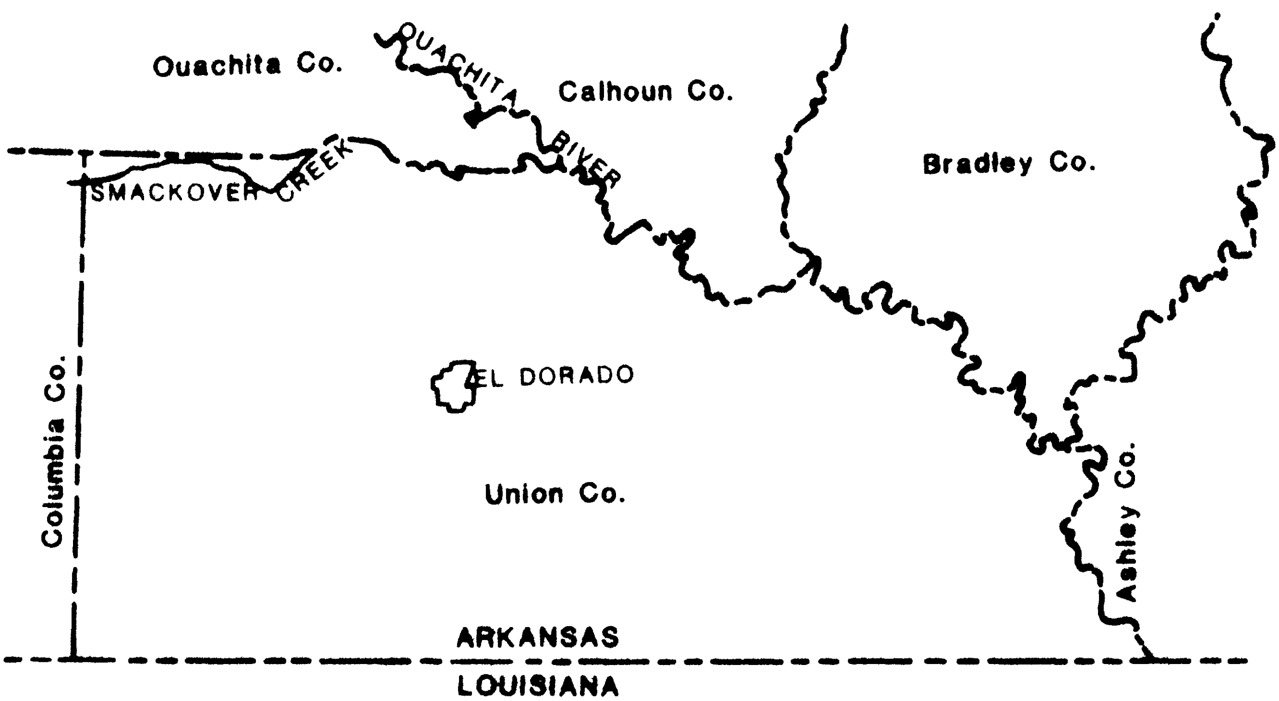

Figure 1.--Location of study area.

Table 1.--Generalized geologic column in Union County, Arkansas

System	Series	Group	Formation	Approximate maximum thickness (feet)	General lithologic description of units
Quaternary	Holocene and Pleistocene			100	Clay, silt, sand and gravel
Tertiary	Eocene	Claiborne	Cockfield Fm	300	Interbedded sand, silt, and clay
			Cook Mountain Fm	150	Clay, some silt and fine sand
			Sparta Sand	600	Interbedded sand, silt, and clay; thinly bedded fine sand in upper part, chiefly clay in middle part, and thickly bedded medium to coarse sand in lower part
			Cane River Fm	300	Clay, some silt and fine sand
			Carrizo Sand	150	Sand (discontinuous in parts of Union County)
		Wilcox	Undivided	400	Interbedded sand and clay
	Paleocene	Midway	Undivided	500	Clay, silty in upper part and limy in lower part

Table 1.--Generalized geologic column in Union County, Arkansas--Continued

System	Series	Group	Formation	Approximate maximum thickness (feet)	General lithologic description of units
Cretaceous	Upper Cretaceous		Arkadelphia Marl	150	Clay, calcareous; some limestone
			Nacatoch Sand	200	Sand and calcareous clay; sand mostly in upper 50 feet of unit
			Saratoga Chalk	50	Clay, calcareous, and chalk
			Marlbrook Marl	150	Clay, calcareous
			Annona Chalk	50	Chalk and calcareous clay
			Ozan Fm	200	Sand and calcareous clay, sand mainly in uppermost part (Meakin sand) and lowermost part (Graves sand)
			Brownstown Marl	150	Clay, calcareous and some fine sand
			Tokio Fm	200	Clay, some tuffaceous sand
			Lewisville Fm	150	Clay, some tuffaceous sand
	Lower Cretaceous	Fredericks-burg	Undivided	100	Interbedded shale and limestone
		Trinity	Undivided	2,000	Interbedded shale, limestone, and sandstone

Table 1.--Generalized geologic column in Union County, Arkansas--Continued

System	Series	Group	Formation	Approximate maximum thickness (feet)	General lithologic description of units
		Cotton Valley	Undivided	1,400	Interbedded sandstone and shale
			Buckner Fm	300	Anhydrite and shale
Jurassic			Smackover Fm	700	Limestone, oolitic in upper part
Triassic			Eagle Mills Fm	1,500	Rock salt and anhydrite

GEOHYDROLOGY AND GENERAL WATER QUALITY OF THE TERTIARY AND QUATERNARY UNITS

The geologic formations of the Tertiary System in the study area generally slope to the southeast and the units are continuous over much of the Coastal Plains of Arkansas, Louisiana, Mississippi, and Texas. For a regional overview of the formations, the reader is referred to Hosman and others (1968).

The three formations that crop out in Union County are shown on plate 1. The Cockfield Formation is the most extensive outcrop area in the county. The Cook Mountain Formation, underlying the Cockfield, crops out only in the northwestern part of the county. Quaternary alluvium mantles both the Cook Mountain and the Cockfield in the bottomlands of the Ouachita River and its tributaries.

Cross sections (pls. 2-5), depict the vertical extent of formations to the top of the Arkadelphia Marl. A structure-contour map of the top of the Arkadelphia Marl (pl. 6) provided the primary structural control. The boundaries between the formations in the sections were established mostly on the basis of electric-log interpretation. A representative electric log is shown in figure 2. Section A (pl. 2) illustrates the general southeasterly slope of the strata. Irregularities of slope chiefly reflect local folding of the formations. The most conspicuous structural feature in section A is a "graben", where a part of the geologic section has dropped between two fault planes. Vertical displacement between the formations inside and outside the graben is about 200 feet. Sections B, C, and D (pls. 3-5) illustrate the structural tops of the formations in directions transverse to the general slope of the formations. The graben is shown in sections C and D, but is not apparent in section B.

Midway Group

The Midway Group, which is undivided in this area, and is underlain by the Arkadelphia Marl and overlain by the Wilcox Group (table 1, fig. 2), is about 550 feet thick. It is composed largely of clay, but tends to be limy near the base and silty near the top. Altitudes on the top of the Midway range from about 1000 feet below sea level in the northwestern part of the county to about 1,500 feet below sea level in the southeastern part of the county (pl. 2). Within the graben (pls. 3-5), the Midway is in contact with the Arkadelphia Marl and the Nacatoch Sand along parts of the fault planes.

The thick sequence of clay that composes the Midway Group is believed to have highly effective confining properties, which severely limits the capacity of the formation to accept, transmit, and discharge fluids. In the absence of possible fractures along fault planes, the Midway Group is considered a "perfect" confining bed or hydrologic barrier to vertical movement of fluids.

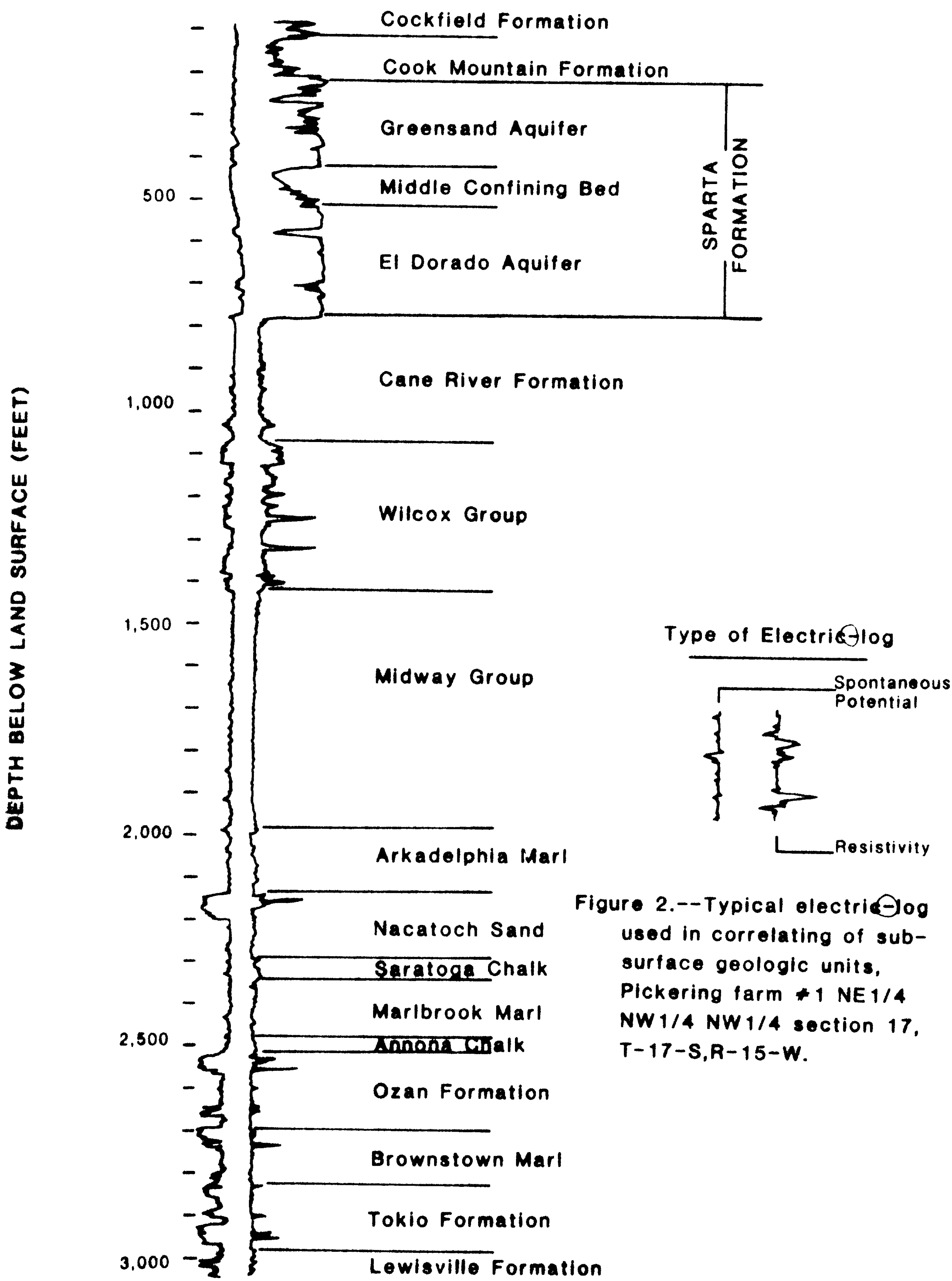

Figure 2.--Typical electric log used in correlating of sub-surface geologic units, Pickering farm #1 NE1/4 NW1/4 NW1/4 section 17, T-17-S,R-15-W.

Wilcox Group

The Wilcox Group undivided in this area, is underlain by the Midway Group and overlain by the Cane River Formation where the Carrizo Sand is absent (table 1, fig. 2) and is about 400 feet thick. It is generally composed of thin beds of lignitic sand, silt, and clay and tends to be sandier in the upper half. The lithologic components of the unit generally are complexly interbedded and lenticular, making it difficult to correlate individual beds over any substantial distance.

Altitudes on the top of the Wilcox Group in Union County range from about 700 feet below sea level in the northwestern part of the county to about 1,500 feet below sea level in the southeastern part of the county (pl. 2). Within the graben (pls. 3-5), the lower half of the Wilcox is bounded by the Midway Group along the fault planes. The sands in the Wilcox are water bearing and the individual beds of sand probably are hydraulically connected. On this premise, the Wilcox Group is considered to be a hydrologic unit.

The water in the Wilcox aquifer occurs under artesian conditions, that is, water in wells that penetrate the Wilcox will rise to levels above the top of the formation. The water level for the Wilcox was measured in well 93A (Lacy B-1). This well (well 93 prior to conversion) produced oil and brine from the Nacatoch Sand until 1982 when it was scheduled for abandonment and plugging. Under the authority of the Arkansas Oil and Gas Commission, and with shared work and cost by the Arkansas Geological Commission, U.S. Geological Survey, TOSCO Corporation, El Dorado Water Utilities, Tennyson Oil Company, and Walter Alderson (landowner), well 93 was converted to a test well to determine the water level and water quality of the Wilcox. This was accomplished by installing a packer in the well below the Wilcox and shot perforating the casing opposite sand lenses in the unit. The water level in well 93A after development in the Wilcox, rose to an altitude of 21 feet above sea level or 199 feet below land surface (table 2). The water from the Wilcox in well 93A contained chloride concentrations, at different sampling levels and times, ranging from 4,100 mg/L to 4,900 mg/L (table 3).

The Wilcox is used in the study area only as a receiving unit for brine disposal, by means of injection wells. The injection well in the Wilcox closest to the problem area is about 4 miles south of El Dorado. At this site, brine from the Cotton Valley Group (Jurassic age) is injected into the Wilcox. An analysis of a composite sample of water from the Cotton Valley is given in table 4. Brine from the Cotton Valley is injected into the Wilcox also in the Shuler and New London oil fields, about 12 miles west and about 16 miles east, respectively, of El Dorado. However, most brine to be disposed of by injection is pumped into Cretaceous and Jurassic units.

Claiborne Group

The Claiborne Group contains most of the fresh ground water in Union County and includes the following formations in ascending order.

Table 2.--Record of wells used for sampling of water in units deeper than the El Dorado aquifer in Union County, Arkansas

Number on map (pl. 10)	Operator	Owner and well number	U.S. Geological Survey number	Year drilled	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)
50	---	Burns No. 3	17S15W31BBB1	---	210	2,200
51	Tennyson Oil Co.	Lacy C-7	17S15W31CDB1	1953	255	2,231
76	Great Lakes Chemical Corp.	BSW-11	17S16W27CAA1	---	248	7,370
93	Tennyson Oil Co.	Lacy B-1	18S15W06BAC1	1955	220	2,180
93A	Tennyson Oil Co.	Lacy B-1	18S15W06BAC2	1955	220	1,230
94	Milam, J.	Pratt A-1	18S15W07AAC1	1982	240	2,180

Number on map (pl. 10)	Unit	Water Level: Depth below land surface (feet)	Water Level: Date of measurement	Remarks
50	Nacatoch Sand	---	---	Oil well.
51	Nacatoch Sand	---	---	Oil well.
76	Smackover Formation	---	---	Brine source well.
93	Nacatoch Sand	2156.80	8-16-82	Oil well. Abandoned in 1982. Used for sampling brine in Nacatoch Sand.
93A	Wilcox Group	198.63	11-27-82	Used for sampling Wilcox Group.
94	Nacatoch Sand	---	---	Oil well.

Table 3.—Chemical and physical analyses of water in units below the El Dorado aquifer in Union County, Arkansas

[Source of data is U.S. Geological Survey; °C, degrees Celsius; Spec. cond., specific conductivity; µmho, micromho per centimeter at 25° Celsius; Al, aluminum; B, boron; Ba, barium; Br, bromide; Ca, calcium; Cl, chloride; CO_3, carbonate; F, fluoride; Fe, iron; HCO_3, bicarbonate; I, iodide; K, potassium; Li, lithium; Mg, magnesium; Na, sodium; NH_4-N, ammonia as nitrogen; SiO_2, silica; SO_4, sulfate; Concentrations of constituents are in milligrams per liter and are from filtered samples]

Number on map (pl. 10)	Operator	Owner and well number	U.S. Geological Survey number	Sampling date	Temp. (°C)	pH	Spec. cond. (µmho)	Solids	Al	B	Ba	Br	Ca	Cl	CO_3	F	Fe	HCO_3	I	K	Li	Mg	Na	NH_4-N	SiO_2	SO_4	V
								WILCOX GROUP																			
93A	Tennyson Oil Co.	Lacy B-1	18S15W06BAC2	08-19-82	26.5	7.5	14,900	—	—	3.0	—	56	69	4,900	—	1.0	0.08	—	—	14	—	24	3,300	—	8.3	12	—
93A	Do.	Lacy B-1	18S15W06BAC2	11-09-82	21.0	8.8	13,500	8,160	0.1	4.1	1.8	25	38	4,900	36	.8	1.0	190	1.5	15	0.20	25	3,000	8.2	.7	300	0.08
93A	Do.	Lacy B-1	18S15W06BAC2	11-09-82	25.0	8.8	12,000	7,090	.2	3.8	1.7	62	55	4,100	68	.8	3.5	210	1.3	13	.17	16	3,000	7.9	4.8	420	—
								NACATOCH SAND																			
50	—	Burns 3	17S15W31BBB1	11-10-82	35.0	7.1	40,000	27,800	0.2	13	9.0	200	690	16,000	—	0.6	5.1	190	5.6	54	0.56	200	8,900	18	15	700	—
51	Tennyson Oil Co.	Lacy C-7	17S15W31CDB1	05-08-82	—	8.6	66,200	—	—	27	—	350	—	28,000	—	.4	—	—	12	—	—	—	—	30	7.8	290	—
93	Do.	Lacy B-1	18S15W06BAC1	08-16-82	42.0	6.8	61,000	—	—	25	—	56	2,100	30,000	—	.5	38	—	—	110	—	85	20,000	—	12	2,800	—
94	Milam, J.	Pratt A-1	18S15W07AAC1	08-18-82	37.0	7.9	11,000	7,200	—	4.3	—	—	57	3,500	—	1.1	.08	—	—	19	—	22	2,900	—	17	210	—
								SMACKOVER FORMATION																			
76	Great Lakes Chemical Corp.	BSW-11	17S16W27CAA1	06-14-82	—	5.7	200,000	—	0.7	120	0.9	—	29,000	160,000	—	5.2	2.9	—	9.5	1,200	120	4,400	85,000	110	17	4,100	—

Table 4.—Chemical and physical analyses of composite samples of brine from the Cotton Valley Group and the Smackover Formation near El Dorado, Arkansas

[B, boron; Br, bromine; Ca, calcium; Cl, chloride; F, fluoride; Fe, iron; I, iodide; K, potassium; Mg, magnesium; Na, sodium; NH_4-N, ammonia as nitrogen; SiO_2, silica; SO_4, sulfate; μmho, micromho per centimeter at 25° Celsius; Concentrations of constituents are in milligrams per liter]

Unit	Location	Sampling date	pH	Specific conductance (μmho)	B	Br	Ca	Cl	F	Fe	I	K	Mg	Na	NH_4-N	SiO_2	SO_4	Remarks
Cotton Valley Group	Catesville, 7 miles south of El Dorado	8-20-82	4.0	---	---	1,600	24,000	150,000	0.1	0.22	---	840	2,600	73,000	---	18	430	Sample made up of brine produced from several Cotton Valley wells. The brine is injected into the Wilcox Group for disposal at Murphy SWD No. 1.
Smackover Formation	Great Lakes Chemical Corp. (El Dorado plant)	5-27-82	5.7	209,000	120	4,500	---	170,000	4.9	---	10	---	---	---	190	5.7	390	Sample made up of brine produced from several Smackover wells. Brine used for the production of bromine.

Cane River Formation

The Cane River Formation, which is underlain by the Wilcox Group and overlain by the Sparta Sand (fig. 2), is about 300 feet thick. It is composed of clay and silty clay throughout most of Union County, but updip the Cane River tends to become siltier and contains some fine sand in the upper part. The Cane River regionally dips from an altitude of about 400 feet below sea level in the northwestern part of the county to an altitude of about 800 feet below sea level in the southeastern part (pl. 2). In the graben, about the lower half of the Cane River is faulted against the Wilcox Group (pls. 3-5).

Like the Midway Group, the Cane River is considered a "perfect" confining bed. With practically no capacity for intake, transmission and release of fluids, it acts as a hydrologic barrier to movement of fluids between units below and above it under natural conditions. However, exceptions to this condition may exist along fractures or fault planes in the graben area.

The top of the Cane River clearly defines the base of water chemically fit for human consumption and for most industrial uses in Union County. Altitudes on the top of the Cane River are shown on plate 7.

Sparta Sand

The Sparta Sand is about 600 feet thick. It is underlain by the Cane River Formation and overlain by the Cook Mountain Formation (fig. 2). Although composed largely of sand, it also contains appreciable amounts of silt and clay that are complexly interbedded and lensing. The Sparta Sand in Union County is divisible into three different units. The lower 300 feet consists of thick-bedded sands with grains ranging from fine to coarse. The lower interval of the Sparta is often referred to locally by drillers as the "El Dorado Sands". The middle 50 to 150 feet is composed of clay and silt. The upper 200 feet is composed of thin-bedded, very fine to fine sands and clays. In places the upper unit is distinctively green due to the presence of glauconite and drillers commonly refer to it as the "Greensand".

Data support the concept that the upper part of the Sparta and the lower part of the Sparta, with the middle interval of clay and silt acting as a confining bed, function as separate aquifers in Union County. Thus, hereinafter the lower Sparta aquifer will be termed the "El Dorado" aquifer; the middle interval of clay will be termed the "middle confining bed"; and the upper Sparta aquifer will be termed the "Greensand" aquifer. Well drillers have noticed differences in well yields and water levels in wells in the upper and lower sandy parts of the Sparta. In general the lower part is much more productive.

El Dorado aquifer

The El Dorado aquifer, which is underlain by the Cane River Formation and overlain by the middle confining bed of the Sparta (pl. 2), regionally dips southeastward from an altitude of about 200 feet below sea level in the northwestern part of the county to an altitude of about 800 feet below sea level in the southeastern part. In the graben, the El Dorado aquifer is faulted against the Cane River Formation as a confining unit (pls. 3-5). Altitudes on top of the El Dorado aquifer are shown on plate 8.

Development of the El Dorado aquifer for water supply essentially began in 1921 with the discovery of oil in the El Dorado area and the resulting growth of the petroleum industry and accompanying increase in population. Withdrawals from the aquifer increased from less than 0.5 Mgal/d in 1921 to about 19 Mgal/d in 1965. Current withdrawals (1982) are about 16 Mgal/d. In response to the withdrawals, the potentiometric surface of the aquifer declined from an initial altitude of about 140 feet above sea level to about 200 feet below sea level in 1968. Currently (1982) the potentiometric surface at El Dorado is at an altitude of about 160 feet below sea level or about 410 feet below land surface. This represents a decline of about 300 feet. Baker and others (1948) describe early development of the "lower Sparta Sand" in the El Dorado area, and provide historical quality-of-water and aquifer test data for the El Dorado aquifer. The decline in the potentiometric-surface altitude at El Dorado and the history of water withdrawals from the El Dorado aquifer are graphically summarized in figures 3 and 4.

The pre-development potentiometric surface of the El Dorado aquifer in Union County sloped east-southeast. As controlled by the direction of slope of the potentiometric surface, the direction of water movement in the El Dorado aquifer was east-southeast (Reed 1972). The potentiometric surface at El Dorado was at an altitude of about 140 feet above sea level, equivalent to water-level depths of about 110 feet below land surface.

The potentiometric surface of the El Dorado aquifer in Union County in 1982 is shown on plate 9. As indicated by the potentiometric-surface slope, the direction of water movement in the aquifer is toward the center of pumping at El Dorado from all directions in Union County. The records of wells and water levels used for the 1982 potentiometric-surface map are in table 5 and the locations of the wells are shown on plate 10. No wells were available to provide potentiometric-surface control for the El Dorado aquifer in the graben area nor in most of the area south of the graben. Thus, the actual geometry of the potentiometric surface in the graben and to the south might be more irregular than is indicated on plate 10.

Water-quality data for the El Dorado aquifer are shown in table 6. The water in the area of greatest use generally is a dilute sodium bicarbonate type. Dissolved solids in the water increase to the east-southeast from less than 200 mg/L in the northwestern corner of the county to about 300 mg/L in the vicinity of El Dorado. Typically, other ranges in water-quality characteristics are: temperature, 20°C to 25°C; pH, 8.0 to 8.5; hardness, less than 10 mg/L; and dissolved iron, less than 0.10 mg/L.

Initial sampling of the water in the El Dorado aquifer during the study focused on chloride concentration to establish the present distribution and to define the extent of saltwater contamination by comparing past and present concentrations. Plate 11 shows the chloride-concentration map of the El Dorado aquifer in 1982. In the northwestern corner of the county (Mt. Holly area), chloride concentrations are as low as 6.9 mg/L. East of the 25 mg/L isochlor (line of equal chloride concentration), the rate of increase of chloride is notably different from that in the west. In most of the area south of El Dorado and the graben, the rate of increase in chloride is about double that of the area to the north. In the area of contamination near El Dorado (pl. 11) chloride concentrations range from 130 to 650 mg/L. Water-quality data were not available for the El Dorado aquifer in the graben and in most of the area south of the graben. However, chloride equivalents as

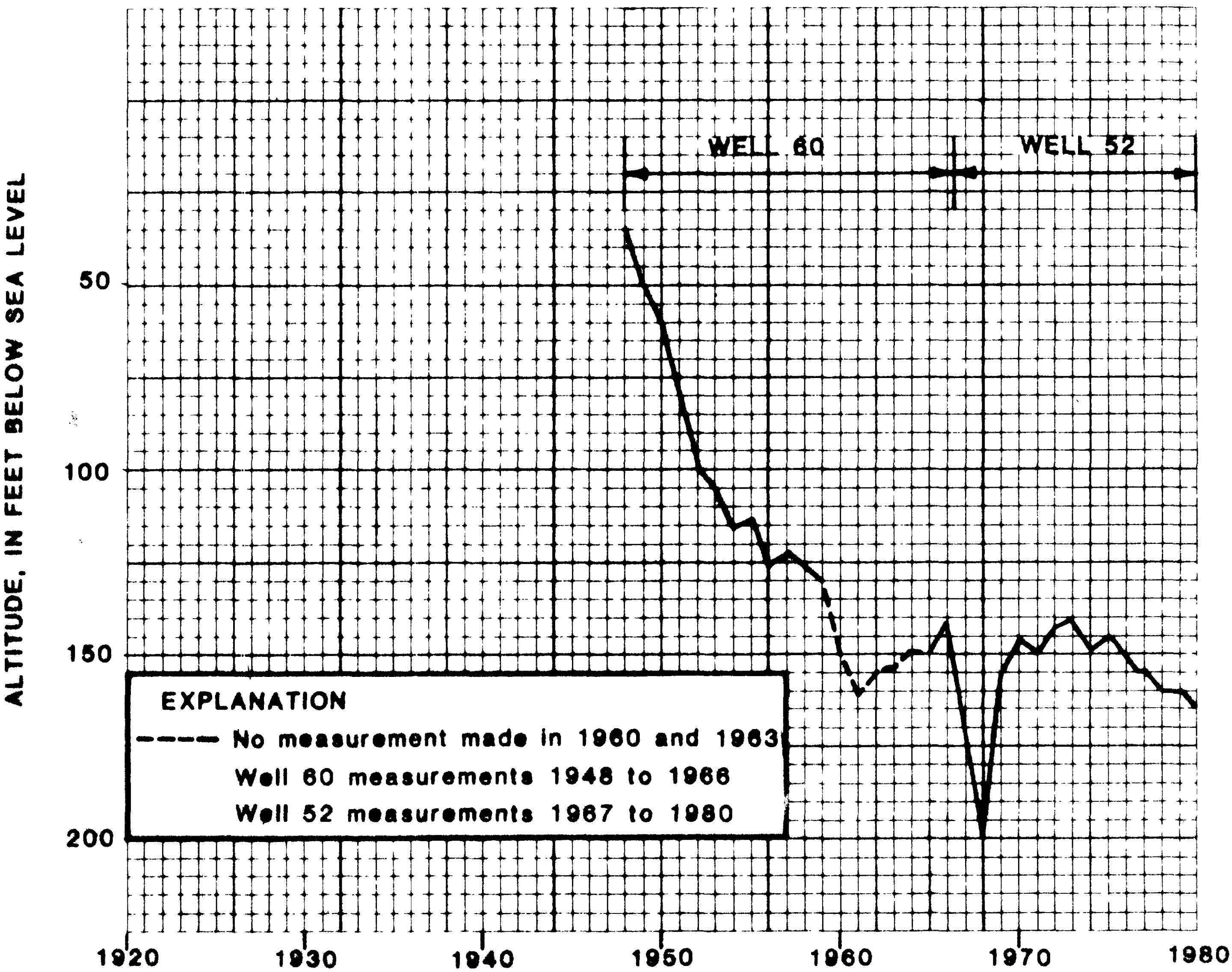

Figure 3.--Water levels in the El Dorado aquifer near center of pumping in Union County, Arkansas.

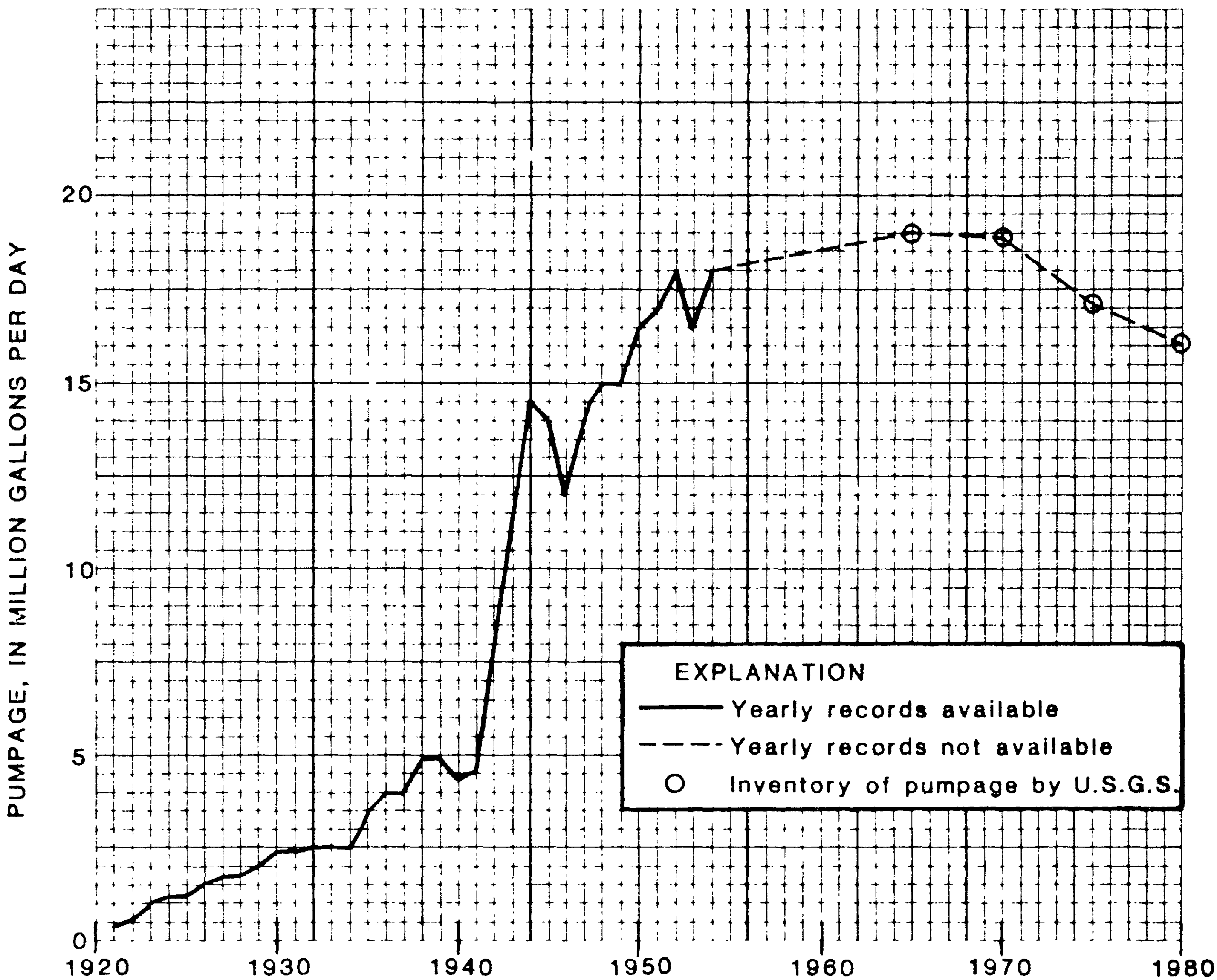

Figure 4.--History of pumpage from the El Dorado aquifer in Union County, Arkansas, from 1920-1980.

Table 5.—Record of wells in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas

[gal/min, gallons per minute; USGS, U.S. Geological Survey; TOSCO, The Oil Shale Company; AGC, Arkansas Geological Commission]

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Driller	Year well drilled	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)	Water Level: Depth below land surface (feet)	Water Level: Date of measurement	Well discharge (gal/min)	Use of water	Remarks
						EL DORADO AQUIFER						
1	U.S. Army Corps of Engineers	—	16S13W30BAA1	Layne-Arkansas	1979	100	363	—	—	80	—	—
2	Town of Calion	—	16S14W15CAB1	do	1970	94	466	130.15	3-02-82	305	Municipal	USGS water-level observation well since 1970.
4	Town of Norphlet	2	16S15W20ADD1	do	1964	190	603	274.81	3-01-82	340	do	USGS water-level observation well since 1964.
5	do	1	16S15W21BCC1	Carloss Well Co.	1936	190	565	—	—	—	do	Well used infrequently.
6	MacMillian Petroleum Co.	1	16S15W21DCD1	Roger Ellis	1930	145	643	—	—	580	Industrial	—
7	do	2	16S15W21DCD2	Carloss Well Co.	1941	160	568	—	—	610	do	—
9	Town of Smackover	8	16S16W01DBC1	Layne-Arkansas	1974	119	473	—	—	300	Municipal	—
10	do	7	16S16W01DDD1	do	1974	112	470	—	—	300	do	—
11	do	5	16S16W02ABC1	do	1954	116	552	159.03	4-01-82	—	do	USGS water-level observation well since 1964.
12	do	6	16S16W02BAA1	do	1958	117	553	—	—	440	do	—
13	do	1	16S16W02BAC1	do	1958	122	550	—	—	—	—	Well unused.
16	Mount Holly Water Assoc.	1	16S18W34ABC1	C&B Drilling Co.	1967	245	430	—	—	—	—	Well abandoned and plugged.
17	do	3	16S18W34ABC2	Layne-Arkansas	1980	248	465	—	—	60	Rural supply	—
18	do	2	16S18W35BBB1	do	1972	235	480	186.05	6-08-82	100	do	—
21	New London Water Assoc.	—	17S12W32BBC1	do	1976	230	822	227.93	4-01-82	150	do	USGS water-level observation well since 1978.
23	Lawson-Urbana Water Assoc.	—	17S13W31BAC1	do	1975	216	772	279.68	5-01-82	150	do	USGS water-level observation well since 1975.
26	—	—	17S14W15BAA1	—	—	195	600	266.99	8-11-82	—	—	Unused oil company well.
28	Monsanto Co.	6	17S15W06CCC1	Coastal Drilling Co.	1942	204	656	—	—	—	Industrial	—
29	do	8	17S15W07DCC1	do	1942	186	634	—	—	—	do	—
30	do	4A	17S15W08AAA1	do	1942	157	539	—	—	—	—	Abandoned and plugged.
31	do	4B	17S15W08AAA2	Layne-Arkansas	1979	157	559	—	—	—	Industrial	—
32	do	5	17S15W08BBB1	Coastal Drilling Co.	1942	189	674	—	—	—	do	—

Table 5.--Record of wells in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas--Continued

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Driller	Year well drilled	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)	Water Level: Depth below land surface (feet)	Water Level: Date of measurement	Well discharge (gal/min)	Use of water	Remarks
						EL DORADO AQUIFER						
33	Monsanto Co.	9A	17S15W08DCC1	Coastal Drilling Co.	1942	175	667	---	---	---	Industrial	---
34	do	10	17S15W09ACB1	do	1942	145	531	---	---	---	do	---
35	do	14	17S15W09CBB1	do	1943	137	540	---	---	600	do	---
36	Arkansas-Louisiana Gas Co.	1	17S15W16BCB1	Layne-Arkansas	1929	171	615	---	---	117	do	---
37	do	2	17S15W16BCB2	do	1929	162	637	---	---	200	do	USGS water-level observation well from 1949 to 1980.
38	El Dorado Water Utilities	16	17S15W17CDA1	---	1960	248	700	---	---	895	Municipal	---
39	Arkansas-Louisiana Gas Co.	---	17S15W17DAD1	---	1929	162	637	---	---	---	Industrial	---
40	Monsanto Co.	8A	17S15W18DBB1	Coastal Drilling Co.	1942	183	540	332.00	3-31-82	---	---	USGS water-level observation well since 1979.
41	do	8B	17S15W18DCC1	do	1942	176	603	---	---	---	---	USGS water-level observation well from 1951 to 1978.
42	El Dorado Water Utilities	7	17S15W28CDC1	Layne-Arkansas	1937	258	728	---	---	630	---	Unused well.
43	do	10	17S15W28CDC2	do	1945	265	746	---	---	1,000	Municipal	---
45	do	8	17S15W28DBA1	do	1937	235	668	398.48	4-29-82	840	do	Standby well.
46	do	11	17S15W28DCC1	do	1946	285	754	---	---	1,000	do	---
47	do	15	17S15W28DDA1	---	---	275	---	---	---	1,000	do	---
48	do	14	17S15W29ACB1	---	---	255	---	---	---	---	do	---
49	do	13	17S15W29CDC1	Carloss Well Co.	1955	220	650	387.55	3-31-82	---	do	Standby well. USGS water-level observation well since 1967.
52	TOSCO	8	17S15W31DCA1	Layne-Arkansas	1959	272	753	433.04	3-31-82	885	---	Unused because of excessive chloride yield. USGS water-level observation well since 1967.
56	do	6	17S15W31DDA1	do	1951	261	740	---	---	717	Industrial	---
57	do	9	17S15W32BCB1	do	1980	222	649	---	---	818	do	---
58	do	5	17S15W32BDD1	do	1943	234	648	---	---	764	do	---
59	do	3	17S15W32CAC1	do	1938	209	680	---	---	760	do	---
60	do	4	17S15W32CCA1	do	1944	224	712	---	---	876	---	Unused because of excessive chloride yield.

Table 5.—Record of wells in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas—Continued

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Driller	Year well drilled	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)	Water Level: Depth below land surface (feet)	Water Level: Date of measurement	Well discharge (gal/min)	Use of water	Remarks
						EL DORADO AQUIFER						
61	TOSCO	7	17S15W32CDA1	do	1955	212	726	—	—	900	Industrial	—
62	El Dorado Water Utilities	12	17S15W33ABB1	Layne-Arkansas	1951	268	709	—	—	1,300	Municipal	—
64	Columbian Chemical Co.	4	17S15W36BAB1	Coastal Drilling Co.	1955	245	637	—	—	294	Industrial	—
67	Monsanto Co.	1	17S16W01ABB1	do	1942	189	707	—	—	—	do	—
68	do	12	17S16W01CCC1	do	1942	233	768	—	—	—	do	—
70	do	13	17S16W12ACB1	do	1943	239	676	—	—	—	do	—
71	do	7	17S16W12DCC1	do	1942	222	640	—	—	—	do	—
72	El Dorado Water Utilities	18	17S16W24BBC1	Layne-Arkansas	1978	220	704	—	—	1,000	Municipal	—
73	do	17	17S16W24BDB1	do	1965	205	615	359.93	3-31-82	—	do	USGS water-level observation well since 1968.
74	do	19	17S16W24CAB1	do	1982	207	710	—	—	—	do	Well under construction during study.
75	Great Lakes Chemical Corp.	11M	17S16W27BDD1	Alford Drilling Co.	1978	240	797	387.40	8-26-82	30	Industrial	—
77	Highway 82 Water Assoc.	—	17S16W33BBB1	—	—	252	>600	—	—	—	Rural Supply	—
80	Goodwin Field (Airport)	1	17S17W25DBA1	Layne-Arkansas	1947	250	600	—	—	—	—	Unused.
81	do	2	17S17W25DBA2	do	1971	250	648	344.23	4-27-82	75	—	Unused.
82	Marysville Water Assoc.	—	17S17W30DCD1	Hamlin-Nolte	1976	280	690	291.67	3-29-82	100	Rural Supply	—
94A	Buchanan, K.	—	18S15W07BAC2	—	1950	255	722	338.77	3-31-82	—	—	Unused. USGS water-level observation well since 1968.
94B	Frisby, W. D.	—	18S15W08ABB1	—	1920	205	800	358.93	3-02-82	—	Domestic	USGS water-level observation well since 1968.
97	Great Lakes Chemical Corp. (South Plant)	1	18S15W32CAA1	Layne-Arkansas	1956	240	756	—	—	200	Industrial	—
98	do	3	18S15W32CBB1	do	1973	250	767	—	—	750	do	—
99	do	2	18S15W32DBC1	do	1960	240	710	327.47	8-04-82	600	do	—
100	Faircrest Water Assoc.	—	18S15W33ADA1	do	1976	253	752	372.97	3-31-82	160	Rural Supply	USGS water-level observation well since 1976.
101	Great Lakes Chemical Corp. (El Dorado Plant)	4	18S16W01DBA1	—	1970	270	800	—	—	—	Industrial	—

Table 5.—Record of wells in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas—Continued

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Driller	Year well drilled	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)	Water Level: Depth below land surface (feet)	Water Level: Date of measurement	Well discharge (gal/min)	Use of water	Remarks
						EL DORADO AQUIFER						
102	Great Lakes Chemical Corp. (El Dorado Plant)	2	18S16W01DBC1	Milam, R. L.	1965	272	780	—	—	250	do	—
103	do	3	18S16W01DBD1	Kern Drilling Co.	1966	270	770	—	—	450	do	—
104	Arkansas Chemical Co.	3	18S16W10CAC1	Lanford Drilling Co.	1969	222	581	—	—	—	do	—
105	Arkansas Chemical Co.	1	18S16W10CDA1	Mayeaux Drilling Co.	1961	188	531	329.00	3-04-82	475	Industrial	—
106	do	2	18S16W10CDD1	Milam R. L.	1965	182	566	—	—	475	do	—
107	Parker's Chapel Water Assoc.	2	18S16W11DAB1	Layne-Arkansas	1976	270	767	419.31	3-31-82	110	Rural Supply	USGS water-level observation well since 1978
108	do	1	18S16W12ACB2	do	1968	303	797	444.54	4-29-82	155	do	—
109	Newell-Wesson Water Assoc.	—	18S16W28BBB1	do	1976	225	636	310.53	4-30-82	—	do	—
111	Great Lakes Chemical Corp.	7M	18S17W04DCC1	Alford Drilling Co.	1977	285	616	—	—	60	Industrial	—
112	Kin-Ark Oil Co.	—	18S17W13ACC1	Layne-Arkansas	1953	225	679	306.17	3-29-82	—	—	Unused. USGS water-level observation well since 1971.
113	Monsanto Co. (Shuler Plant)	3	18S17W18BBD1	do	1941	270	715	296.21	3-29-82	1,030	—	Unused. USGS water-level observation well since 1967.
114	do	2	18S17W18BCD1	do	1941	280	727	—	—	850	—	Unused.
115	do	1	18S17W18CAB1	do	1941	265	737	—	—	1,200	Industrial	—
116	McKinnon, H. G.	—	18S17W22BDD1	Eddington Drilling Co.	1955	285	705	339.61	3-31-82	—	—	Unused. USGS water-level observation well since 1969.
119	Great Lakes Chemical Corp. (West Plant)	1	18S18W11ACA1	Layne-Arkansas	1975	245	634	—	—	600	Industrial	—
120	do	2	18S18W11ACD1	do	1979	235	704	—	—	600	do	—
135	Junction City	2	19S16W35DDC1	C&B Drilling Co.	1967	175	601	210.26	3-31-82	412	Municipal	USGS water-level observation well since 1967.
139	do	1	20S16W02AAC1	Carloss Well Co.	1933	185	529	—	—	225	do	—

Table 5.--Record of wells in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas--Continued

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Driller	Year well drilled	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)	Water Level: Depth below land surface (feet)	Water Level: Date of measurement	Well discharge (gal/min)	Use of water	Remarks
						GREENSAND AQUIFER						
24	Gregory, W. E.	—	17S14W10DCC1	Windam Drilling Co.	1965	180	300	90.21	4-01-82	—	Domestic	USGS water-level observation well since 1966.
25	Wilson, D. C.	—	17S14W15ABA1	Hillyard Drilling Co.	1966	180	250	90.09	4-01-82	—	do	USGS water-level observation well since 1966.
54	TOSCO	AGC-USGS No. 2	17S15W31DCA3	AGC	1982	259	240	167.26	8-05-82	—	—	—
55	Great Lakes Chemical Corp.	AGC-USGS No. 3	17S15W31DCB1	do	1982	242	260	86.85	10-28-82	—	—	—
78	do	10M	17S16W34DCA1	Alford Drilling Co.	1977	218	255	—	—	40	Industrial	—
84	King, C. P.	—	18S11W09ABC1	SEECO	1978	135	330	78.96	10-13-81	—	Domestic	—
87	Town of Strong	1	18S12W32AAD1	Layne-Arkansas	1947	115	430	—	—	80	Municipal	—
88	do	2	18S12W32ABC1	Miller, J. F.	1956	112	400	57.56	6-09-82	—	do	—
89	do	4	18S12W32ACD1	Will, G. A.	1978	145	312	88.86	6-09-82	35	do	—
90	do	3	18S12W33BBB1	Layne-Arkansas	1971	112	466	—	—	185	do	—
121	U.S. Army Corps of Engineers	—	19S10W15CAC1	—	1977	64	575	—	—	—	—	—
122	Felsenthal Water Assoc.	1	19S10W16CDB1	Hamlin-Nolte	1976	82	652	71.67	6-15-82	40	Rural Supply	—
124	Town of Huttig	1	19S10W19CCD1	Layne-Arkansas	1956	98	450	90.42	3-01-82	—	Municipal	USGS water-level observation well since 1964.
126	Batts-Lapile Water Assoc.	—	19S11W18BBB1	Pender Well Drilling	1979	190	600	—	—	82	Rural Supply	—
127	Benson, J. J.	—	19S11W23ACA1	Delaney Drilling	1979	142	500	133.10	10-26-82	—	Domestic	—
128	Town of Huttig	2	19S11W25AAA1	Layne-Arkansas	1964	135	529	135.71	3-01-82	300	Municipal	USGS water-level observation well since 1964.
129	Furgerson M. L.	—	19S12W11CCD1	Bell-Stevens	1974	172	380	—	—	—	Domestic	—
137	Smith, E. J.	—	19S18W14ADA1	SEECO	1978	185	529	167.87	10-13-81	—	do	—

Table 5.—Record of wells in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas—Continued

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Driller	Year well drilled	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)	Water Level: Depth below land surface (feet)	Water Level: Date of measurement	Well discharge (gal/min)	Use of water	Remarks
						COCKFIELD FORMATION						
3	Haynes, P.	—	16S14W36DBB1	—	—	163	35	23.49	10-18-79	—	Domestic	—
8	Pugh, C. H.	—	16S15W26ADB1	—	1952	173	40	18.03	4-25-78	—	—	—
14	Burns, J. T.	—	16S16W24DDD1	—	—	220	17	10.77	10-22-81	—	Domestic	—
15	Rodgers, K.	—	16S17W07DDD1	—	—	192	35	22.59	10-17-79	—	do	—
19	Johnson, J.	—	16S18W36BCD1	—	—	182	17	10.60	10-17-79	—	do	—
20	Frisby, N.	—	17S12W27DCA1	—	1917	170	24	10.00	10-28-81	—	do	—
22	Wylie, R. L.	—	17S13W17DDC1	Childers Drilling Co.	1966	193	156	42.78	3-25-81	—	do	—
27	Spencer, B.	—	17S14W31BAB1	—	1973	260	39	22.81	10-29-81	—	do	—
44	El Dorado Water Utilities	2	17S15W28CDC3	—	1926	258	160	24.43	6-14-82	—	—	Unused well.
53	TOSCO	AGC-USGS No. 1	17S15W31DCA2	AGC	1982	259	110	53.38	8-05-82	—	—	Water level and quality-of-water monitoring well.
63	Energy Systems Co. (ENSCO)	—	17S15W34AAA2	—	—	242	150	—	—	—	Industrial	—
65	Columbian Chemical Co.	1	17S15W36BAC1	Layne-Arkansas	1951	240	125	—	—	—	do	—
66	do	—	17S15W36BAD1	—	—	248	111	44.20	3-31-82	—	—	USGS water-level observation well since 1968.
69	Jewel	—	17S16W08ABB1	—	1971	240	50	44.04	10-17-79	—	Domestic	—
79	Coke, J. E.	—	17S17W18AAA1	—	—	235	18	6.35	10-17-79	—	—	—
83	Tissure W.	—	17S18W15CDA1	—	—	290	35	27.22	10-27-81	—	—	—
85	King, C. W.	—	18S11W09CAD1	—	—	135	60	41.41	3-21-80	—	—	—
86	Hammons, C.	—	18S12W04AAD1	—	—	210	38	22.75	10-21-80	—	—	—
91	Anthony Forest Products	—	18S13W16ABA1	—	—	152	210	—	—	—	Industrial	—
92	White, C.	—	18S14W25ABB1	—	—	270	13	1.05	4-04-79	—	—	—
95	Georgia-Pacific Corp.	—	18S15W22DDC1	Kelly J. W.	1972	182	53	12.55	8-20-82	125	Industrial	—
96	do	—	18S15W27ABA1	do	1972	195	70	—	—	110	do	—
110	Attaway, C. C.	—	18S16W30DBD1	—	1953	225	61	30.77	10-16-80	—	Domestic	—
117	Moore, S.	—	18S17W34ADC1	—	—	315	48	37.62	10-18-79	—	do	—
118	Futrell, D. W.	—	18S18W10BBA1	—	—	242	30	11.92	4-05-79	—	Domestic	—
123	Felsenthal Water Assoc.	2	19S10W16CDB2	Hamlin-Nolte	1976	82	206	24.30	6-15-82	—	Rural Supply	—
125	Towns, B.	—	19S11W10DCD1	—	1965	160	28	0.50	4-04-79	—	do	—

Table 5.—Record of wells in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas—Continued

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Driller	Year well drilled	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)	Water Level: Depth below land surface (feet)	Water Level: Date of measurement	Well discharge (gal/min)	Use of water	Remarks
						COCKFIELD FORMATION						
130	Johnson, H.	—	19S12W28CBA1	—	1970	200	25	10.87	10-28-81	—	do	—
131	Sade, Y.	—	19S13W25AAA1	—	—	255	31	26.46	10-19-79	—	do	—
132	Tillman, G.	—	19S14W13ACA1	—	—	260	41	28.60	10-18-79	—	—	—
133	Pratt, D.	—	19S15W24ABB1	—	—	205	37	29.41	5-26-78	—	—	—
134	Griffith, E.	—	19S16W08DCC1	—	1969	222	25	14.88	10-18-79	—	Domestic	—
136	Lewis, T.	—	19S17W30ACA1	—	1953	222	43	26.49	10-27-81	—	do	—
138	Jones, G. R.	—	19S18W25ABD1	—	—	227	70	51.87	10-27-81	—	do	—

Table 6.—Chemical and physical analyses of water in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas

[°C, degress Celsius; Spec. cond., specific conductivity; μmho, micromho per centimeter at 25° Celsius; Al, aluminum; B, boron; Ba, barium; Cl, chloride; CO_3, carbonate; F, fluoride; Fe, iron; HCO_3, bicarbonate; I, iodide; K, potassium; Li, lithium; Mg, magnesium; Na, sodium; NH_4-N, ammonia as nitrogen; SiO_2, silica; SO_4, sulfate; V, vanadium; USGS, U.S. Geological Survey; ADH, Arkansas Department of Health. Concentrations of constituents are in milligrams per liter. When USGS is source, concentrations are for filtered samples; concentrations are for whole-water samples when USGS is not the source of data.]

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Sampling date	Temp. (°C)	pH	Spec. cond. (μmho)	Solids	Al	B	Ba	Br	Ca	Cl	CO_3	F	Fe	HCO_3	I	K	Li	Mg	Na	NH_4-N	SiO_2	SO_4	V	Source of data
								EL DORADO AQUIFER																				
1	U.S. Army Corps of Engineers	—	16S13W30BAA1	12-17-78	—	—	—	264	—	—	—	—	—	30	—	—	—	—	—	—	—	—	—	—	—	—	—	Owner
2	Town of Calion	—	16S14W15CAB1	12-29-70	—	—	—	342	—	—	—	—	—	56	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
2	do	—	16S14W15CAB1	10-26-82	—	—	540	—	—	—	—	—	—	63	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
4	Town of Norphlet	2	16S15W20DAA1	07-20-67	—	—	—	330	—	—	—	—	—	37	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
4	do	2	16S15W20DAA1	08-10-82	24.0	—	300	—	—	—	—	—	—	40	—	—	—	—	—	—	—	—	—	—	—	—	—	do
5	do	1	16S15W21BCC1	06-28-38	—	—	—	326	—	—	—	—	—	47	—	—	—	—	—	—	—	—	—	—	—	—	—	do
5	do	1	16S15W21BCC1	08-06-46	—	8.4	543	322	0.6	—	—	—	1.0	46	12	0.2	0.01	241	—	1.1	—	0.4	128	—	12	0.4	—	USGS
5	do	1	16S15W21BCC1	12-08-54	—	—	—	313	—	—	—	—	—	41	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
5	do	1	16S15W21BCC1	03-01-57	—	—	—	290	—	—	—	—	—	42	—	—	—	—	—	—	—	—	—	—	—	—	—	do
5	do	1	16S15W21BCC1	07-10-67	—	—	—	324	—	—	—	—	—	42	—	—	—	—	—	—	—	—	—	—	—	—	—	do
6	MacMillian Petroleum Co.	1	16S15W21DCD1	09-28-40	—	8.1	—	320	—	—	—	—	—	23	—	—	—	245	—	—	—	2.6	—	—	14	—	—	Owner
9	Town of Smackover	8	16S16W01DBC1	09-11-74	—	—	—	318	—	—	—	—	—	24	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
9	do	8	16S16W01DBC1	01-07-76	—	—	—	293	—	—	—	—	—	23	—	—	—	—	—	—	—	—	—	—	—	—	—	do
10	do	7	16S16W01DDD1	09-12-74	—	—	—	298	—	—	—	—	—	25	—	—	—	—	—	—	—	—	—	—	—	—	—	do
10	do	7	16S16W01DDD1	01-07-76	—	—	—	276	—	—	—	—	—	26	—	—	—	—	—	—	—	—	—	—	—	—	—	do
11	do	5	16S16W02ABC1	12-08-54	—	—	—	294	—	—	—	—	—	24	—	—	—	—	—	—	—	—	—	—	—	—	—	do
11	do	5	16S16W02ABC1	07-13-55	—	—	—	287	—	—	—	—	—	25	—	—	—	—	—	—	—	—	—	—	—	—	—	do
11	do	5	16S16W02ABC1	08-12-60	—	—	—	280	—	—	—	—	—	22	—	—	—	—	—	—	—	—	—	—	—	—	—	do
11	do	5	16S16W02ABC1	01-06-65	—	—	—	287	—	—	—	—	—	21	—	—	—	—	—	—	—	—	—	—	—	—	—	do
12	do	6	16S16W02BAA1	09-02-58	—	—	—	253	—	—	—	—	—	19	—	—	—	—	—	—	—	—	—	—	—	—	—	do
12	do	6	16S16W02BAA1	08-12-60	—	—	—	254	—	—	—	—	—	14	—	—	—	—	—	—	—	—	—	—	—	—	—	do
12	do	6	16S16W02BAA1	01-06-65	—	—	—	272	—	—	—	—	—	13	—	—	—	—	—	—	—	—	—	—	—	—	—	do
12	do	6	16S16W02BAA1	08-17-67	—	—	—	283	—	—	—	—	—	14	—	—	—	—	—	—	—	—	—	—	—	—	—	do
12	do	6	16S16W02BAA1	02-19-70	—	—	—	256	—	—	—	—	—	13	—	—	—	—	—	—	—	—	—	—	—	—	—	do
12	do	6	16S16W02BAA1	01-08-75	—	—	—	304	—	—	—	—	—	19	—	—	—	—	—	—	—	—	—	—	—	—	—	do
13	do	1	16S16W02BAC1	12-04-45	—	8.2	445	275	.7	—	—	—	1.8	20	0	—	.02	256	—	1.4	—	.3	106	—	12	.6	—	USGS

Table 6.—Chemical and physical analyses of water in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas—Continued

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Sampling date	Temp. (°C)	pH	Spec. cond. (μmho)	Solids	Al	B	Ba	Br	Ca	Cl	CO_3	F	Fe	HCO_3	I	K	Li	Mg	Na	NH_4-N	SiO_2	SO_4	V	Source of data
16	Mount Holly Water Assoc.	1	16S18W34ABC1	03-16-67	—	—	—	128	—	—	—	—	—	7.0	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
17	do	3	16S18W34ABC2	08-01-80	—	—	—	210	—	—	—	—	—	6.0	—	—	—	—	—	—	—	—	—	—	—	—	—	do
18	do	2	16S18W35BBB1	10-17-72	—	—	—	227	—	—	—	—	—	9.0	—	—	—	—	—	—	—	—	—	—	—	—	—	do
18	do	2	16S18W35BBB1	06-08-82	21.5	—	360	—	—	—	—	—	—	16	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
21	New London Water Assoc.	—	17S12W32BBC1	04-21-76	—	—	—	478	—	—	—	—	—	100	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
21	do	—	17S12W32BBC1	08-11-82	—	—	950	—	—	—	—	—	—	145	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
23	Lawson-Urbana Water Assoc.	—	17S13W31BAC1	10-01-72	—	—	—	356	—	—	—	—	—	60	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
28	Monsanto Co.	6	17S15W06CCC1	09-11-42	—	—	—	263	—	—	—	—	2.1	24	—	—	—	234	—	—	—	0.4	103	—	17	1.4	—	Owner
29	do	8	17S15W07DCC1	09-16-42	—	—	—	—	—	—	—	—	1.2	26	—	—	—	232	—	—	—	.3	106	—	16	1.8	—	do
30	do	4A	17S15W08AAA1	08-20-42	—	8.0	—	241	—	—	—	—	1.6	20	—	—	—	220	—	—	—	.6	94	—	15	1.6	—	do
31	do	4B	17S15W08AAA2	04-14-82	22.0	—	440	—	—	—	—	—	—	28	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
32	do	5	17S15W08BBB1	12-05-42	—	7.8	—	282	—	—	—	—	1.9	22	—	—	—	250	—	—	—	.4	116	—	16	2.0	—	Owner
32	do	5	17S15W08BBB1	04-14-82	24.5	—	470	—	—	—	—	—	—	36	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
33	do	9A	17S15W08DCC1	09-22-42	—	7.8	—	271	—	—	—	—	1.3	30	—	—	—	232	—	—	—	.3	106	—	18	1.0	—	Owner
34	do	10	17S15W09ACB1	09-21-42	—	7.0	—	250	—	—	—	—	1.5	22	—	—	—	224	—	—	—	.5	97	—	18	1.1	—	do
35	do	14	17S15W09CBB1	02-17-43	—	7.0	—	—	—	—	—	—	1.0	20	—	—	—	232	—	—	—	.2	100	—	12	.4	—	do
38	El Dorado Water Utility	16	17S15W17CDA1	01-25-62	—	—	—	270	—	—	—	—	—	21	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
38	do	16	17S15W17CDA1	07-24-81	—	—	—	253	—	—	—	—	—	36	—	—	—	—	—	—	—	—	—	—	—	—	—	do
42	do	7	17S15W28CDC1	11-30-38	—	—	—	292	—	—	—	—	—	37	—	—	—	—	—	—	—	—	—	—	—	—	—	do
42	do	7	17S15W28CDC1	10-09-57	—	—	—	260	—	—	—	—	—	30	—	—	—	—	—	—	—	—	—	—	—	—	—	do
43	do	10	17S15W28CDC2	11-28-45	—	8.4	454	275	0.1	—	—	—	2.2	36	9	0.1	0.02	213	—	1.5	—	.6	106	—	10	.8	—	USGS
43	do	10	17S15W28CDC2	01-08-52	—	—	—	248	—	—	—	—	—	38	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
43	do	10	17S15W28CDC2	10-09-57	—	—	—	275	—	—	—	—	—	32	—	—	—	—	—	—	—	—	—	—	—	—	—	do
43	do	10	17S15W28CDC2	11-16-60	—	—	—	255	—	—	—	—	—	30	—	—	—	—	—	—	—	—	—	—	—	—	—	do
43	do	10	17S15W28CDC2	05-15-68	—	8.4	450	261	.0	—	—	—	1.4	23	3	.2	.00	222	—	1.3	—	.2	102	—	10	.7	—	USGS
43	do	10	17S15W28CDC2	10-27-71	—	—	—	267	—	—	—	—	—	34	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
43	do	10	17S15W28CDC2	07-24-81	—	—	—	274	—	—	—	—	—	42	—	—	—	—	—	—	—	—	—	—	—	—	—	do
43	do	10	17S15W28CDC2	05-26-82	23.5	8.6	468	—	<.1	0.20	0.012	0.40	1.7	63	—	<.1	.01	—	0.02	1.1	0.006	.3	130	0.44	12	<1.0	<0.1	USGS
45	do	8	17S15W28DBA1	03-15-45	—	—	—	271	—	—	—	—	—	50	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
45	do	8	17S15W28DBA1	10-08-57	—	—	—	263	—	—	—	—	—	26	—	—	—	—	—	—	—	—	—	—	—	—	—	do
45	do	8	17S15W28DBA1	11-16-60	—	—	—	248	—	—	—	—	—	26	—	—	—	—	—	—	—	—	—	—	—	—	—	do
46	do	11	17S15W28DCC1	02-29-52	20.0	8.3	452	263	1.9	—	—	—	4.5	38	3	.2	.02	222	—	1.6	—	1.1	104	—	11	1.3	—	USGS
46	do	11	17S15W28DCC1	10-09-57	—	—	—	277	—	—	—	—	—	32	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH

Table 6.—Chemical and physical analyses of water in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas—Continued

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Sampling date	Temp. (°C)	pH	Spec. cond. (µmho)	Solids	Al	B	Ba	Br	Ca	Cl	CO_3	F	Fe	HCO_3	I	K	Li	Mg	Na	NH_4-N	SiO_2	SO_4	V	Source of data
46	El Dorado Water Utility	11	17S15W28DCC1	11-16-60	—	—	—	264	—	—	—	—	—	32	—	—	—	—	—	—	—	—	—	—	—	—	—	do
46	El Dorado Water Utility	11	17S15W28DCC1	10-27-71	—	—	—	264	—	—	—	—	—	34	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
46	do	11	17S15W28DCC1	07-24-81	—	—	—	278	—	—	—	—	—	35	—	—	—	—	—	—	—	—	—	—	—	—	—	do
46	do	11	17S15W28DCC1	03-31-82	23.5	8.8	465	—	—	—	—	—	—	38	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
47	do	15	17S15W28DDA1	11-16-60	—	—	—	278	—	—	—	—	—	32	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
47	do	15	17S15W28DDA1	10-27-71	—	—	—	262	—	—	—	—	—	32	—	—	—	—	—	—	—	—	—	—	—	—	—	do
47	do	15	17S15W28DDA1	03-31-82	23.5	8.3	500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
48	do	14	17S15W29ACB1	07-21-64	—	—	—	262	—	—	—	—	—	31	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
48	do	14	17S15W29ACB1	11-03-71	—	—	—	204	—	—	—	—	—	24	—	—	—	—	—	—	—	—	—	—	—	—	—	do
49	do	13	17S15W29CDC1	07-17-64	—	—	—	246	—	—	—	—	—	25	—	—	—	—	—	—	—	—	—	—	—	—	—	do
49	do	13	17S15W29CDC1	10-27-71	—	—	—	242	—	—	—	—	—	20	—	—	—	—	—	—	—	—	—	—	—	—	—	do
56	TOSCO	6	17S15W31DDA1	05-26-82	24.5	8.4	375	—	0.1	0.19	0.014	0.20	1.7	30	0	<0.1	0.06	220	0.01	1.0	0.005	0.4	100	<0.01	11	3.0	0.0002	USGS
56	do	6	17S15W31DDA1	06-03-82	24.5	8.5	740	—	<.1	.19	.034	—	6.4	110	—	.3	.05	—	.04	1.4	.017	1.0	180	.54	11	5.0	.0016	do
57	do	9	17S15W32BCB1	05-25-82	25.0	8.6	427	—	.1	.20	.013	.27	1.6	27	2	.3	.02	229	.05	1.0	.005	.5	180	—	12	5.0	.0080	do
58	do	5	17S15W32BDD1	05-25-82	23.5	8.5	433	—	<.1	.19	.016	.20	2.3	24	6	.3	.05	222	.02	1.1	.005	.4	110	.42	11	3.0	<.0010	do
59	do	3	17S15W32CAC1	05-25-82	24.0	8.5	700	—	<.1	.20	.028	.90	2.9	100	3	.3	.06	241	.04	1.3	.008	.6	220	.48	11	4.0	.0012	do
59	do	3	17S15W32CAC1	05-25-82	24.0	8.5	760	—	<.1	.19	.035	1.3	3.3	130	3	.2	.04	214	.05	1.2	.010	.7	170	.56	11	<1.0	.0019	do
60	do	4	17S15W32CCA1	03-28-47	—	8.1	475	280	1.5	—	—	—	1.5	36	6	.3	.12	220	—	1.2	—	.5	109	—	9.4	.9	—	do
60	do	4	17S15W32CCA1	05-26-82	24.0	8.2	2270	—	.3	.26	.20	7	27	650	0	.2	.02	278	.22	4.0	.020	6.0	430	.98	30	6.0	.46	do
61	do	7	17S15W32CDA1	05-25-82	24.0	8.5	612	—	.2	.19	.017	.62	2.0	64	4	<.1	.02	242	.03	1.1	.007	.4	230	.42	11	15	.0031	do
62	El Dorado Water Utility	12	17S15W33ABB1	01-12-55	—	—	—	298	—	—	—	—	—	43	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
62	do	12	17S15W33ABB1	10-09-57	—	—	—	315	—	—	—	—	—	57	—	—	—	—	—	—	—	—	—	—	—	—	—	do
62	do	12	17S15W33ABB1	11-16-60	—	—	—	310	—	—	—	—	—	46	—	—	—	—	—	—	—	—	—	—	—	—	—	do
62	do	12	17S15W33ABB1	10-27-71	—	—	—	325	—	—	—	—	—	61	—	—	—	—	—	—	—	—	—	—	—	—	—	do
62	do	12	17S15W33ABB1	07-24-81	—	—	—	317	—	—	—	—	—	114	—	—	—	—	—	—	—	—	—	—	—	—	—	do
62	do	12	17S15W33ABB1	03-31-82	23.5	—	650	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
64	Columbian Chemical Co.	4	17S15W36BAB1	06-02-82	22.5	8.5	470	—	.2	.24	.020	—	1.9	35	2	—	.03	259	—	1.4	<.004	.4	120	.68	9.9	—	—	do
67	Monsanto Co.	1	17S16W01ABB1	11-25-42	—	7.0	—	292	—	—	—	—	2.3	27	—	—	—	242	—	—	—	.6	109	—	27	6.8	—	Owner

Table 6.—Chemical and physical analyses of water in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas—Continued

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Sampling date	Temp. (°C)	pH	Spec. cond. (μmho)	Solids	Al	B	Ba	Br	Ca	Cl	CO_3	F	Fe	HCO_3	I	K	Li	Mg	Na	NH_4-N	SiO_2	SO_4	V	Source of data
68	Monsanto Co.	12	17S16W01CCC1	12-16-42	—	8.0	—	306	—	—	—	—	0.8	36	—	—	—	244	—	—	—	0.1	115	—	32	1.2	—	Owner
70	do	13	17S16W12ACB1	01-28-43	—	8.0	—	266	—	—	—	—	1.4	18	—	—	—	232	—	—	—	.2	101	—	25	6.0	—	do
71	do	7	17S16W12DCC1	09-02-42	—	—	—	230	—	—	—	—	2.7	16	—	—	—	206	—	—	—	.5	92	—	15	2.9	—	do
72	El Dorado Water Utility	18	17S16W24BBC1	07-24-81	—	—	—	237	—	—	—	—	—	28	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
72	do	18	17S16W24BBC1	03-31-82	23.0	—	475	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
73	do	17	17S16W24BDB1	10-27-71	—	—	—	259	—	—	—	—	—	27	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
73	do	17	17S16W24BDB1	06-15-72	23.0	8.5	446	260	—	—	—	—	1.0	27	4	0.2	0.02	224	—	1.5	—	.2	110	—	11	1.8	—	USGS
73	do	17	17S16W24BDB1	08-31-77	23.0	7.8	447	—	—	—	—	—	—	—	0	—	—	240	—	—	—	—	—	—	—	—	—	do
73	do	17	17S16W24BDB1	06-10-81	23.5	8.6	456	268	—	0.12	—	—	1.0	28	—	.2	.02	—	—	1.1	—	.5	100	0.56	12	.6	—	do
73	do	17	17S16W24BDB1	07-24-81	—	—	—	246	—	—	—	—	—	31	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
73	do	17	17S16W24BDB1	05-27-82	—	8.5	442	—	0.3	.14	0.012	0.31	1.2	38	8	.3	.03	220	0.02	1.0	—	.3	110	.42	11	<1.0	0.0009	USGS
75	Great Lakes Chemical Co.	11M	17S16W27BDD1	08-26-82	25.0	8.3	670	384	—	.21	—	1.0	.7	82	—	.3	.08	—	—	.90	—	.2	160	—	13	3.0	—	do
77	Highway 82 Water Assoc.	—	17S16W33BBB1	04-29-82	23.0	8.6	328	—	—	—	—	—	—	23	—	—	—	—	—	—	—	—	—	—	—	—	—	do
82	Marysville Water Assoc.	—	17S17W30DCD1	10-18-76	—	—	—	206	—	—	—	—	—	10	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
82	do	—	17S17W30DCD1	09-26-77	—	—	—	200	—	—	—	—	—	9.0	—	—	—	—	—	—	—	—	—	—	—	—	—	do
82	do	—	17S17W30DCD1	04-29-82	25.0	8.5	310	—	—	—	—	—	—	15	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
98	Great Lakes Chemical Corp.	3	18S15W32CBB1	08-03-82	26.0	7.9	650	411	—	.29	—	1.4	2.4	120	—	.3	.01	—	—	1.1	—	.5	160	—	12	4.0	—	do
100	Faircrest Water Assoc.	—	18S15W33ADA1	04-29-76	—	—	—	395	—	—	—	—	—	80	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
100	do	—	18S15W33ADA1	11-13-78	—	—	—	355	—	—	—	—	—	86	—	—	—	—	—	—	—	—	—	—	—	—	—	do
100	do	—	18S15W33ADA1	05-07-79	—	—	—	344	—	—	—	—	—	85	—	—	—	—	—	—	—	—	—	—	—	—	—	do
100	do	—	18S15W33ADA1	03-25-81	—	—	—	371	—	—	—	—	—	102	—	—	—	—	—	—	—	—	—	—	—	—	—	do
100	do	—	18S15W33ADA1	04-30-82	24.0	9.0	660	—	—	—	—	—	—	110	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
102	Great Lakes Chemical Corp.	2	18S16W01DBC1	05-27-82	24.0	8.5	520	—	<.1	.20	.015	—	1.7	42	3	.3	.02	234	.02	1.0	<.004	.3	110	.46	11	11	.0005	do
104	Arkansas Chemical Co.	3	18S16W10CAC1	04-04-82	22.0	8.6	475	—	—	—	—	—	—	40	—	—	—	—	—	—	—	—	—	—	—	—	—	do
108	Parkers Chapel Water Assoc.	1	18S16W12ACB1	03-22-68	—	—	—	310	—	—	—	—	—	34	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
108	do	1	18S16W12ACB1	12-29-70	—	—	—	315	—	—	—	—	—	35	—	—	—	—	—	—	—	—	—	—	—	—	—	do
108	do	1	18S16W12ACB1	01-08-75	—	—	—	344	—	—	—	—	—	38	—	—	—	—	—	—	—	—	—	—	—	—	—	do
108	do	1	18S16W12ACB1	07-30-75	—	—	—	310	—	—	—	—	—	35	—	—	—	—	—	—	—	—	—	—	—	—	—	do
108	do	1	18S16W12ACB1	05-27-82	—	8.5	546	—	.2	.21	.017	.47	1.9	59	4	.1	.05	238	.02	1.8	.007	.4	130	.46	11	36	<.0001	USGS
109	Newell-Wesson Water Assoc.	—	18S16W28BBB1	12-02-76	—	—	—	356	—	—	—	—	—	28	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH

Table 6.—Chemical and physical analyses of water in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas—Continued

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Sampling date	Temp. (°C)	pH	Spec. cond. (µmho)	Solids	Al	B	Ba	Br	Ca	Cl	CO_3	F	Fe	HCO_3	I	K	Li	Mg	Na	NH_4-N	SiO_2	SO_4	V	Source of data
109	Newell-Wesson Water Assoc.	—	18S16W28BBB1	05-10-79	—	—	—	332	—	—	—	—	—	29	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
109	do	—	18S16W28BBB1	04-30-82	24.0	8.8	575	—	—	—	—	—	—	33	—	—	—	—	—	—	—	—	—	—	—	—	—	do
111	Great Lakes Chemical Corp.	7M	18S17W04DCC1	08-27-82	23.0	8.2	370	218	—	0.17	—	0.10	2.1	11	—	0.3	0.01	—	—	1.2	—	0.6	89	—	13	2.0	—	USGS
115	Monsanto Co.	1	18S17W18CAB1	04-28-82	28.0	8.5	345	—	—	—	—	—	—	20	—	—	—	—	—	—	—	—	—	—	—	—	—	do
119	Great Lakes Chemical Corp.	1	18S18W11ACA1	04-27-82	24.5	8.6	372	—	—	—	—	—	—	17	—	—	—	—	—	—	—	—	—	—	—	—	—	do
120	do	2	18S18W11ACD1	04-07-82	24.5	8.7	330	—	—	—	—	—	—	24	—	—	—	—	—	—	—	—	—	—	—	—	—	do
135	Junction City	2	19S16W35DDC1	10-02-67	—	—	—	242	—	—	—	—	—	42	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
135	do	2	19S16W35DDC1	04-22-77	—	—	—	295	—	—	—	—	—	71	—	—	—	—	—	—	—	—	—	—	—	—	—	do
135	do	2	19S16W35DDC1	05-07-79	—	—	—	265	—	—	—	—	—	77	—	—	—	—	—	—	—	—	—	—	—	—	—	do
135	do	2	19S16W35DDC1	08-04-82	23.5	—	510	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
139	do	1	20S16W02AAC1	07-06-38	—	—	—	225	—	—	—	—	—	38	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
139	do	1	20S16W02AAC1	01-25-46	—	8.4	355	219	0.5	—	—	—	1.0	35	0	.0	.02	158	—	.90	—	.2	81	—	10	2.4	—	USGS
139	do	1	20S16W02AAC1	01-21-60	—	—	—	217	—	—	—	—	—	41	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
139	do	1	20S16W02AAC1	06-21-62	—	—	—	222	—	—	—	—	—	40	—	—	—	—	—	—	—	—	—	—	—	—	—	do
139	do	1	20S16W02AAC1	04-26-67	—	—	—	273	—	—	—	—	—	49	—	—	—	—	—	—	—	—	—	—	—	—	—	do
								GREENSAND AQUIFER																				
54	TOSCO	AGC-USGS 2	17S15W31DCA3	07-30-82	21.5	7.4	360	196	—	0.04	—	0.09	27	12	—	<0.1	<0.01	—	—	3.8	—	6.8	26	—	35	5.0	—	USGS
54	do	AGC-USGS 2	17S15W31DCA3	11-10-82	20.5	7.4	285	189	0.1	.07	0.27	.08	25	13	—	< .1	.25	160	0.01	4.1	0.012	7.4	22	0.06	34	8.0	0.0004	do
55	Great Lakes Chemical Corp.	AGC-USGS 3	17S15W31DCB1	11-10-82	20.5	6.9	310	210	.1	.06	.23	.39	22	24	—	< .1	1.5	130	.03	4.7	.018	6.0	31	.03	42	6.0	.0008	do
78	do	10M	17S16W34DCA1	08-26-82	19.5	7.7	275	182	—	.05	—	.09	17	7.0	—	< .1	.01	—	—	3.1	—	4.2	50	—	14	5.0	—	do
87	Town of Strong	1	18S12W32AAD1	08-01-50	20.0	7.8	510	309	1.1	—	—	—	5.7	25	0	—	.04	286	—	7.4	—	2.1	116	—	12	0.7	—	do
87	do	1	18S12W32AAD1	10-28-53	—	—	—	302	—	—	—	—	—	27	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
87	do	1	18S12W32AAD1	12-02-60	—	—	—	304	—	—	—	—	—	23	—	—	—	—	—	—	—	—	—	—	—	—	—	do
87	do	1	18S12W32AAD1	01-28-64	—	—	—	303	—	—	—	—	—	22	—	—	—	—	—	—	—	—	—	—	—	—	—	do
88	do	2	18S12W32ABC1	04-17-57	—	—	—	286	—	—	—	—	—	22	—	—	—	—	—	—	—	—	—	—	—	—	—	do
88	do	2	18S12W32ABC1	12-02-60	—	—	—	319	—	—	—	—	—	19	—	—	—	—	—	—	—	—	—	—	—	—	—	do
88	do	2	18S12W32ABC1	01-28-64	—	—	—	314	—	—	—	—	—	22	—	—	—	—	—	—	—	—	—	—	—	—	—	do
88	do	2	18S12W32ABC1	06-09-82	19.5	—	415	—	—	—	—	—	—	26	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
89	do	4	18S12W32ACD1	06-09-82	20.0	—	500	—	—	—	—	—	—	30	—	—	—	—	—	—	—	—	—	—	—	—	—	do
90	do	3	18S12W33BBB1	08-17-71	—	—	—	580	—	—	—	—	—	160	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH

Table 6.--Chemical and physical analyses of water in the El Dorado, Greensand, and Cockfield aquifers in Union County, Arkansas--Continued

Number on map (pl. 10)	Owner of well	Owner's well number	U.S. Geological Survey number	Sampling date	Temp. (°C)	pH	Spec. cond. (µmho)	Solids	Al	B	Ba	Br	Ca	Cl	CO_3	F	Fe	HCO_3	I	K	Li	Mg	Na	NH_4-N	SiO_2	SO_4	V	Source of data
90	Town of Strong	3	18S12W33BBB1	06-19-73	—	—	—	485	—	—	—	—	—	165	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
90	do	3	18S12W33BBB1	06-15-82	21.0	—	980	—	—	—	—	—	—	190	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
121	U.S. Army Corps of Enginers	—	19S10W15CAC1	11-02-77	—	—	—	712	—	—	—	—	—	220	—	—	—	—	—	—	—	—	—	—	—	—	—	Owner
122	Felsenthal Water Assoc.	1	19S10W16CDB1	06-15-82	24.0	—	1390	—	—	—	—	—	—	245	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
124	Town of Huttig	3	19S10W19CCD1	05-23-56	—	—	—	679	—	—	—	—	—	212	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
124	do	3	19S10W19CCD1	05-05-58	—	—	—	655	—	—	—	—	—	220	—	—	—	—	—	—	—	—	—	—	—	—	—	do
124	do	3	19S10W19CCD1	03-25-81	—	—	—	670	—	—	—	—	—	237	—	—	—	—	—	—	—	—	—	—	—	—	—	do
124	do	3	19S10W19CCD1	06-10-82	21.5	—	1000	—	—	—	—	—	—	260	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
126	Batts-Lapile Water Assoc.	—	19S11W18BBB1	10-26-82	23.0	8.3	1170	—	—	—	—	—	—	209	—	—	—	—	—	—	—	—	—	—	—	—	—	do
127	Benson, J. J.	—	19S11W23ACA1	10-26-82	22.0	8.5	880	—	—	—	—	—	—	131	—	—	—	—	—	—	—	—	—	—	—	—	—	do
128	Town of Huttig	2	19S11W25AAA1	02-04-65	—	—	—	663	—	—	—	—	—	214	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
128	do	2	19S11W25AAA1	08-20-75	—	—	—	637	—	—	—	—	—	224	—	—	—	—	—	—	—	—	—	—	—	—	—	do
128	do	2	19S11W25AAA1	06-10-82	22.5	—	1050	—	—	—	—	—	—	240	—	—	—	—	—	—	—	—	—	—	—	—	—	USGS
129	Furgerson, M. L.	—	19S12W11CCD1	08-12-82	—	—	625	—	—	—	—	—	—	60	—	—	—	—	—	—	—	—	—	—	—	—	—	do
	COCKFIELD FORMATION																											
44	El Dorado Water Utility	2	17S15W28CDC3	11-30-38	—	—	—	117	—	—	—	—	—	23	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
44	do	2	17S15W28CDC3	11-28-45	—	6.8	133	114	2.1	—	—	—	7.4	18	0	0.0	—	17	—	4.4	—	3.8	9.5	—	40	20	—	USGS
44	do	2	17S15W28CDC3	02-15-50	—	—	—	64	.0	—	—	—	3.4	5.5	0	.0	0.02	17	—	—	—	1.4	5.0	—	20	21	—	do
44	do	2	17S15W28CDC3	06-25-52	—	—	—	165	—	—	—	—	—	30	—	—	—	—	—	—	—	—	—	—	—	—	—	ADH
53	TOSCO	AGC-USGS 1	17S15W31DCA2	08-05-82	20.0	7.0	98	—	—	0.05	—	0.10	4.1	15	—	<.1	.01	—	—	1.4	—	1.9	6.2	—	15	13	—	USGS
53	do	AGC-USGS 1	17S15W31DCA2	11-10-82	19.5	5.9	99	71	.1	.03	0.10	.17	5.3	4.7	—	<.1	.02	26	<0.01	1.9	<0.004	1.9	10	0.05	15	18	<0.0001	do
63	Energy Systems Co.	—	17S15W34AAA2	04-15-82	20.0	5.7	92	—	—	—	—	—	—	15	—	—	—	—	—	—	—	—	—	—	—	—	—	do
65	Columbian Chemical Co.	1	17S15W36BAC1	06-02-82	20.0	5.9	115	—	.1	.01	.10	—	4.2	26	0	—	1.3	28	—	2.2	.007	2.0	11	.03	48	—	—	do
91	Anthony Forest Products	—	18S13W16ABA1	08-26-82	20.0	—	480	—	—	—	—	—	—	14	—	—	—	—	—	—	—	—	—	—	—	—	—	do
95	Georgia-Pacific Co.	—	18S15W27ABA1	08-20-82	19.0	—	74	—	—	—	—	—	—	16	—	—	—	—	—	—	—	—	—	—	—	—	—	do
123	Felsenthal Water Assoc.	2	19S10W16CDB2	06-15-82	20.0	—	1000	—	—	—	—	—	—	130	—	—	—	—	—	—	—	—	—	—	—	—	—	do

high as 2,500 mg/L were estimated from electric logs of No. 1 Dykes and No. 1 Tatum wells, respectively, in the graben (pl. 11). If the rate of increase in chloride concentration remained constant east of the 125 mg/L isochlor and south of the graben (pl. 11), chloride concentration in the El Dorado aquifer could be about 500 mg/L at Strong and 700 mg/L at Huttig.

Greensand aquifer

The Greensand aquifer, underlain by the middle confining bed of the Sparta Sand and overlain by the Cook Mountain Formation (fig. 2), regionally dips from an altitude of about 150 feet above sea level in the northwestern corner of the county to about 250 feet below sea level in the southeastern corner (pl. 12). In the graben, the Greensand aquifer is partly in contact at the fault planes with the middle confining bed and the El Dorado aquifer (pls. 2, 4, and 5). Altitudes of the top of the Greensand aquifer are shown on plate 12.

Water withdrawals from the Greensand aquifer, about 70 percent of it in the Strong-Huttig area, were about 0.5 million gallons per day (Mgal/d) in 1982. Water levels in wells of the Greensand aquifer (table 5) in 1982 ranged from about 58 to 168 feet below land surface. Locally, differences in the hydrostatic head between sand beds in the Greensand aquifer indicate that some of the intervening clay beds in the Greensand act as confining beds. Some head differential would be consistent with the lithologic makeup of the aquifer and the light pumping stress on the aquifer.

Water-level trends in the Greensand were examined to determine whether leakage might occur through the middle confining bed, particularly in the vicinity of El Dorado. Water-level records dating back to 1966, were available for wells 24 and 25 (table 5, pl. 10). These wells are about 6 miles from El Dorado, but are well within the area of heavy pumping stress on the El Dorado aquifer. Both of the wells in the Greensand aquifer showed nearly identical annual hydrographs. The hydrograph for well 25 is shown in figure 5. On the basis of this hydrograph little, if any, water-level decline in the Greensand aquifer can be attributed to leakage to the El Dorado aquifer. Figure 5 also shows a water-level hydrograph for well 128, Town of Huttig No. 2. Here, a decline of about 20 feet in the water level of the Greensand since 1966 is apparent. Because well 128 is remote from the pumping stress on the El Dorado aquifer, the water-level decline is attributed solely to withdrawals from the Greensand aquifer. The sharp change in slope of the hydrograph of well 128 after 1970 was caused by a significant increase in industrial withdrawals near Huttig.

Water-level data for the Greensand aquifer were too few to construct more than a very generalized potentiometric-surface map. As indicated by the data, the potentiometric surface of the aquifer (pl. 13) slopes south-southeast from an altitude of about 100 feet above sea level at El Dorado to about sea level in the southeastern corner of the county. The direction of water movement in the aquifer, which is perpendicular to the potentiometric contours, is also south-southeast. The slope and general configuration of the potentiometric surface of the Greensand aquifer sharply contrast with those of the El Dorado aquifer, further supporting the concept that the two aquifers function independently.

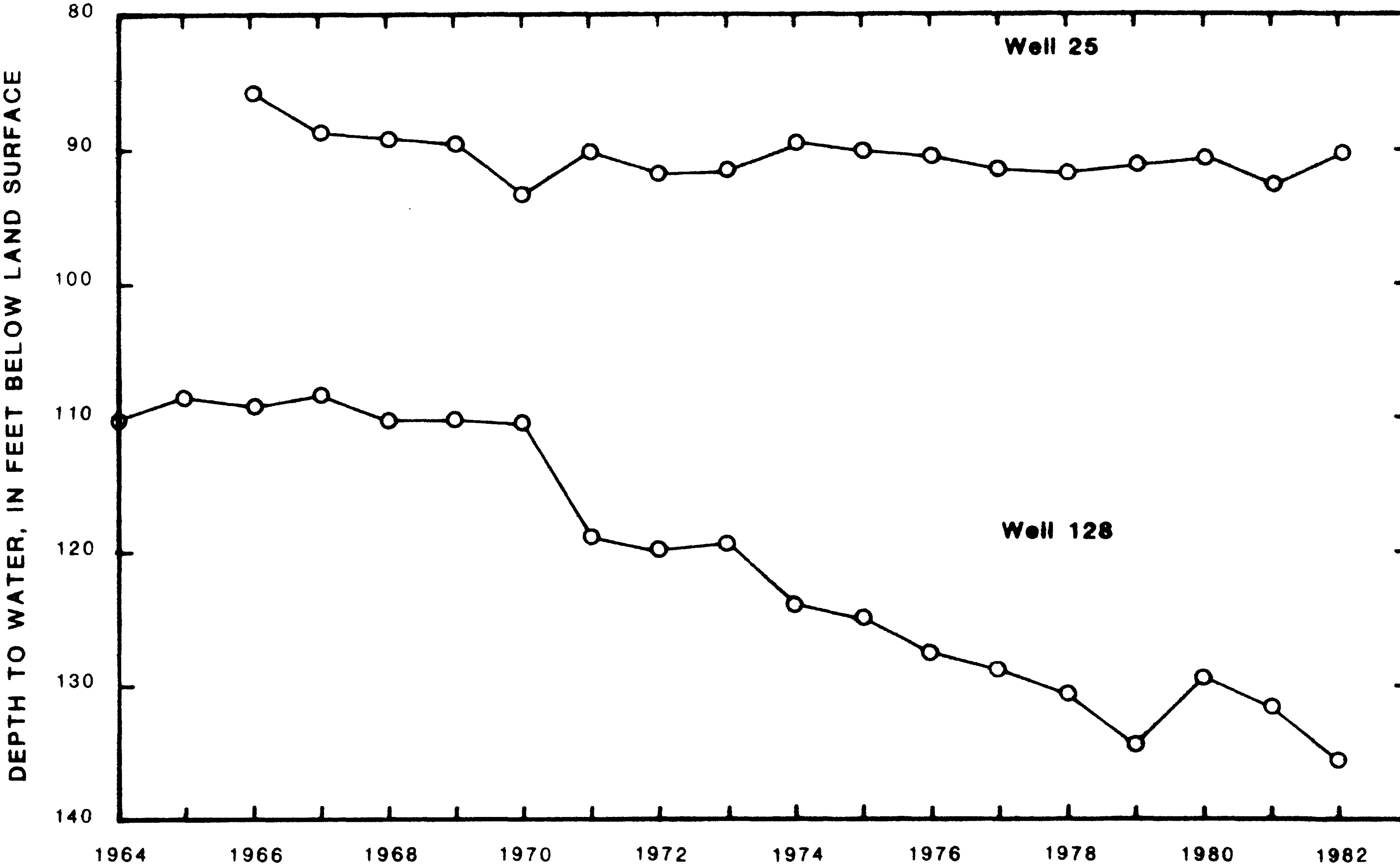

Figure 5.--Water levels in wells tapping the Greensand aquifer, Union County, Arkansas.

Water-quality data for the Greensand aquifer are shown in table 3. Most of the samples are from the Strong-Huttig area where the Greensand is the main source of ground water and the area of apparent saltwater contamination near El Dorado.

Analyses of water from wells 54 and 55 (AGC-USGS wells 2 and 3 at El Dorado) and well 78 (Great Lakes 10M) about 2 miles west of El Dorado (pl. 10), show the water from the Greensand aquifer to be a very dilute sodium and calcium bicarbonate type with about 200 mg/L dissolved solids. Chloride concentrations range from 7 to 24 mg/L. Other water-quality characteristics from the wells include: temperature ranging from 19.5°C to 21.5°C; pH from 6.9 to 7.4; and dissolved iron from less than 0.003 to 1.5 mg/L.

Water in the Greensand aquifer in the Strong-Huttig area is a sodium bicarbonate type with dissolved solids concentrations ranging from about 300 mg/L near Strong to about 700 mg/L near Huttig, and chloride concentrations range from about 30 to 250 mg/L, respectively. Temperature ranges from 19.5°C to 24°C and pH ranges from 7.8 to 8.5. In the Strong-Huttig area, some data indicate a considerable range of chloride concentration within the Greensand aquifer. The deepest of the four wells at Strong yields water with a chloride concentration of about 190 mg/L, whereas the other three wells have concentrations of not more than 30 mg/L. Water-quality data for the Greensand were not available in the graben. It is likely that water in the Greensand aquifer in the graben would be highly mineralized.

Cook Mountain Formation

The Cook Mountain, which crops out in the northwestern part of the county (pl. 1), dips southeast to an altitude of about 50 feet below sea level in the southeastern corner of the county. Except in the outcrop area, where it is overlain unconformably by Quaternary alluvium in stream bottomlands, the unit is overlain by the Cockfield Formation and underlain by the Greensand aquifer of the Sparta Sand. The Cook Mountain is 100 to 150 feet thick, and is composed of clay and silty clay containing minor amounts of very fine sand in places. The formation serves as a confining unit between the more permeable overlying Cockfield Formation and the underlying Greensand aquifer. The Cook Mountain probably has been entirely removed by erosion in places beneath the alluvium along Smackover Creek. In the graben (pls. 2, 4, and 5), the Cook Mountain is bounded at the faults by the Greensand aquifer. Because of its very low permeability, the Cook Mountain is not considered an aquifer in Union County.

Cockfield Formation

The Cockfield Formation, except where mantled by Quaternary alluvium in stream bottomlands, crops out in all parts of the county downslope from the outcrop area of the Cook Mountain Formation (pl. 1). Throughout most of the county, the Cockfield is about 200 feet thick. However, in the graben (pls. 2, 4, and 5) the formation may be 300 feet or more in thickness. The Cockfield, locally referred to as the "lignite sand", is composed of interbedded and lenticular beds of lignitic sand and clay. In places the sand beds in the Cockfield are as much as 100 feet thick, and make up 50 to 75 percent of the formation's thickness.

The Cockfield has been the principal aquifer for rural domestic supply. Prior to the 1920's, it was the source of all ground water used in Union County, including the El Dorado water supply. In recent years the use of the Cockfield for rural domestic supply has decreased considerably. Since the development of the Parker's Chapel Water Association in 1968, most of the rural water needs have been met by rural water association wells that in most instances tap the El Dorado aquifer. Water withdrawals from the Cockfield Formation in Union County in 1982, mainly for rural homes and a few industries, were about 0.7 Mgal/d.

Water levels in wells of the Cockfield Formation (table 5) are shallow, ranging from near land surface in bottomlands to about 50 feet below land surface on hills and ridges. Water movement in the Cockfield in any area of the county is in the direction of land slope and toward streams draining the area. Ground water in the Cockfield generally occurs under water-table conditions and most of the discharge from the Cockfield is to streams and to evapotranspiration. Recharge to the Cockfield is mostly local and in the form of rainfall. Surface impoundments with hydraulic connection to the Cockfield could also be sources of recharge.

Annual fluctuations of water levels of wells in the Cockfield Formation are shown in figure 6.

Results of water-quality sampling from wells in the Cockfield are shown in table 6, and the locations of the wells sampled are shown on plate 10. Water in the Cockfield generally has a low mineral content with dissolved solids concentrations ranging from less than 100 mg/L to about 200 mg/L in most of the county. Analyses of water from wells in the Cockfield sampled in 1982 in the vicinity of El Dorado, including the area of contamination, showed chloride concentrations ranging from 5 to 26 mg/L (table 6). However, water from one well in the Cockfield in the southeast part of Union County had a chloride concentration of 130 mg/L (table 6). Also high chloride concentrations in water from the Cockfield have been reported in some areas not sampled during the present study (James Warnock, TOSCO Corp. oral commun., 1982).

Quaternary Alluvium

Quaternary alluvium is present in the bottomlands of most of the streams in Union County. The alluvium probably does not exceed 25 feet in thickness, except along the lower reaches of Smackover Creek and the Ouachita River where a few wells penetrate as much as 60 feet. The alluvium typically grades from sand and gravel in the lower part to silt and clay in the upper part. Because most streams draining the alluvium are perennial, it can be inferred that the alluvium has a very shallow water table. It can also be inferred that the alluvium, with a gravelly and sandy lower part, is in hydraulic connection with the Cockfield Formation where the alluvium is underlain by sandy beds of the Cockfield. Recharge to the alluvium is by local rainfall, and in places upward leakage from the Cockfield. Movement of water in the alluvium is downslope and toward stream channels. Practically all discharge is to streams and by evapotranspiration.

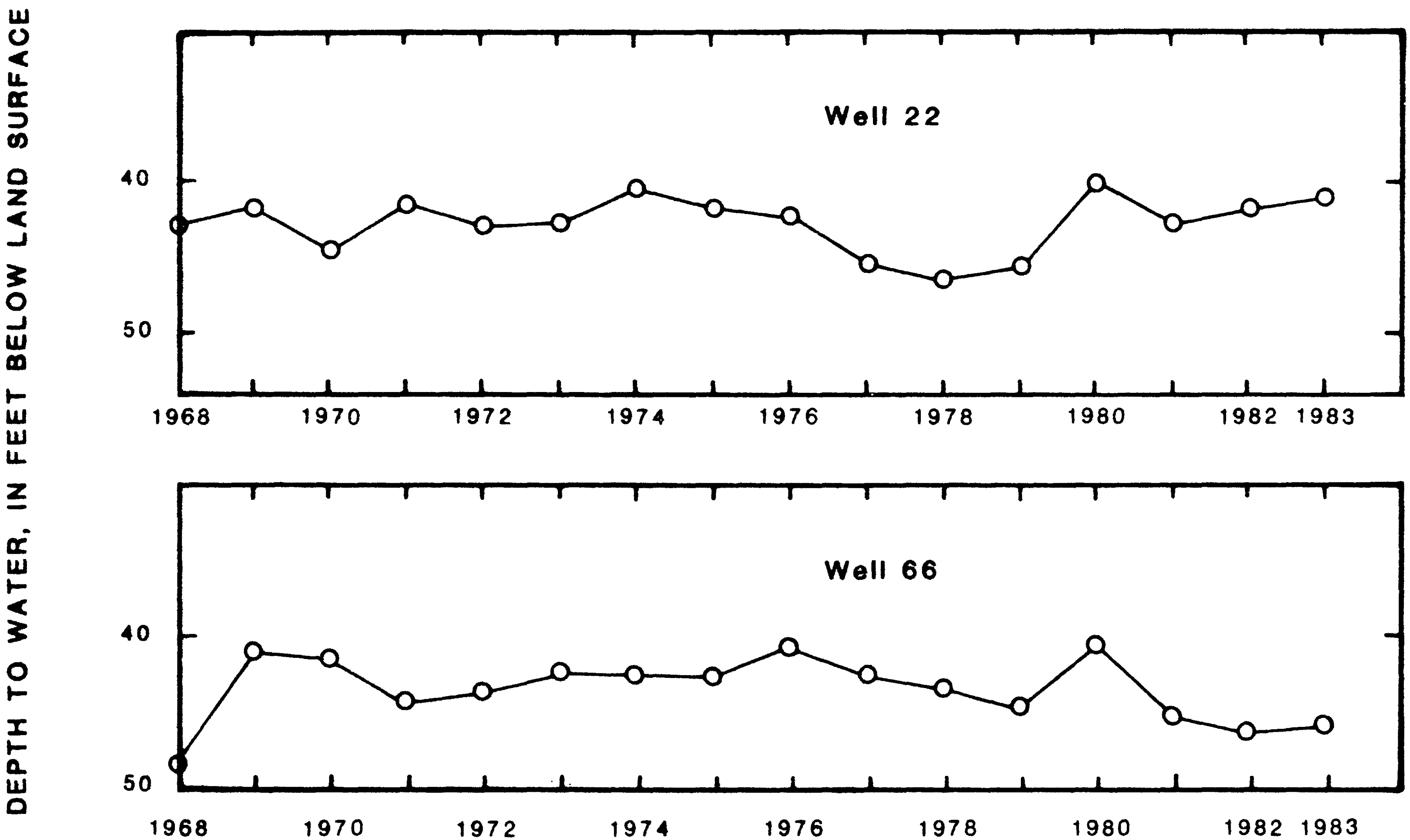

Figure 6.--Water levels in wells tapping the Cockfield Formation, Union County, Arkansas.

OIL DEVELOPMENT IN THE AREA OF SALTWATER CONTAMINATION IN THE EL DORADO AQUIFER

Previous investigators, including Baker and others (1948), have expressed concern that substantial decline in the hydraulic head or potentiometric surface of the El Dorado aquifer might result in some leakage of brine from old abandoned oil wells. Those concerns had merit then as they do now, particularly in view of the methods of oil-well construction and the age of many of the wells. However, all of the hydrologic changes resulting from oil development did not necessarily enhance the potential for contamination of the El Dorado aquifer today. The following discussion was taken partly from Fancher and Mackay (1946).

The area of contamination is on the northeast fringe of the south El Dorado oil field which, since its discovery in 1920, has produced oil chiefly from the Nacatoch Sand. Some production from the field, but not in the area of contamination, is from the Ozan Formation (Upper Cretaceous) and Cotton Valley Group (Jurassic). Also in the field but just west of the area of contamination, brine is produced commercially from the Smackover Formation (Jurassic).

Development of the south El Dorado field was rapid. During the days of early development, the tools and scientific principles used today for oil-reservoir management and conservation were not at hand. Peak production was reached within two years of discovery, after which production dropped by more than 50 percent by about 1925. The drop in oil production was accompanied by a large increase in the production of brine. The rapid increase in initial production resulted in a rapid decline of the hydraulic head in the Nacatoch. From a flowing head at the start of production, the head probably dropped to a level below the El Dorado aquifer by 1926. At the time of this study the fluid level in the Nacatoch was below the top of the formation in well 93 (table 2). This well is near the center of pumping from the El Dorado aquifer (pls. 9 and 10). This eliminates the Nacatoch Formation as a source of contamination to the El Dorado aquifer.

The oil wells in the south El Dorado field were drilled by the rotary method, except for some cable tool drilling in the producing interval. Most of the wells were constructed with 12 1/2-inch diameter iron surface casing, set, uncemented, to a depth of about 200 feet below land surface. Metal inner liners of 5 to 6 inches were then set to the top of Nacatoch. Some wells were completed as open holes, but most were completed with perforated pipe or screen. Within a one-half mile radius of the contaminated area about 85 oil wells have been completed in the Nacatoch. Most of them are abandoned and some are unplugged. Oil operators have been required to plug abandoned wells drilled since 1939 according to rules of the Arkansas Oil and Gas Commission.

EXTENT OF SALTWATER CONTAMINATION IN THE EL DORADO AQUIFER

The data show evidence of saltwater contamination in a small area in the southwest part of the city of El Dorado (pl. 11). Elsewhere in Union County a pattern of chloride concentration in the El Dorado aquifer is generally consistent with the pre-development direction of water movement and with the regional slope of the aquifer. The area affected by the contamination lies within the isochlors that are elongated to the northwest near El Dorado (pl. 11). The axis of elongation would pass through the refinery and the southwest corner of El Dorado. It is notable also that the axis of elongation is in perfect alignment with the graben.

Signs of increased chloride concentrations were first observed by personnel at the oil refinery in the southwest part of the city of El Dorado. An increase in the chloride content in well 52 was first observed in 1960. Since that date contamination has increased steadily. The magnitude of increase is shown by well 60, where samples taken in 1947 and 1982 had 36 mg/L and 650 mg/L chloride, respectively (table 6). Comparison of other long-term analyses of water wells shows chloride concentrations increasing from 36 to 63 mg/L (1945-82) in water from well 43 and from 43 to 85 mg/L (1955-82) in water from well 62.

It was recognized at the refinery that chloride concentrations in the water from certain wells varied with the length of the pumping period and the discharge rate. An example of chloride concentration relative to pumping time and rate from well 52 is illustrated in figure 7. Refinery personnel reported that after pumping had ceased for 2 to 3 months, chloride concentrations at well 52 had decreased significantly but were still greater than before pumping began. A test conducted during this study showed chloride concentration increasing from 100 to 130 mg/L in well 59 (table 6) after pumping 4 hours and 40 minutes at a constant pumping rate of about 700 gallons per minute. Another test showed chloride concentration increasing from 30 to 110 mg/L in well 56 after pumping 6 1/2 days at an average pumping rate of about 500 gallons per minute.

POTENTIAL SOURCES AND AVENUES OF SALTWATER CONTAMINATION IN THE EL DORADO AQUIFER

Brine in Surface Ponds

Millions of barrels of brine have been pumped from the Nacatoch Sand during the more than 60 years of oil development in the area of contamination. Most of this brine was discharged to the south-southeastward draining streams, namely Bayou de Loutre and its tributaries. Appreciable amounts of the brine were injected through wells back into the Nacatoch Sand for disposal and formation repressurization. Generally the brine has been held in surface ponds before going to streams or to injection wells. Brine in surface ponds leaking to the water table would contaminate the Cockfield Formation. A number of geologic and hydrologic factors control the path the brine takes in the Cockfield.

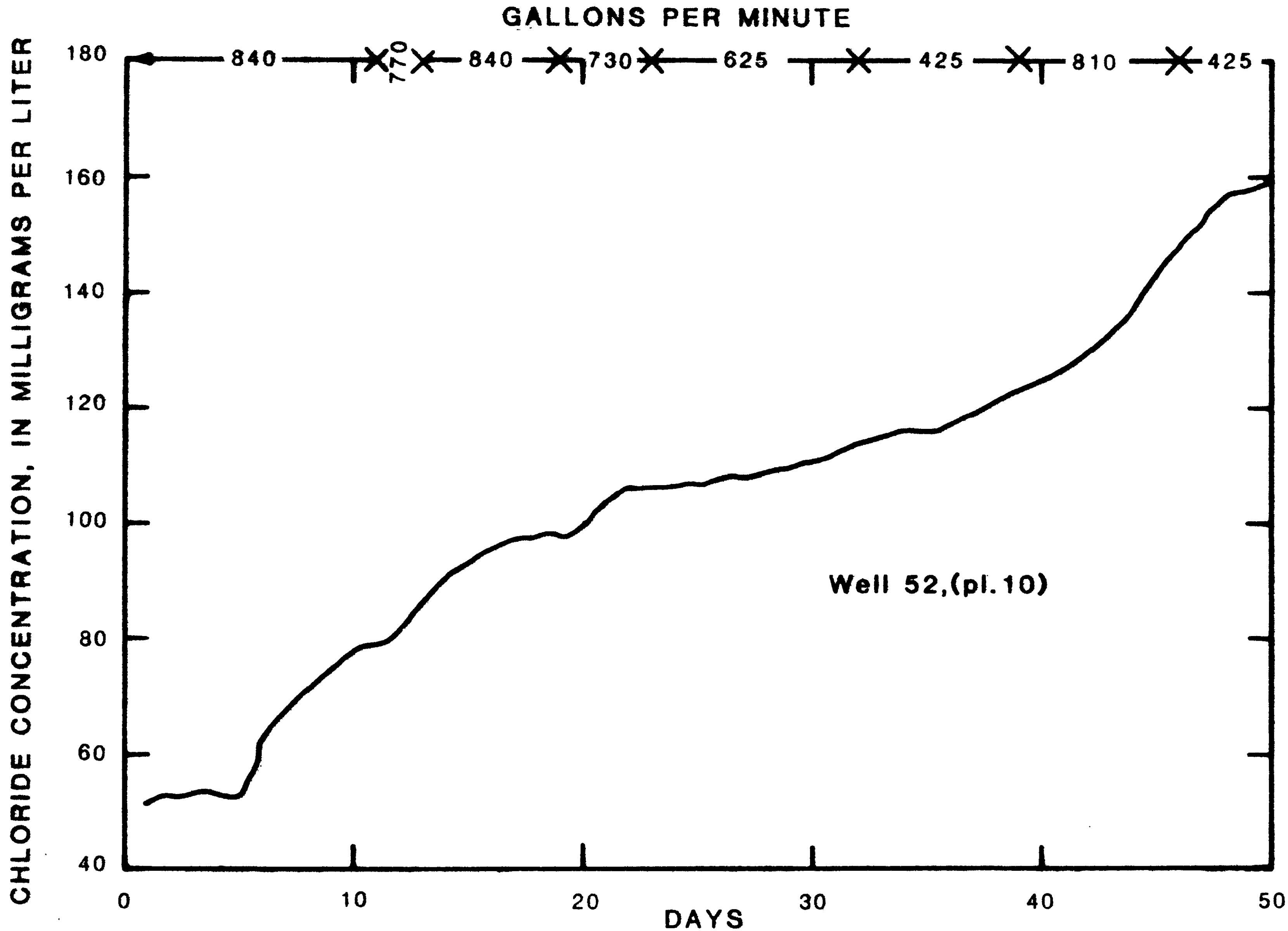

Figure 7.--Relation of chloide concentration to pumping rate and time.

As stated previously, the hydrologic regimen of the Cockfield has not been measurably stressed by water development. Today as in the past, any brine contaminant in the Cockfield from surface ponds would move in the direction of land slope. Land slope generally is south-southeast from the area of contamination in the El Dorado aquifer. Because of a large lateral component of water movement, enhanced by the high water table and locally by clay lenses in the formation, much of the contaminant would be discharged to streams rather than penetrating deeply into the Cockfield. However, the contaminant could be captured in water wells of the Cockfield in the path of the contaminant. In the absence of open bore holes and leaky wells, which would allow fluid communication between the Cockfield and deeper units, the Cook Mountain Formation would act as a hydrologic barrier to movement of the contaminant to units below the Cockfield Formation.

According to the hydrostatic heads indicated for the different units (fig. 8), the direction of flow would be from the Cockfield to any of the deeper units if avenues of flow were provided by wells. Thus, open bore holes and leaky wells could be plausible avenues of brine contamination from the surface ponds and contaminated areas of the Cockfield to the El Dorado and Greensand aquifers.

With one exception, the few water-quality data for the Cockfield Formation in the area of contamination of the the El Dorado aquifer show no evidence of brine contamination. The exception is in water from a well near the area of contamination where some brine contamination was noted by refinery personnel in 1982. The few water-quality data for the Greensand aquifer in the area of contamination show no evidence of brine contamination.

Saltwater-Bearing Units Below the El Dorado Aquifer

Natural and Developmental Factors

All units deeper than the El Dorado aquifer in Union County yield saltwater or brine. Under natural controls, fluid movement between Cretaceous and Tertiary units is prevented by the confining Midway Group; likewise, fluid movement between the Wilcox Group and the El Dorado aquifer is prevented by the Cane River Formation. The hydrostatic head differences between the Nacatoch Sand, the Wilcox Group, and the El Dorado aquifer are evidence that the confining beds are highly effective in preventing fluid mixing (fig. 8). Apparently then, with the exception of fractures related to faulting, the only plausible means of mixing between the El Dorado aquifer and the underlying saltwater-bearing units is through "leaky" wells. Leaky wells can result from inappropriate methods and mater'ıls used during construction of the wells and from deterioration of casings and liners. However, deterioration of casings and liners will not necessarily lead to the mixing of fluids between discrete aquifers. Residual drilling-mud cake and natural clay bridges in the annular space between the hole wall and casings (or liners) can be effective in preventing fluid mixing between the units penetrated by the well.

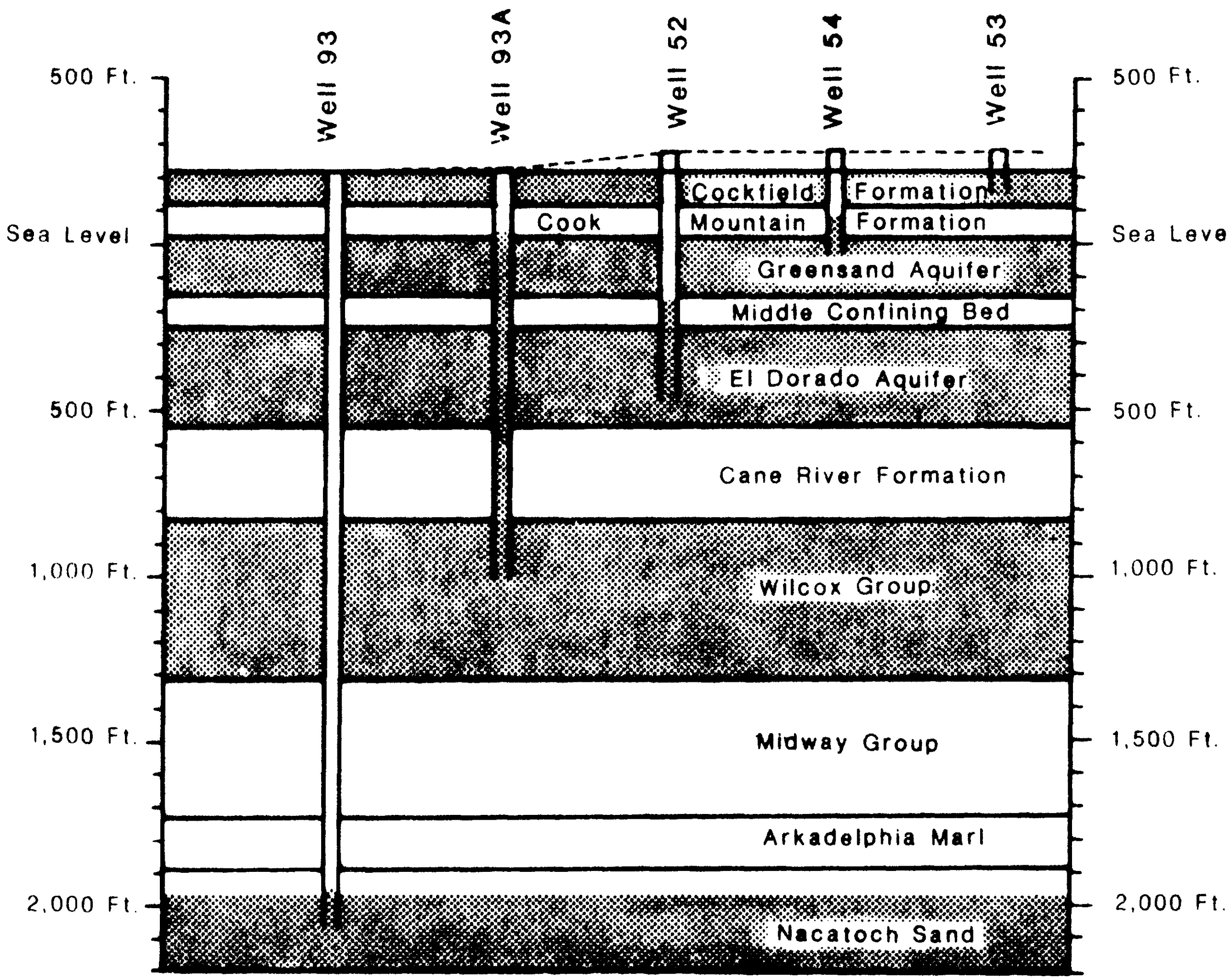

Figure 8.--Relation of water levels in wells in different units near El Dorado in 1982.

Nearly all of the oil wells in the area of contamination produce from the Nacatoch Sand. According to data on hydrostatic heads in the Nacatoch and all overlying units (fig. 8), a nonpumping or abandoned Nacatoch well at the present time could not leak brine to the El Dorado aquifer nor to any of the other freshwater units. However, the El Dorado aquifer and any of the other freshwater-bearing units plus the saltwater-bearing Wilcox Group might leak water to the Nacatoch. An abandoned or non-pumping well in the Nacatoch plugged only between the Nacatoch and the Wilcox, could leak saltwater from the Wilcox to the El Dorado or Greensand aquifers. Wells in the El Dorado aquifer with inadequate or deteriorated casing might receive leakage from the Greensand aquifer, the Cockfield Formation, and from the surface.

Geochemical Analysis

Water samples were collected in 1982 for detailed analysis from wells in the vicinity of El Dorado that produced from the El Dorado aquifer. Some of the samples reflect saltwater contamination. Samples were also collected from wells in deeper saltwater-bearing units that were considered possible sources of the contamination in the El Dorado aquifer. The deeper units sampled were the Wilcox Group, Nacatoch Sand, Cotton Valley Group, and the Smackover Formation.

The purpose of the analyses was to characterize the water from the different units and then, by geochemical methods, to determine whether a mixture of the uncontaminated water from the El Dorado aquifer and water from the possible contaminating unit was similar to a sample of heavily contaminated water from the El Dorado aquifer. In this way one or more units might be identified as a probable source or sources of contamination. Alternatively, a unit could be eliminated as a probable source.

Plotting concentrations of selected constituents against chloride found in the different samples of water is a convenient method of comparing waters on the basis of geochemistry. Bromide and iodide versus chloride plots are shown in figure 9. The bromide-chloride (Br-Cl) relation is about the same in all samples, as indicated by their straight-line plot. Using this relation, any of the deeper units could be the source of the saltwater in the El Dorado aquifer. Similarly, because of the straight-line nature of the plot of the iodide-chloride concentrations (I-Cl), any of the deeper formations could be the source for the contamination in the El Dorado aquifer, except perhaps the Smackover Formation which plots significantly below the straight-line plot of the other deep formations. Water from the Smackover is relatively dilute in iodine and probably could not form a contaminated water with the I-Cl ratio found in the contaminated water from the El Dorado aquifer.

The boron versus chloride plot is shown in figure 10. This straight-line plot indicates that the heavily contaminated El Dorado aquifer water continues the trend of fresh and only slightly contaminated El Dorado aquifer water. This trend is distinctly different from the trend found for the deeper, more saline waters, and indicates that the source of the contaminating water is from the El Dorado aquifer. Lithium and ammonia versus chloride plots (fig. 10) are less definitive, but show a similar trend.

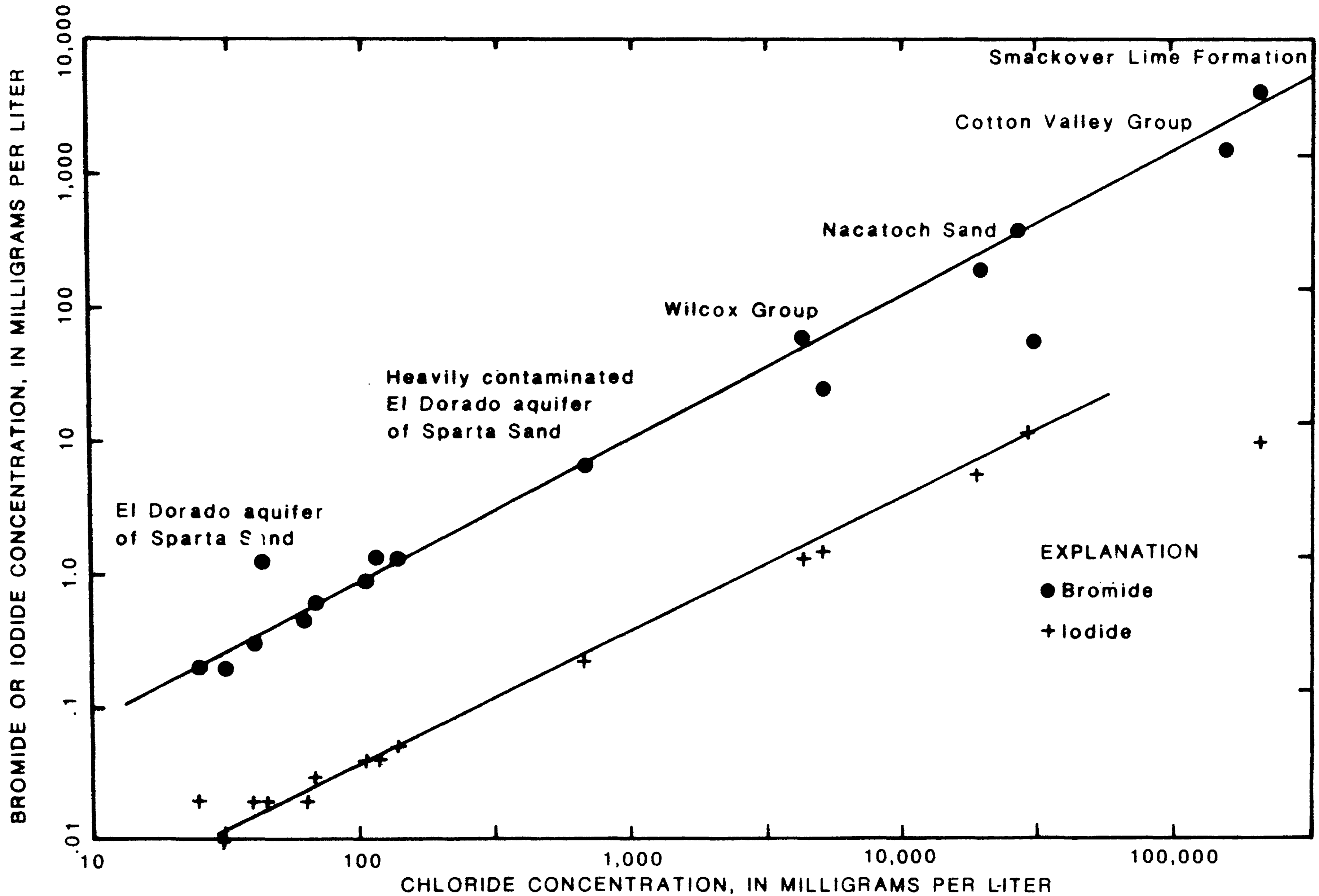

Figure 9.--Bromide versus chloride and iodide versus chloride in waters from different units near Union County, Arkansas.

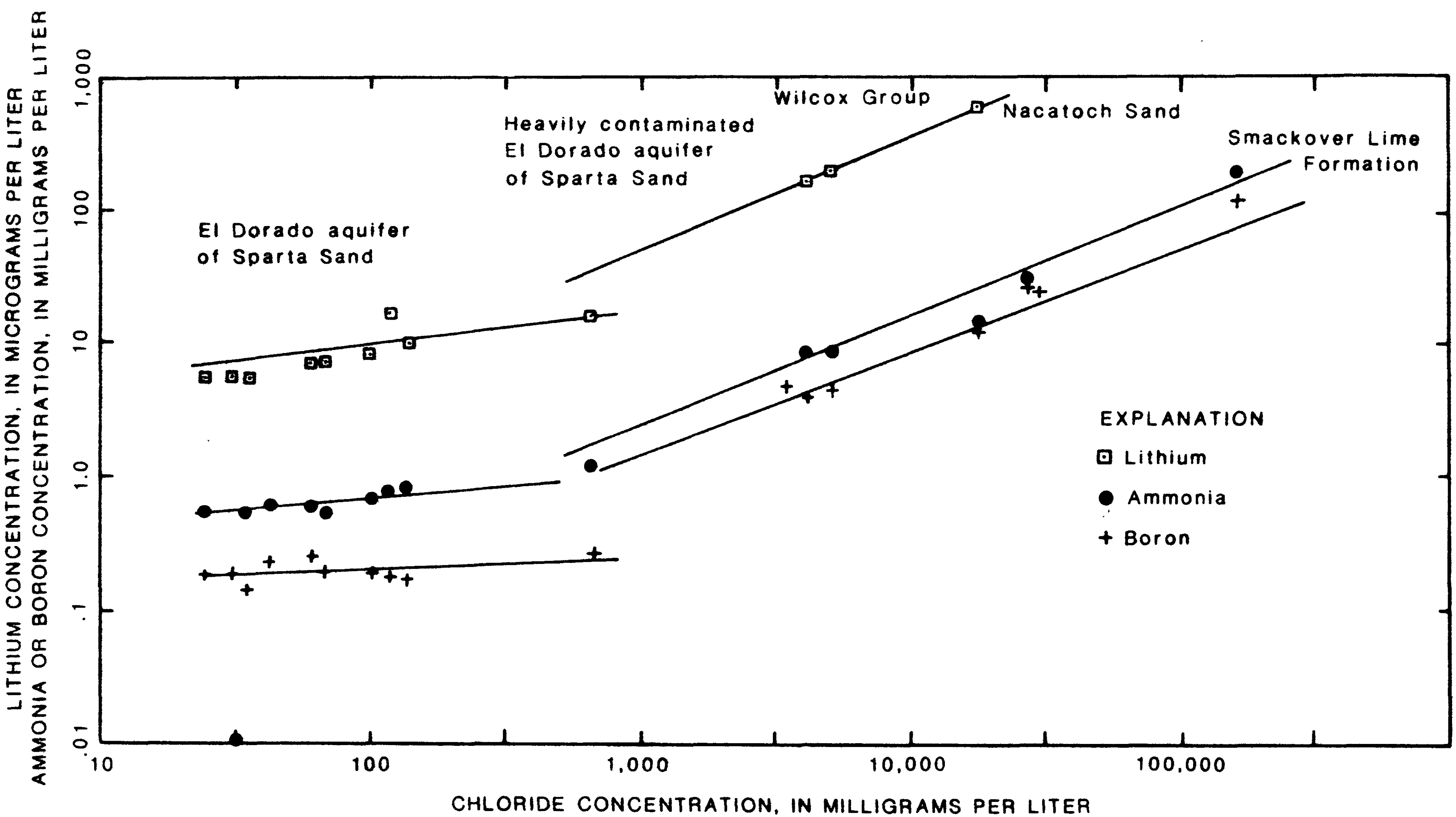

Figure 10.--Lithium versus chloride, ammonia versus chloride, and boron versus chloride in waters from different units near Union County, Arkansas.

A calcium versus chloride plot is shown in figure 11. The calcium-chloride (Ca-Cl) data show the same trends as boron, lithium and ammonia, further supporting the concept of the contamination coming from the El Dorado aquifer. Although the El Dorado points could be considered on a trend with the Wilcox points in figure 11, it is unlikely the Wilcox is the source of contamination because the heavily contaminated sample from the aquifer does not fit well on this trend line. This would imply dissolution of calcite. However, the heavily contaminated water from the El Dorado aquifer is supersaturated with calcite indicating dissolution will not occur. Additionally, a source of calcite in the El Dorado aquifer is unlikely.

The only chemical evidence of fluid communication between units near the area of contamination was in water from well 94 (table 3), an oil well producing from the Nacatoch Sand. The water from well 94 is much less saline than water from the Nacatoch from nearby wells 50, 51 and 93. However, the water from well 94 is very similar to water from the Wilcox (well 93A) in both dissolved-solids concentration and in specific chemical characteristics, including anomalously high calcium content. In addition, well 94 water has nearly the same degree of calcite supersaturation as the water from well 93A.

El Dorado Aquifer in the Graben

Geologic, hydrologic, and chemical data consistently support the concept that the El Dorado aquifer within the graben is the principal source of the saltwater contamination in the El Dorado aquifer near El Dorado. The vertical displacement of the units in the graben has partially isolated the El Dorado aquifer within the graben. Along the fault planes of the graben the El Dorado is partially bounded by the Cane River Formation, previously described as a confining unit (pls. 2, 3, and 4). In the graben the aquifer is confined vertically by the Cane River below and the middle confining bed of the Sparta Sand above. Thus, natural movement and replenishment of water in the El Dorado aquifer in the graben, particularly near the base, has been severely restricted for millions of years.

As previously mentioned, the salinity of the water in the El Dorado determined by electrical logs of two wells may be as high as 2,500 mg/L chloride equivalents. Further support for the estimate of the high salinity water in the El Dorado aquifer in the graben is the pattern of isochlors for the aquifer (pl. 11). The northwest elongation of the isochlors near El Dorado is particularly interesting. The axis of the elongation passes through the area of saltwater contamination near El Dorado and is perfectly aligned with the axis of the graben. The isochlor patterns further suggest relatively unrestricted flow in the aquifer north of the graben, and relatively restricted flow to the south.

Conceptualizing further, the pre-development slope of the potentiometric surface of the El Dorado aquifer and the dip direction of the aquifer, both south-southeast, served to contain the saline water in the graben. But with development of the aquifer near El Dorado and the resultant water declines, the hydraulic gradient at the graben was reversed. This local reversal of the gradient allows water to move updip within the graben to wells near El Dorado. The exact path of flow to the wells may be somewhat circuitous because of irregularities in aquifer properties and aquifer geometry. Further, pumping rates and pumping schedules of the wells near El Dorado probably are additional factors controlling the flow of water from the graben.

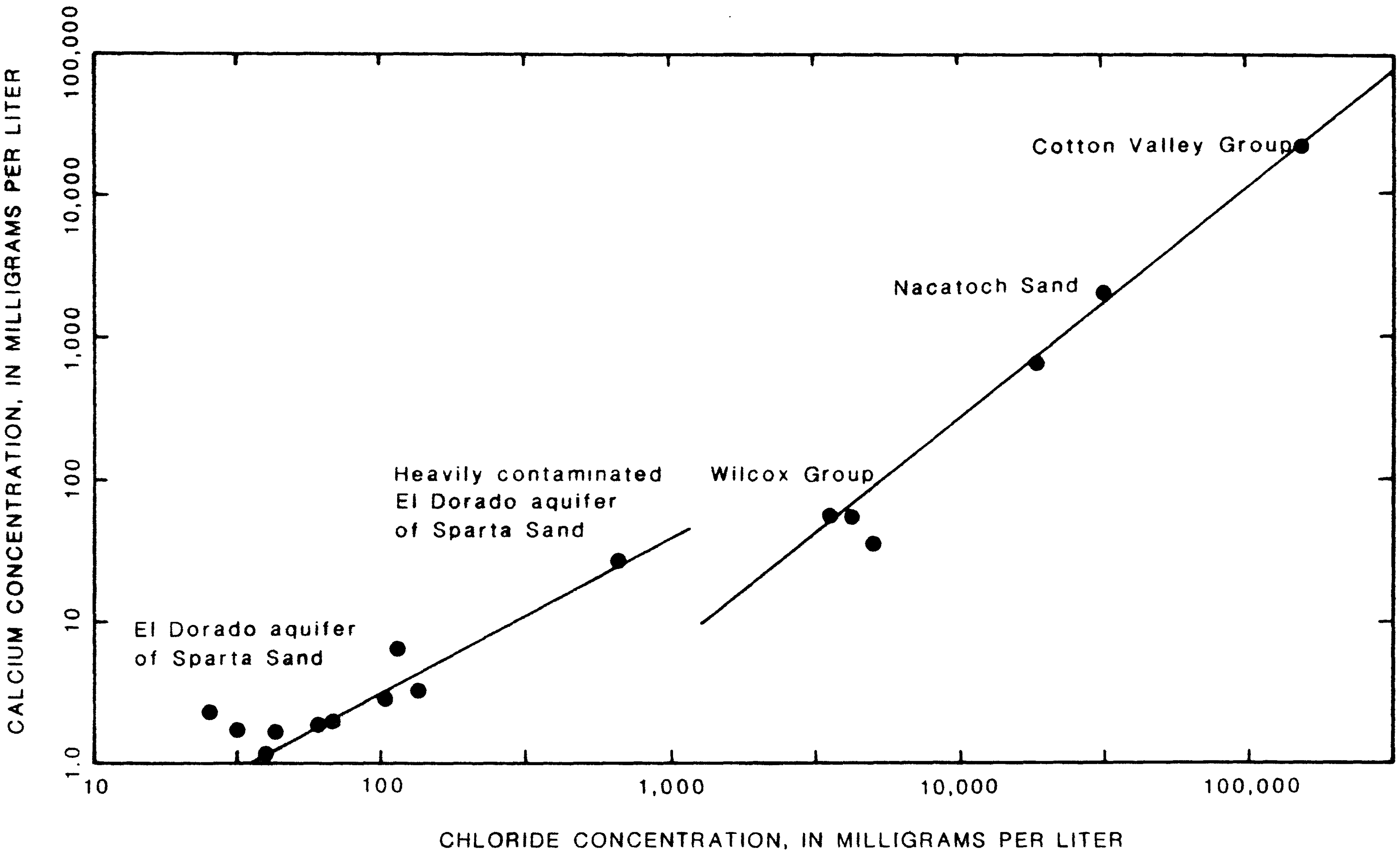

Figure 11.--Calcium versus chloride in water from different units near Union County, Arkansas.

CONCLUSIONS

The El Dorado aquifer, in the lower part of the Sparta Sand, has been the major water supply in the study area for more than 60 years. Heavy withdrawals have lowered the water level more than 300 feet and changed the direction of water movement from east-southeast to the center of pumping at El Dorado. A steadily increasing chloride concentration in some wells in the El Dorado aquifer in the southwest part of the city has caused the water to be unfit for some industrial uses. With any substantial increase in current withdrawals and no redistribution of wells in the vicinity of El Dorado, the potentiometric surface will lower below the top of the aquifer and well yields and water quality will decline.

Data indicate little, if any, fluid communication between the El Dorado aquifer and units that overlie or underlie the aquifer. Several of the units underlying the El Dorado aquifer in the area of contamination contain saltwater. However, geochemical characteristics of water in these units make them unlikely sources of the contaminant. The units include the Wilcox Group, the Nacatoch Sand, the Cotton Valley Group, and the Smackover Formation. The Nacatoch Sand, is further ruled out (at least in the last 60 years) on the basis of its low hydrostatic head relative to the hydrostatic head of the El Dorado aquifer.

Geologic, hydrologic and chemical data all point to the conclusion that the principal source of the saltwater contamination is from that part of the El Dorado aquifer that lies in the graben. The graben trends southeast and downdip from El Dorado. The alignment of the graben allows an unobstructed avenue for flow between the graben and the area of contamination. Before development of the El Dorado aquifer as the major water source, the direction of flow in the aquifer was southeast toward the inlet of the graben. Natural dynamics of the flow tended to trap the saltwater in the graben. The large water-level declines associated with withdrawals from the aquifer near El Dorado, caused the direction of flow to change locally from southeast to northwest, so that saltwater now flows from the graben toward the center of pumping.

The lack of data precludes an accurate determination of the magnitude of the saltwater flow from the graben. However, the rate of flow is large enough to cause ever-increasing contamination if plans for future use and development of the El Dorado aquifer do not reckon with this problem. Basically, the solution is to reduce the hydraulic gradient between the contaminant source area and the center of present withdrawals near El Dorado. Theoretically, there are a number of ways to do this but probably the most feasible way would be to gradually redistribute wells to areas away from the present center of heavy withdrawals. With carefully selected sites and appropriate spacing of new wells with respect to the source and avenues of the saltwater contamination, the El Dorado aquifer can meet future needs in Union County with water uncontaminated by salt.

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UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
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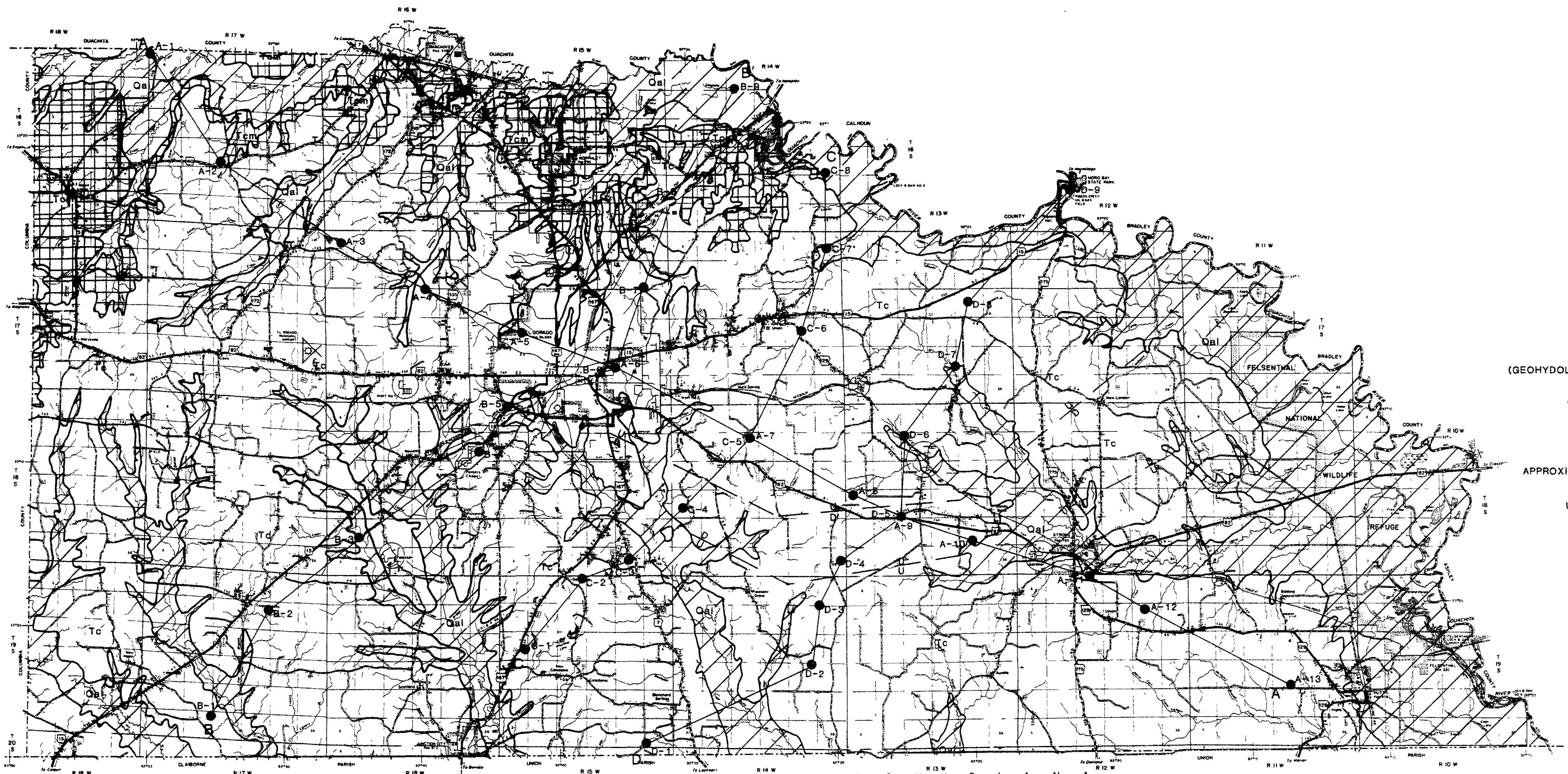
AND THE ARKANSAS DEPARTMENT OF POLLUTION CONTROL AND ECOLOGY

WATER RESOURCES INVESTIGATIONS REPORT 84-4012
PLATE 1



Arkansas State Highway and Transportation Department county base map 1976

EXPLANATION

Qal — ALLUVIUM
Gravel, sand, silt and clay — HOLOCENE AND PLEISTOCENE

Tc — COCKFIELD FORMATION
Sand, silt, clay and lignite

Tcm — COOK MOUNTAIN FORMATION
Clay, silt and some sand

CLAIBORNE GROUP — EOCENE

CONTACT

A-11 — A-12 — A-13
TRACE OF GEOHYDROLOGIC SECTION
(GEOHYDOLOGIC SECTIONS SHOWN ON PLATES 2, 3, 4 AND 5)

Geology modified from Hosman (1982)

U / D
APPROXIMATE SURFACE TRACE OF FAULT ZONE, INFERRED FROM ELECTRICAL LOG INTERPRETATION
U, UPTHROWN SIDE:D, DOWNTHROWN SIDE.

1 0 1 2 3 4 MILES
1 0 1 2 3 4 5 6 KILOMETERS

GEOLOGIC MAP OF UNION COUNTY, ARKANSAS.

NITED STATES DEPARTMENT OF THE INTERIOR
EOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
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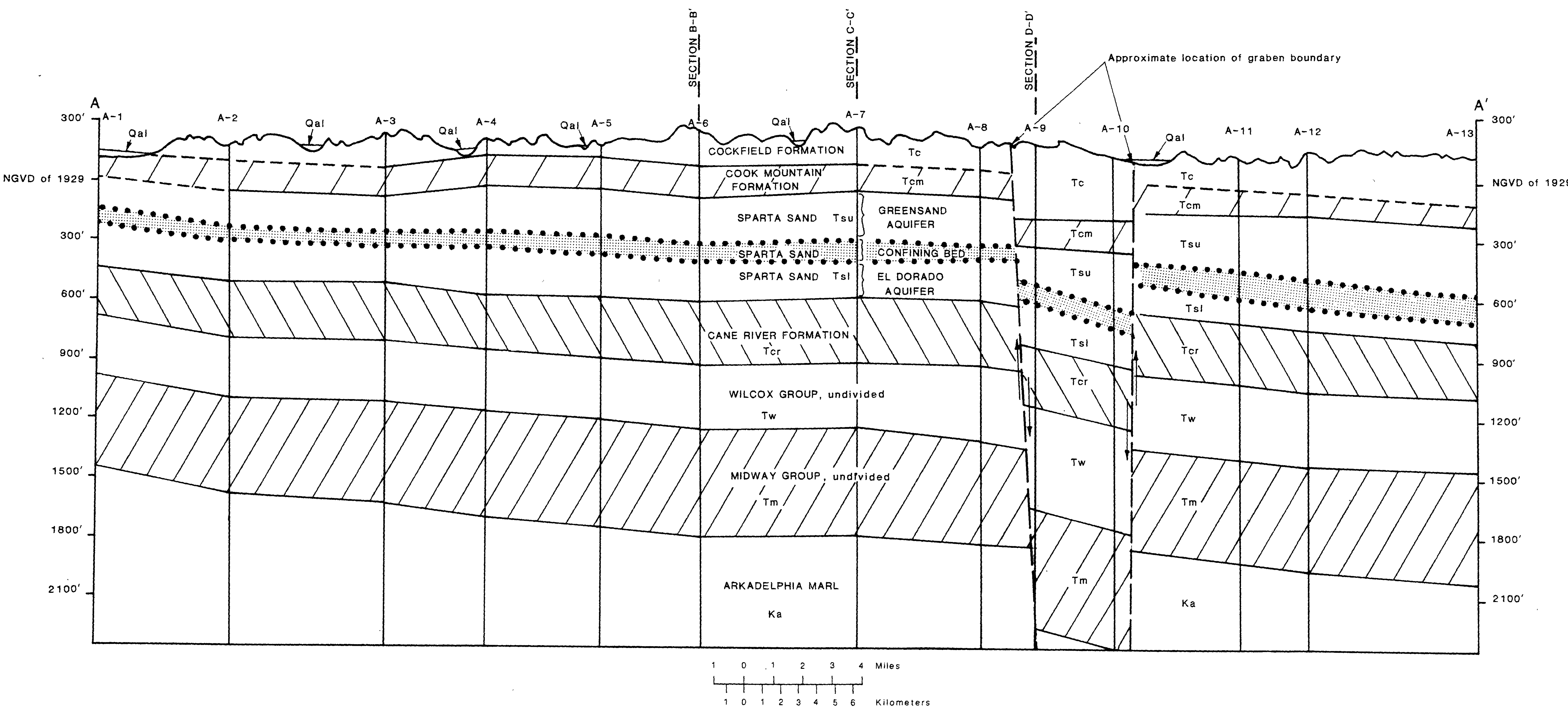
WATER RESOURCES INVESTIGATIONS REPORT 84-401
PLATE 2



VERTICAL EXAGGERATION X35

NGVD IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

GEOLOGIC SECTION A, UNION COUNTY, ARKANSAS

PREPARED IN COOPERATION WITH
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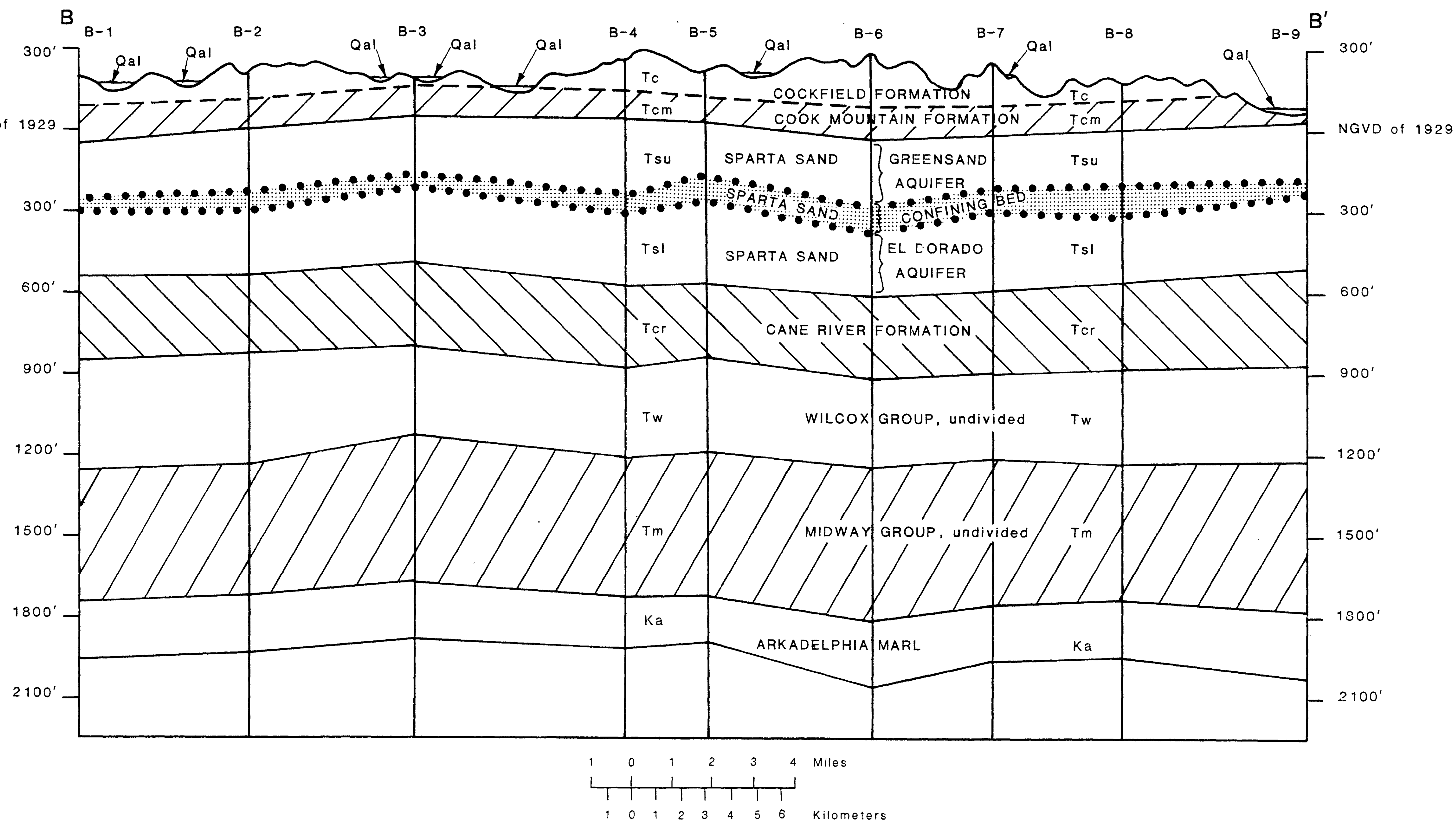

VERTICAL EXAGGERATION X35

NGVD IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

GEOLOGIC SECTION B, UNION COUNTY, ARKANSAS

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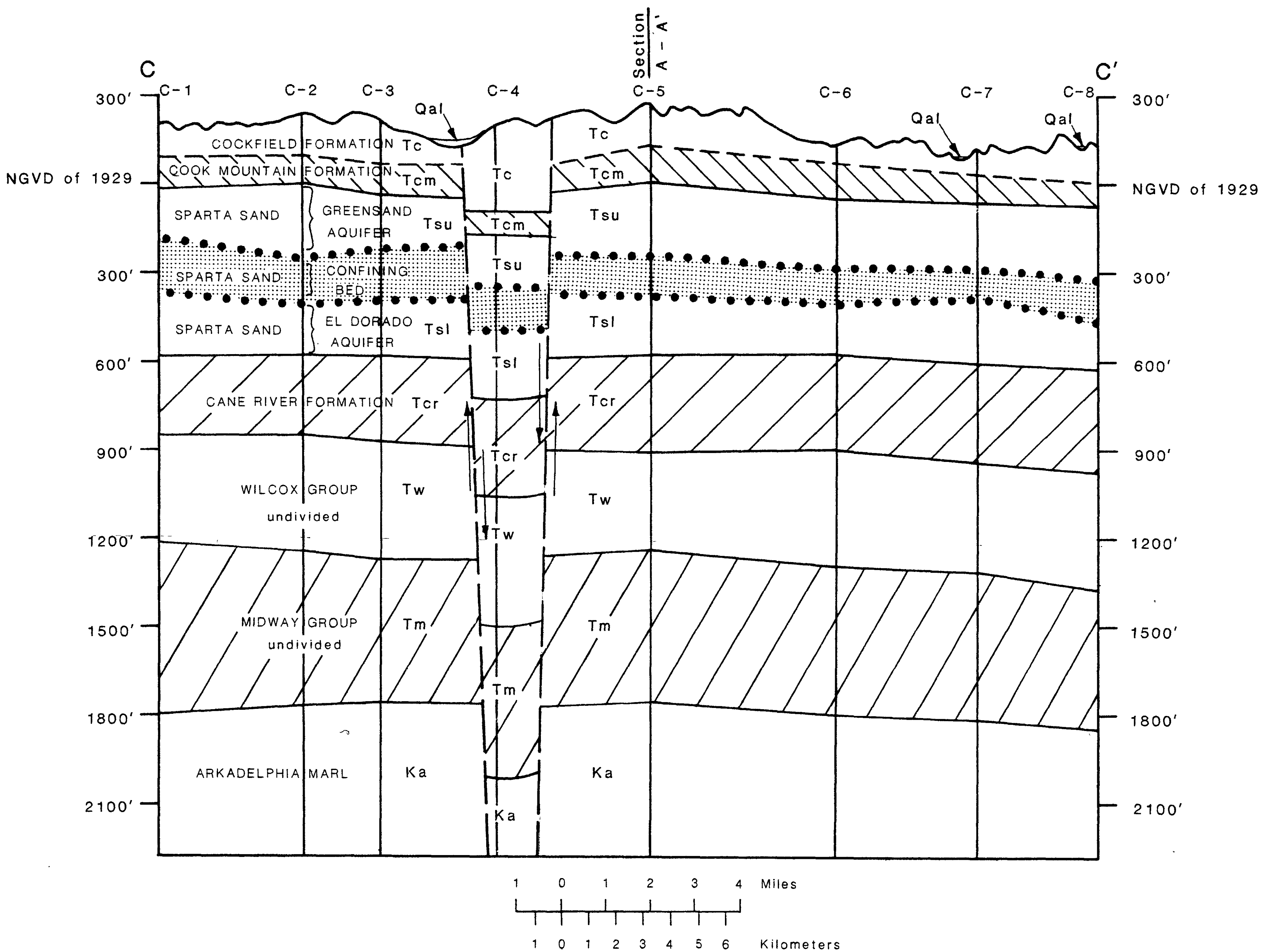
WATER RESOURCES INVESTIGATIONS REPORT 84-4012
PLATE 4



VERTICAL EXAGGERATION X35

NGVD IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

GEOLOGIC SECTION C, UNION COUNTY, ARKANSAS

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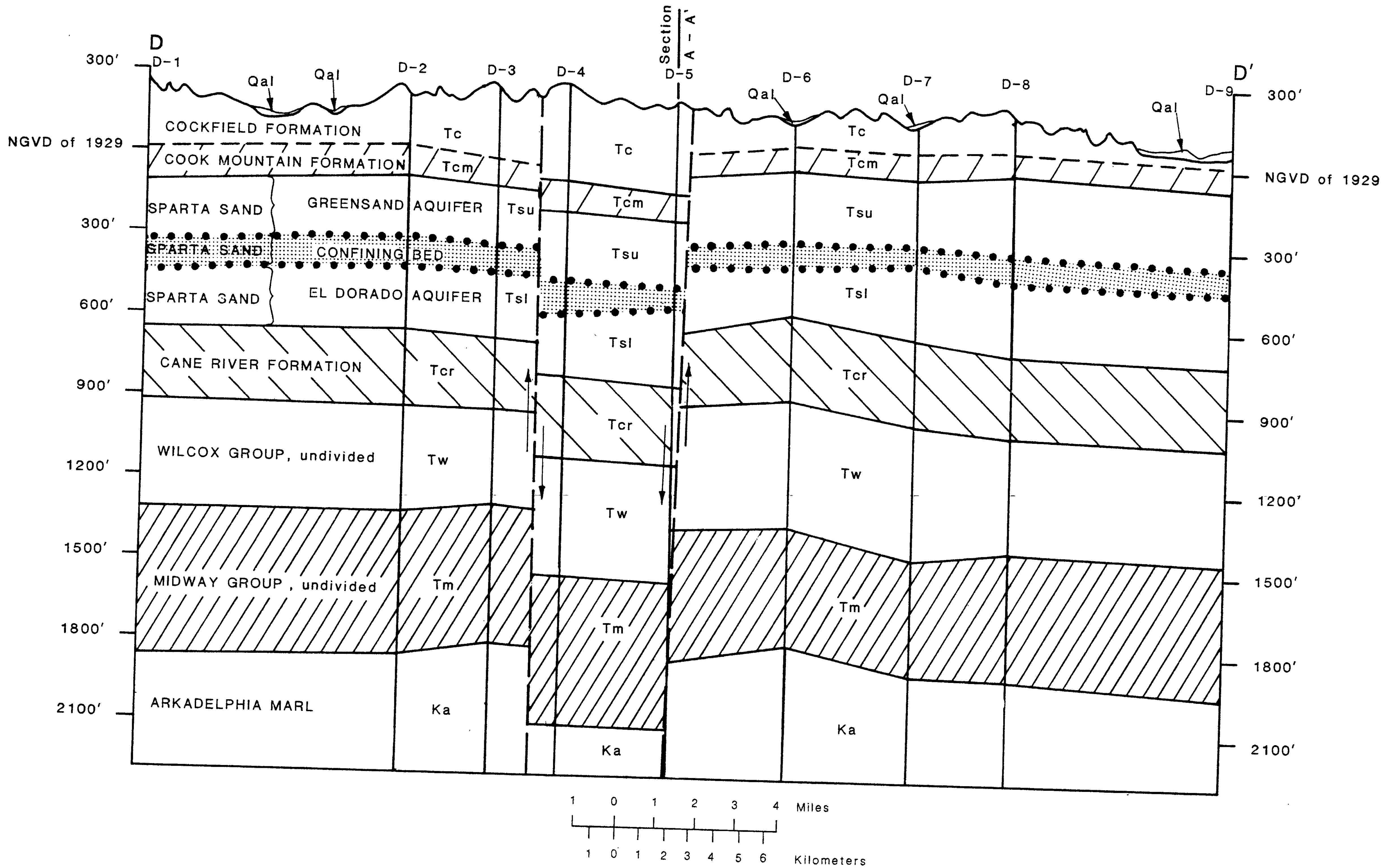

VERTICAL EXAGGERATION X35

NGVD IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

GEOLOGIC SECTION D, UNION COUNTY, ARKANSAS

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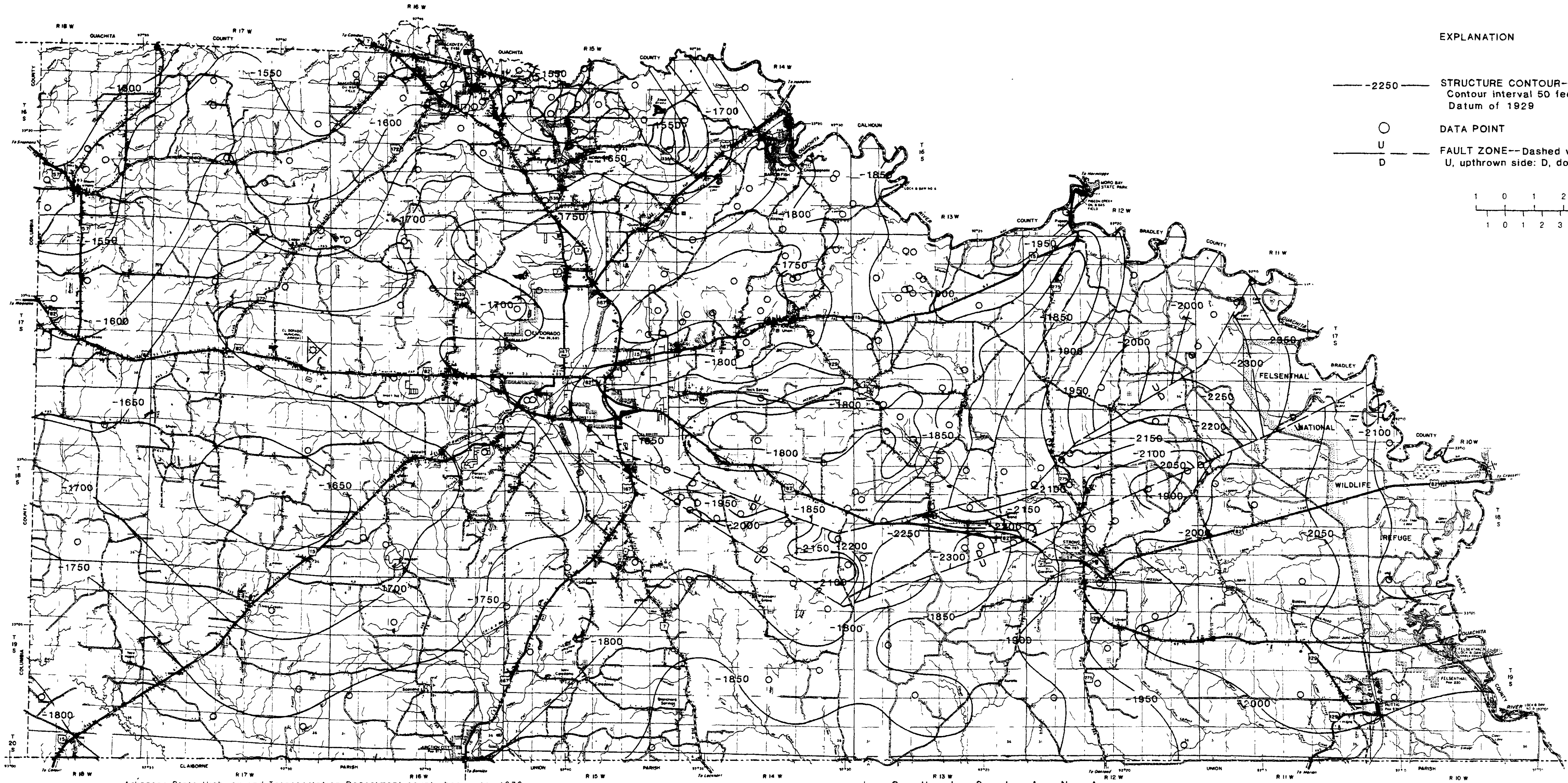

Arkansas State Highway and Transportation Department county base map, 1976

EXPLANATION

——-2250—— STRUCTURE CONTOUR-- Shows altitude of top of Arkadelphia Marl. Contour interval 50 feet. Datum is National Geodetic Vertical Datum of 1929

○ DATA POINT

——U/D— — — FAULT ZONE--Dashed where approximately located. U, upthrown side: D, downthrown side.

1	0	1	2	3	4			MILES
1	0	1	2	3	4	5	6	KILOMETERS

STRUCTURE OF TOP OF ARKADELPHIA MARL, UNION COUNTY, ARKANSAS.

PREPARED IN COOPERATION WITH
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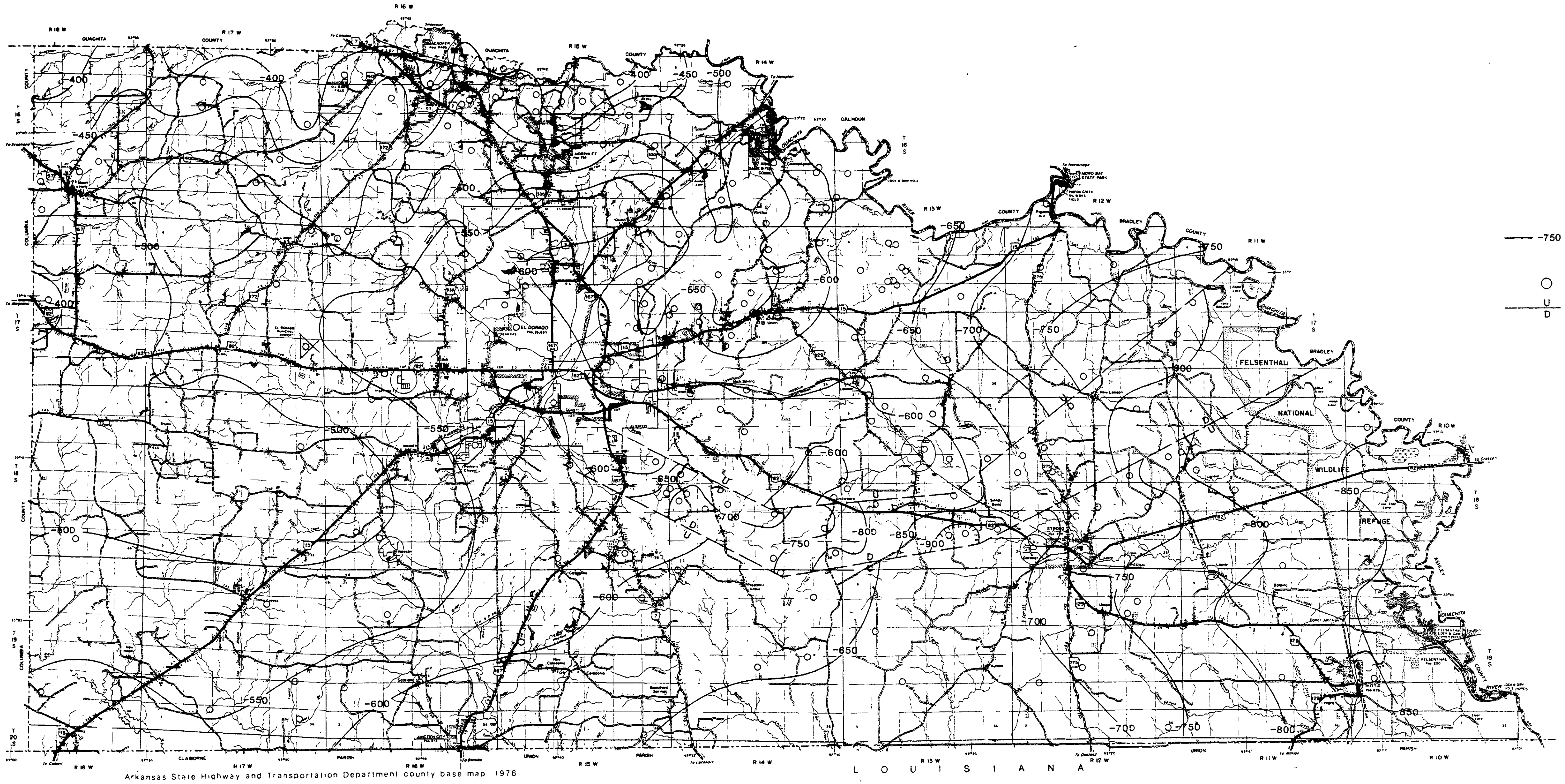

EXPLANATION

—— -750 —— STRUCTURE CONTOUR-- Shows altitude of top of Cane River Formation. Contour interval 50 feet. Datum is National Geodetic Vertical Datum of 1929.

○ DATA POINT

U/D — — FAULT ZONE-- Dashed where approximately located. U, upthrown side; D, downthrown side.

1 0 1 2 3 4 MILES

1 0 1 2 3 4 5 6 KILOMETERS

STRUCTURE OF TOP OF CANE RIVER FORMATION, UNION COUNTY, ARKANSAS.

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WATER RESOURCES INVESTIGATIONS REPORT 84-4012
PLATE 8

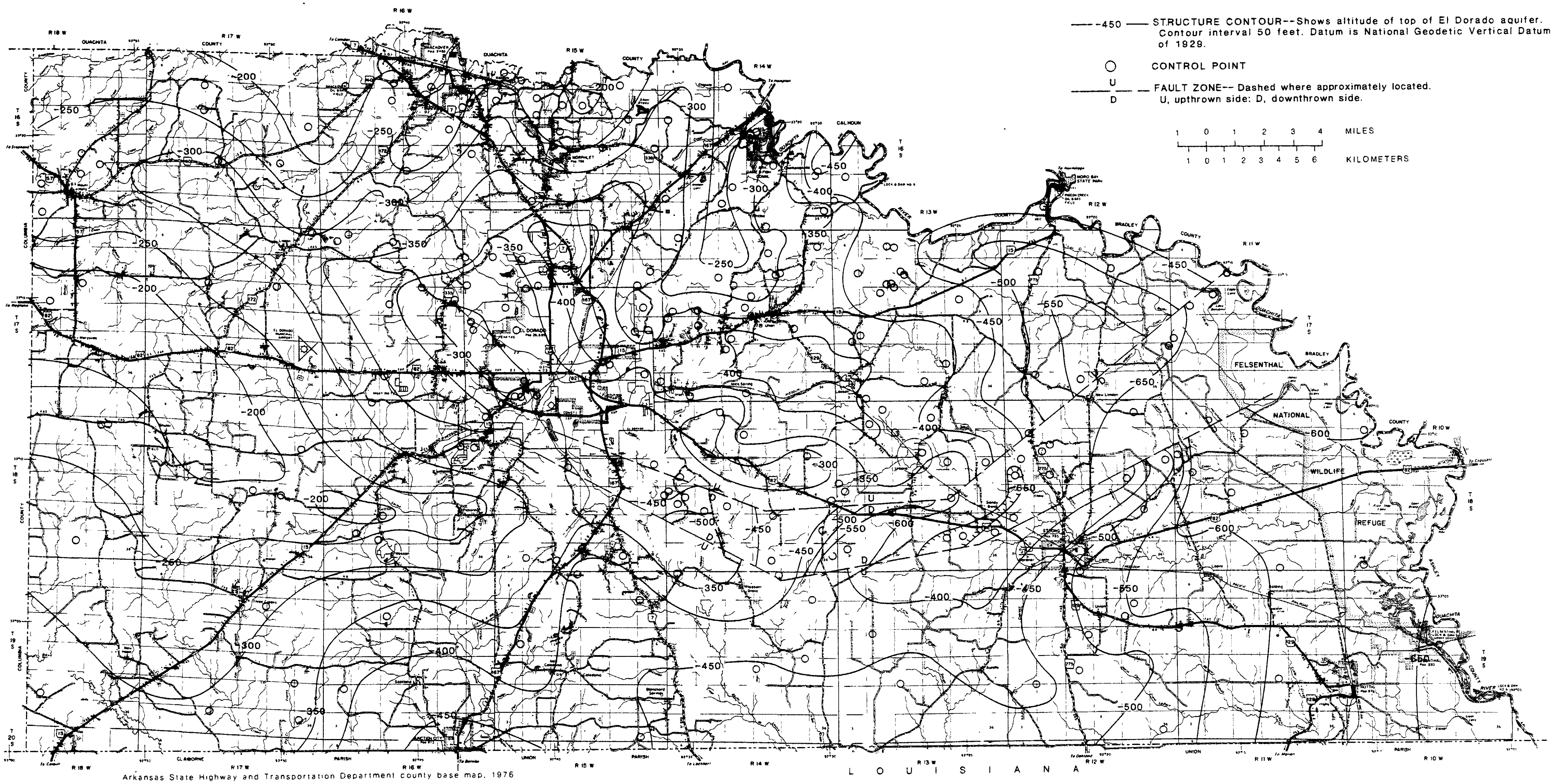
EXPLANATION

—— -450 —— STRUCTURE CONTOUR--Shows altitude of top of El Dorado aquifer. Contour interval 50 feet. Datum is National Geodetic Vertical Datum of 1929.

○ CONTROL POINT

U/D — — FAULT ZONE-- Dashed where approximately located. U, upthrown side; D, downthrown side.

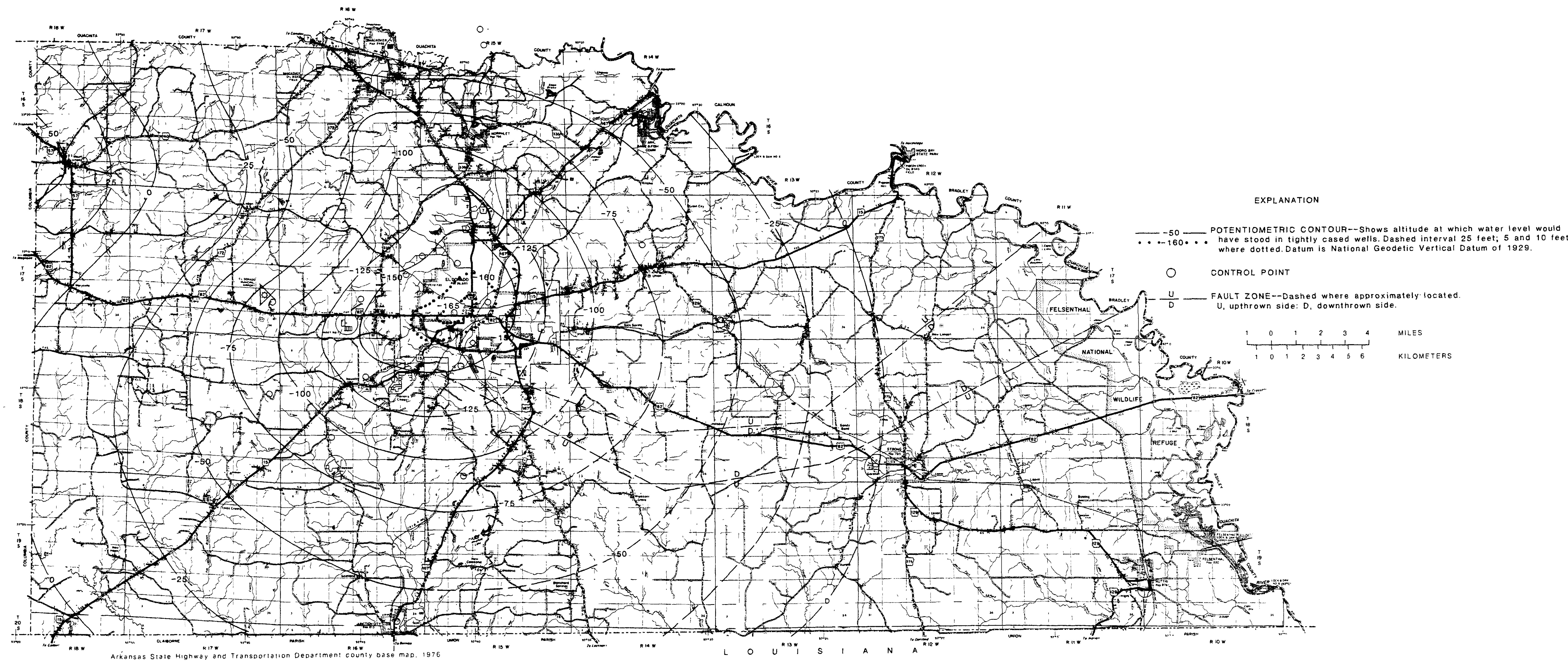
Scale: 0–4 MILES; 0–6 KILOMETERS



Arkansas State Highway and Transportation Department county base map, 1976

STRUCTURE OF TOP OF EL DORADO AQUIFER, UNION COUNTY, ARKANSAS.

PREPARED IN COOPERATION WITH
THE ARKANSAS GEOLOGICAL COMMISSION
AND THE ARKANSAS DEPARTMENT OF POLLUTION CONTROL AND ECOLOGY

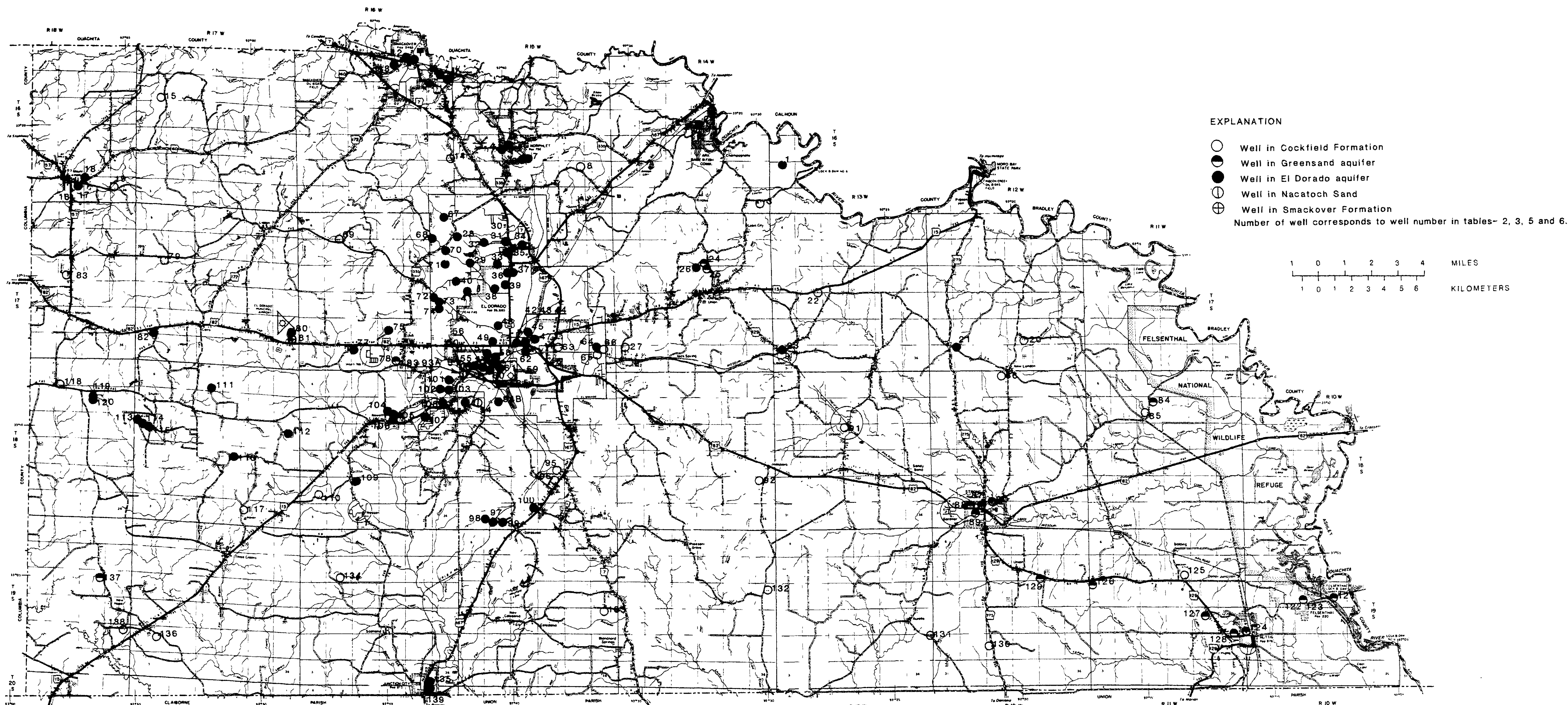


POTENTIOMETRIC SURFACE OF THE EL DORADO AQUIFER, UNION COUNTY, ARKANSAS, 1982.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
THE ARKANSAS GEOLOGICAL COMMISSION
AND THE ARKANSAS DEPARTMENT OF POLLUTION CONTROL AND ECOLOGY

WATER RESOURCES INVESTIGATIONS REPORT 84-4012
PLATE 10



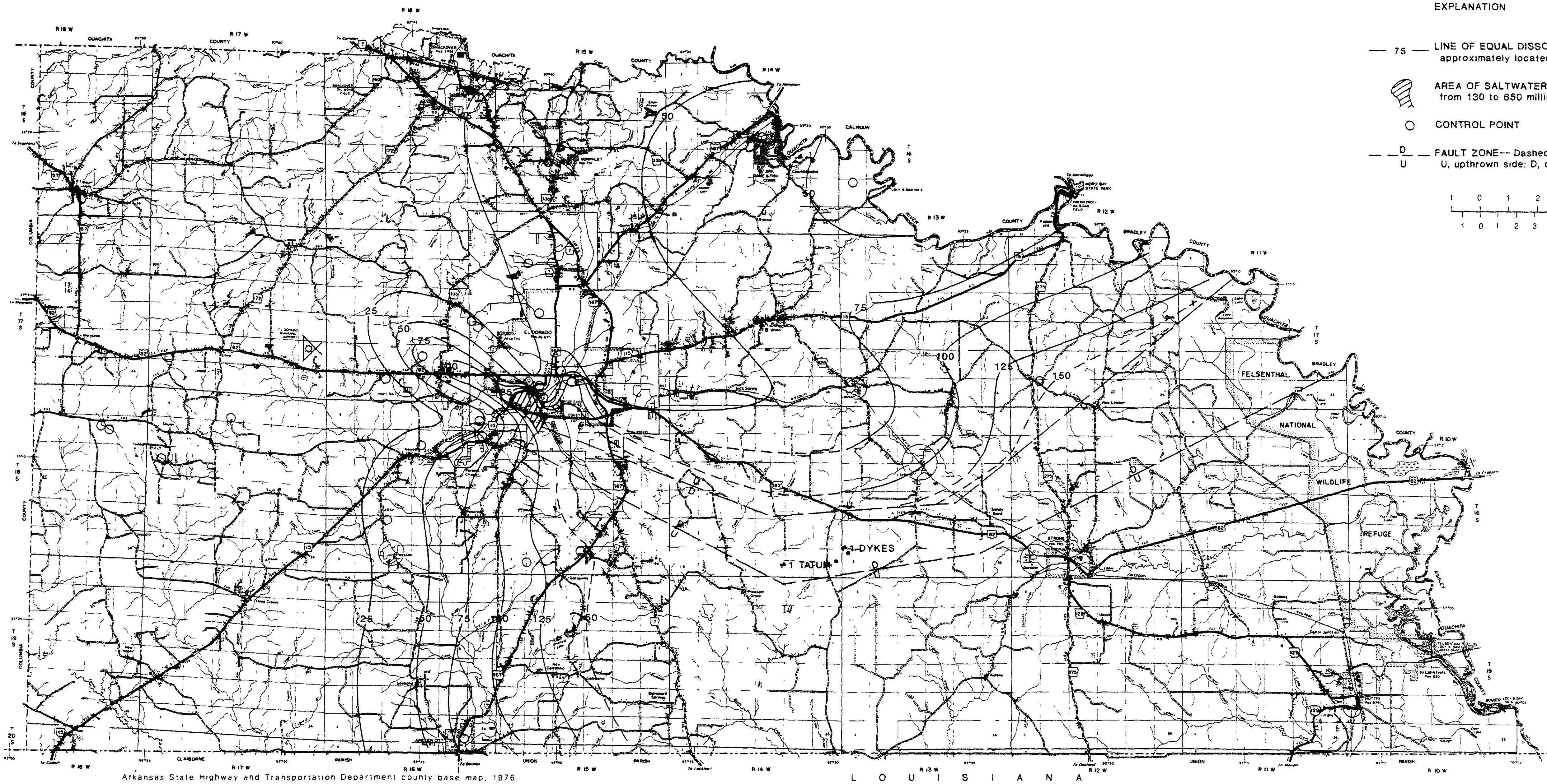
Arkansas State Highway and Transportation Department county base map. 1976

LOCATION OF SELECTED WELLS IN UNION COUNTY, ARKANSAS.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
THE ARKANSAS GEOLOGICAL COMMISSION
AND THE ARKANSAS DEPARTMENT OF POLLUTION CONTROL AND ECOLOGY

WATER RESOURCES INVESTIGATIONS REPORT 84-4012
PLATE 11



Arkansas State Highway and Transportation Department county base map, 1976

EXPLANATION

— 75 — LINE OF EQUAL DISSOLVED CHLORIDE CONCENTRATION-- Dashed where approximately located. Interval 25 milligrams per liter.

AREA OF SALTWATER CONTAMINATION-- Chloride concentrations range from 130 to 650 milligrams per liter under controlled pumping rates.

○ CONTROL POINT

— —D/U— — FAULT ZONE-- Dashed where approximately located. U, upthrown side; D, downthrown side.

Scale: 0 1 2 3 4 MILES; 0 1 2 3 4 5 6 KILOMETERS

CHLORIDE CONCENTRATIONS IN WATER FROM THE EL DORADO AQUIFER, UNION COUNTY, ARKANSAS, 1982.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
THE ARKANSAS GEOLOGICAL COMMISSION
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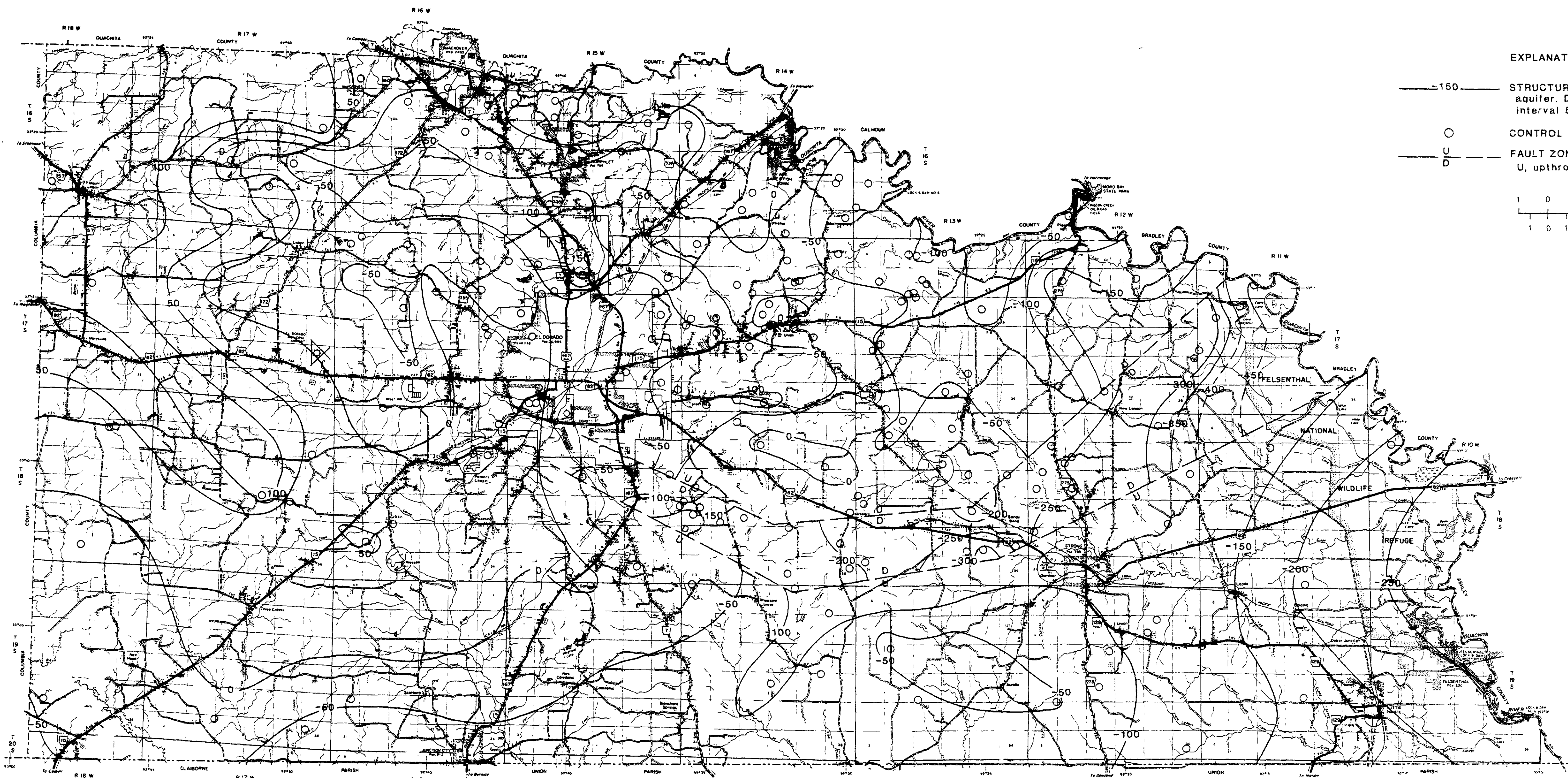
WATER RESOURCES INVESTIGATIONS REPORT 84-4012
PLATE 12



Arkansas State Highway and Transportation Department county base map, 1976

L O U I S I A N A

EXPLANATION

—150— STRUCTURE CONTOUR--Shows altitude of top of Greensand aquifer. Dashed where approximately located. Contour interval 50 feet. Datum is National Geodetic Vertical Datum of 1929.

○ CONTROL POINT

U/D — — FAULT ZONE--Dashed where approximately located. U, upthrown side; D, downthrown side.

1 0 1 2 3 4 MILES

1 0 1 2 3 4 5 6 KILOMETERS

STRUCTURE OF TOP OF GREENSAND AQUIFER, UNION COUNTY, ARKANSAS.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
THE ARKANSAS GEOLOGICAL COMMISSION
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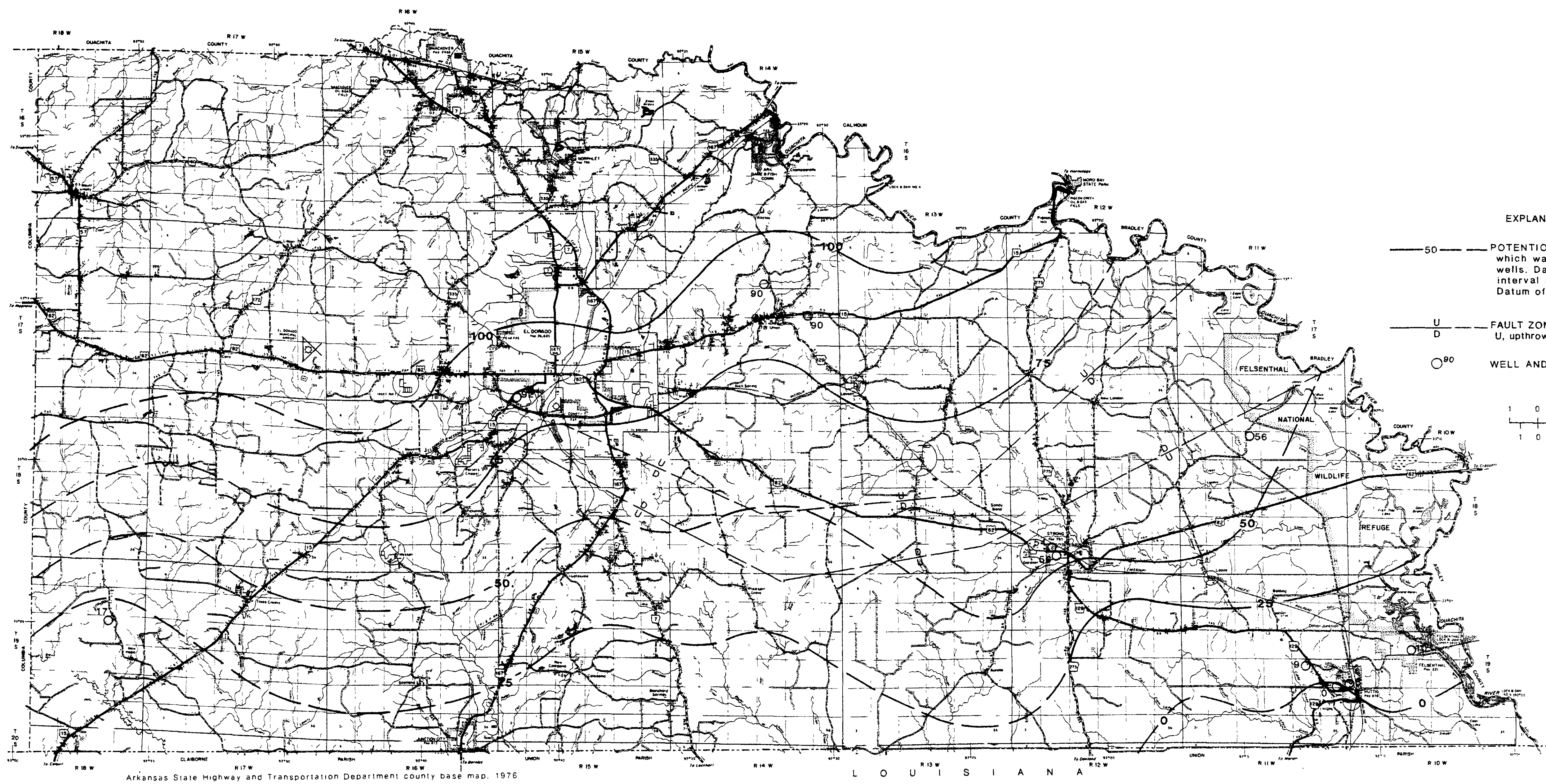
WATER RESOURCES INVESTIGATIONS REPORT 84-4012
PLATE 13



EXPLANATION

——50—— —— POTENTIOMETRIC CONTOUR-- Shows altitude at which water level would have stood in tightly cased wells. Dashed where data are insufficient. Contour interval 50 feet. Datum is National Geodetic Vertical Datum of 1929.

U/D —— —— FAULT ZONE-- Dashed where approximately located. U, upthrown side: D, downthrown side.

○90 WELL AND ALTITUDE OF WATER LEVEL

1 0 1 2 3 4 MILES

1 0 1 2 3 4 5 6 KILOMETERS

Arkansas State Highway and Transportation Department county base map, 1976

POTENTIOMETRIC SURFACE OF GREENSAND AQUIFER, UNION COUNTY, ARKANSAS, 1982.