OVERVIEW OF SUSCEPTIBILITY OF AQUIFERS TO CONTAMINATION, UNION COUNTY, ARKANSAS

By Valarie A. Leidy and Richard E. Taylor

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per year (ft/yr)	0.3048	meter per year
gallon per day (gal/d)	0.003785	cubic meter per day
gallon per minute (gal/min)	0.003785	cubic meter per minute
million gallons per day (Mgal/d)	0.04381	cubic meter per second
mile (mi)	1.609	kilometer

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

In an effort to provide an overview of the susceptibility of aquifers in Union County, Arkansas, to contamination from potential surface sources, hydrogeologic conditions were assessed at 51 public-supply well sites and potential contaminant sources were located. Almost all of these wells are completed in the Sparta Sand, either in the locally known Greensand aquifer or the underlying El Dorado aquifer. The city of El Dorado and surrounding area have been affected by urban growth and industrial activities. The major industry in Union County is the petrochemical industry. Major sources of potential contamination in Union County include numerous surface waste impoundments, 6 active landfills, and more than 300 injection wells. The overview of the susceptibility of aquifers to contamination from potential surface sources was based partly on the computation of travel times of ground water through confining units and from areas of recharge to points of withdrawal.

Analytical techniques based on modifications of Darcy's Law were described and used to estimate travel times. Estimated travel time for water to move downward through the Cook Mountain confining unit to the Greensand aquifer ranged from about 70 to 1,000 years. Estimated travel time for water to move downward through the middle confining unit of the Sparta Sand to the El Dorado aquifer ranged from about 35 to 600 years. Estimated average velocities of lateral ground-water movement within the Sparta Sand in and around Union County were about 1 to 70 feet per year. These computations provide only a general estimate of travel time and may not apply at specific sites.

Although analytical techniques indicate that the aquifers, and hence the public-supply wells, in Union County generally are protected from surface contamination, natural and manmade breaches in confining units could allow a surface contaminant to bypass the confining unit and move directly into the aquifer. A natural breach caused by faulting is of particular concern in the vicinity of a graben located just southeast of the city of El Dorado; however, manmade breaches in confinement such as abandoned wells, injection wells, and open boreholes are also of concern. More than 7,500 oil, gas, and related wells that penetrated the confining units were drilled in Union County prior to 1981.

One well near Felsenthal and two wells near Calion possibly are more susceptible to contamination than most other public-supply wells in Union county because these wells are relatively shallow and are located in the flood plain of the Ouachita River. However, all public-supply wells in Union County are probably susceptible to some degree to contamination from surface sources because of natural or manmade breaches in the confining units.

INTRODUCTION

Ground water is the source of drinking water for the entire population of Union County. Fifty-one public-supply wells are located in Union County and withdrew a total of approximately 8 Mgal/d of water in 1985 (Holland, 1987). The protection of the quality of ground water in the county is of particular concern because of the potential threat of contamination posed by several sources. About 80 percent of all hazardous waste produced in the State is generated in Union County (Ralph DesMarais, Arkansas Department of Pollution Control and Ecology, written commun., 1988).

The Arkansas Department of Health is the State agency responsible for the protection of public-supply wells from potential surface contamination. The U.S. Geological Survey (USGS), under a cooperative agreement with the Arkansas Department of Health, conducted a study in Union County to provide an overview of the susceptibility of aquifers to contamination from surface sources. Knowledge of the susceptibility of aquifers to contamination may then lead to a better understanding of the susceptibility of public-supply wells, which are completed in these aquifers, to contamination.

Purpose and Scope

The purposes of this report are to (1) describe the general hydrogeology and ground-water flow system of Union County, (2) identify sources of potential contaminants, and (3) provide an overview of the susceptibility of major aquifers to contamination. The focus of the investigation is on three aquifers and two confining units that constitute the hydrogeologic framework of the fresh ground-water system in Union County. The average vertical travel time of water through the confining units and the average velocity of lateral ground-water movement in an aquifer help to provide an overview of the susceptibility of these aquifers to potential contamination. These aquifers provide water to 21 municipalities and rural water associations in Union County, which were included in a 1989 community public-water system list provided by the Arkansas Department of Health (Arkansas Department of Health, 1989). Ownership, location, description, and hydrogeologic information of these public-supply wells are presented in tabular form.

The results of this study can be used by the Arkansas Department of Health in its continuing efforts to monitor, protect, and plan for the safe use of ground water by public-supply systems. Water managers and planners can use the preliminary and generalized information provided in this report to obtain an overview of the susceptibility of aquifers, which provide ground water to their public-supply wells, to contamination from potential surface sources.

Geographic Setting

Union County is located in the West Gulf Coastal Plain in south-central Arkansas (fig. 1). The Ouachita River forms the northeastern and eastern boundaries of the county, and the Arkansas-Louisiana State line forms the southern boundary of the county. The area is characterized in most places by a sandy, gently rolling terrain with a vegetative cover of pine

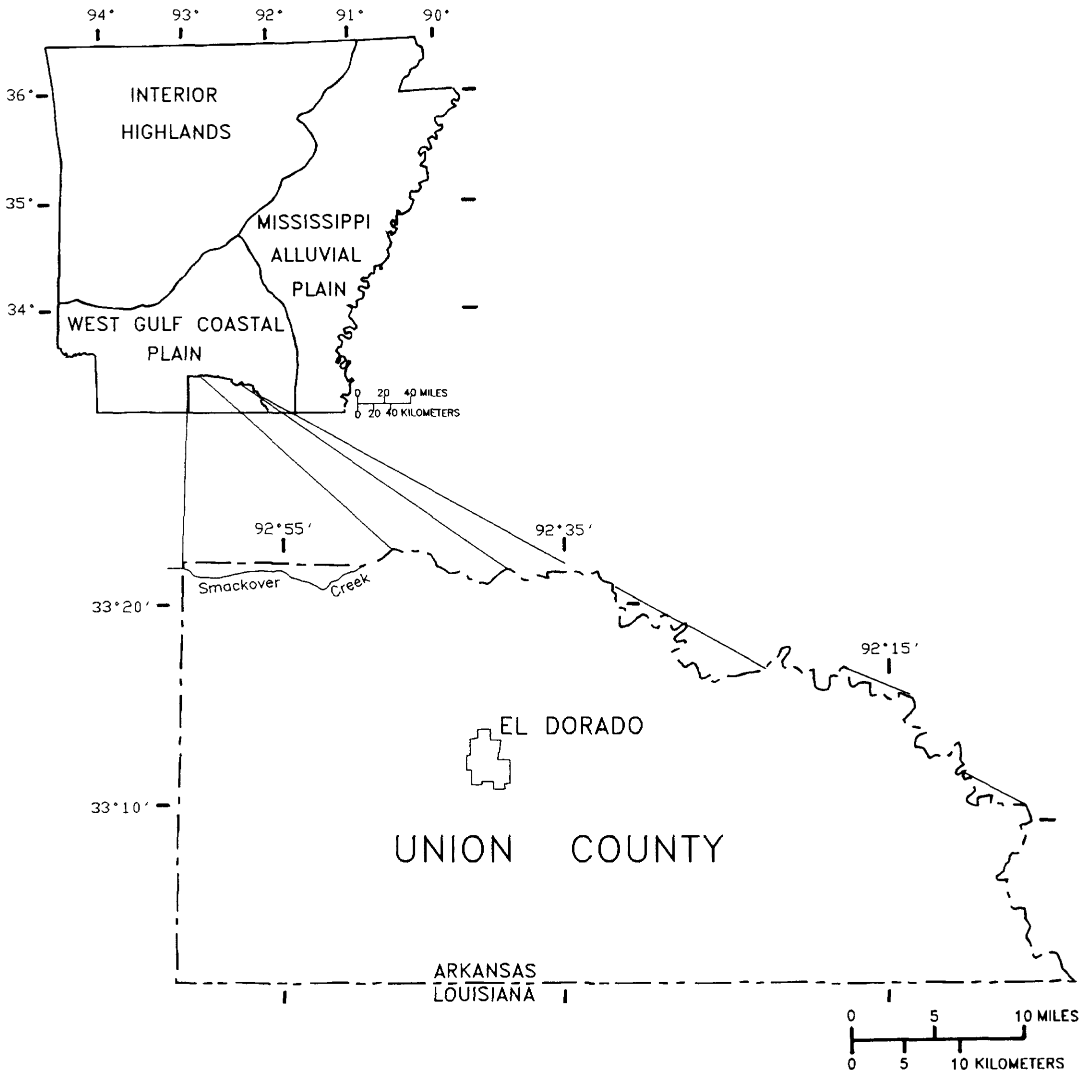


Figure 1.--Location of study area.

forests and pastures. However, land surrounding the city of El Dorado (population approximately 35,000) has been affected by urban growth and industrial activities. The major industry in Union County is the petrochemical industry. Oil and gas fields are scattered throughout the study area.

The land surface generally slopes north-northeast and south-southeast from a central ridge extending from the western edge of Union County eastward through El Dorado 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 streams that flow into the Ouachita River in Louisiana.

Method of Study

Analytical computations based on modifications of Darcy's Law can be used to determine travel time and velocities of ground water. The accuracy of the computations is predicated upon the availability and accuracy of the data needed to solve the proper equation. Some generalized values are provided in this report, but the reader is advised to use caution when interpreting travel times and flow rates calculated using these values. The lack of site-specific data in the stressed ground-water flow regime in Union County and the variability in aquifer characteristics may result in local flow conditions that are substantially different from average conditions estimated from these generalized values of aquifer properties.

The methodology used in this report to help provide an overview of the susceptibility of aquifers to contamination from surface sources considers, in part, the analytical computation of the time-of-travel necessary for water to move vertically or horizontally through geologic units. Transport of potential contaminants is considered to occur only by advection, that is, at the same rate as ground-water flow and is not subject to the variety of conditions that attenuate or otherwise affect the mobility and fate of various types of contaminants. Accordingly, transport processes not considered in time-of-travel estimates developed for this study include hydrodynamic dispersion, transformation and decay, sorption, partitioning, dissolution, and precipitation. For purposes of this report, potential contaminants are assumed to be soluble in ground water. In summary, potential contaminants are presumed to enter the ground-water flow system and travel, without transformation or attenuation, in the aquifer at the velocity of ground-water flow.

In Union County, hydrogeologic information from 51 public-supply wells (21 water systems) was assembled and potential contaminant sources were located in order to provide an overview of the susceptibility of the aquifers to contamination from surface sources. Open sections of 37 wells are completed in the deepest aquifer, which is overlain by two confining units. Thirteen wells are completed in the middle aquifer, which is confined only by one confining unit. Only 1 of the 51 public-supply wells is completed in the unconfined shallow aquifer. The locations of the public-supply wells are shown in figure 2. Descriptions of these wells are listed by site number in table 1.

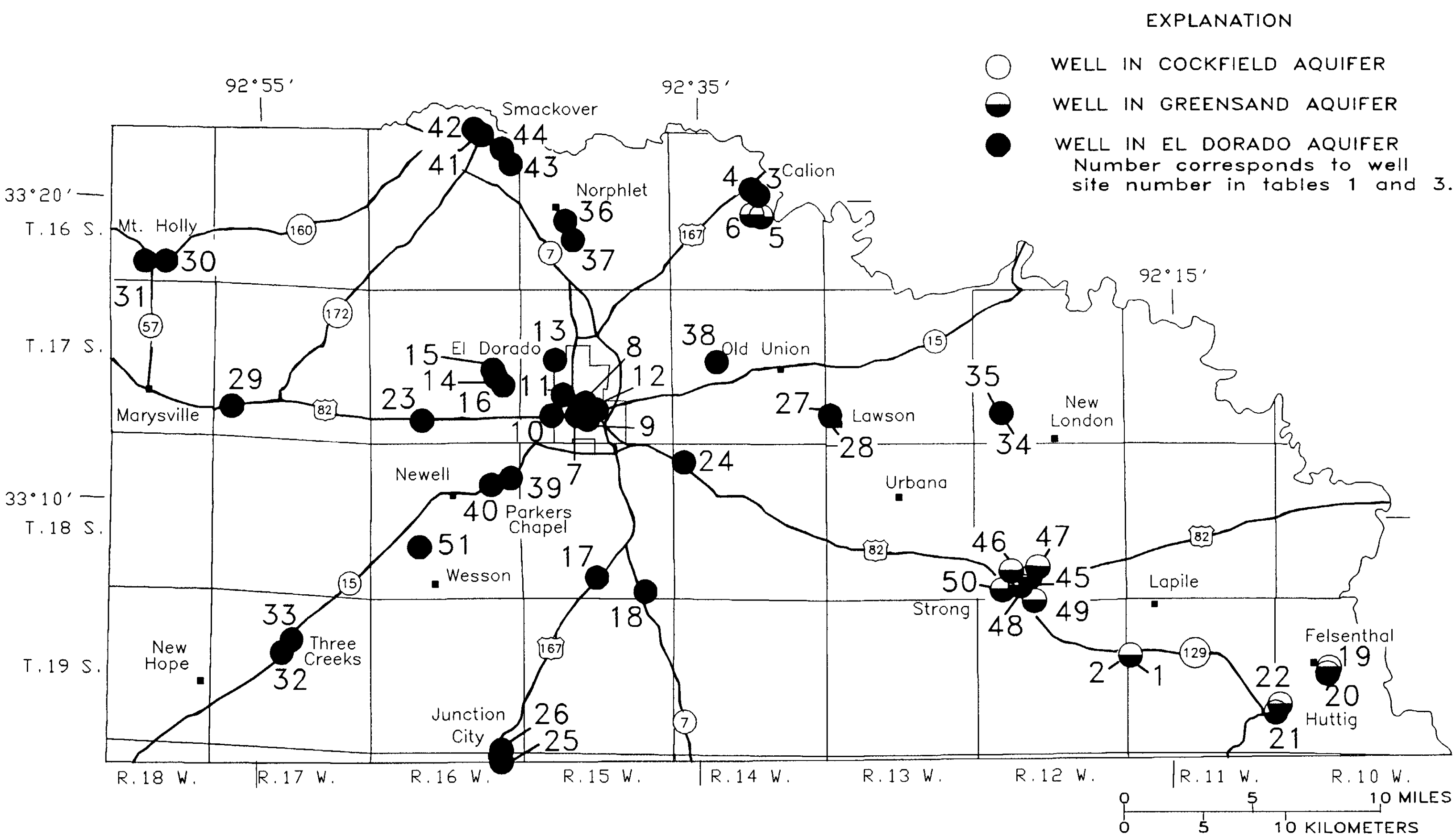


Figure 2.--Location of public-supply wells in Union County, Arkansas.

Table 1.--***Location and description of public-supply wells in Union County, Arkansas***

[fig., figure; USGS, U.S. Geological Survey; gal/min, gallons per minute; Assoc., Association; --, no data; do., ditto]

Well site number (fig.2)	Owner of well	Owner's well number	Location: USGS well number (land-net location)	Location: Latitude	Location: Longitude	Year well drilled	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)	Length of screen (feet)	Well discharge 1989 (gal/min)	Aquifer
1	Batts-Lapile Water Assoc.	1	19S11W18BBB1	330409	921713	1979	190	600	74	70	Greensand
2	do.	2	19S12W13AAA1	330410	921716	1989	180	339	30	80	Greensand
3	Calion Water Works	1	16S14W15CAB1	331944	923217	1970	94	466	50	305	El Dorado
4	do.	2	16S14W15BCC1	331948	923232	1989	95	508	70	300	El Dorado
5	Crabapple Point Water System	2	16S14W15CDA1	331927	923211	[1] 1950	90	130	--	--	Greensand
6	do.	1	16S14W15CDB1	331926	923216	[1] 1959	90	130	--	--	Greensand
7	El Dorado Water Works	10A	17S15W28CDC2	331227	923937	1961	265	740	70	810	El Dorado
8	do.	11	17S15W28DCB1	331237	923921	1947	275	754	105	805	El Dorado
9	do.	12	17S15W33ABB1	331223	923923	1951	267	712	100	990	El Dorado
10	do.	13	17S15W29CDC1	331228	924038	1955	220	650	115	750	El Dorado
11	do.	14	17S15W29ACB1	331303	924009	1955	270	712	115	750	El Dorado
12	do.	15	17S15W28DDA1	331236	923856	1960	275	755	100	1,220	El Dorado
13	do.	16	17S15W17CDA1	331425	924030	1960	248	700	70	750	El Dorado
14	do.	17	17S16W24BDB1	331358	924248	1965	205	611	80	720	El Dorado
15	do.	18	17S16W24BBC1	331407	924256	1978	210	704	80	1,066	El Dorado
16	do.	19	17S16W24CAB1	331349	924244	1982	207	709	100	950	El Dorado
17	Faircrest Water Assoc.	1	18S15W33ADA1	330657	923859	1976	253	752	41	160	El Dorado
18	do.	2	18S15W35DAC1	330631	923708	1983	201	685	80	250	El Dorado
19	Felsenthal Water Assoc.	1	19S10W16CBC1	330327	920905	1976	82	652	56	25	Greensand
20	do.	2	19S10W16CBC2	330327	920905	1976	82	206	37	25	Cockfield
21	Huttig Water Works	1	19S11W25AAB1	330208	921121	1984	120	528	80	400	Greensand
22	do.	2	19S11W25AAA1	330219	921112	1964	135	550	60	300	Greensand
23	Highway 82 Water Assoc.	--	17S16W33BBB1	331226	924601	1978	252	660	20	--	El Dorado
24	Johnson Township Water Assoc.	--	18S14W06CCD1	331040	923531	1989	225	783	60	100	El Dorado
25	Junction City Water Works	1	20S16W02AAC1	330057	924327	1980	185	529	52	300	El Dorado
26	do.	2	19S16W35DDC1	330110	924321	1967	175	601	55	412	El Dorado
27	Lawson-Urbana Water Assoc.	1	17S13W31BAC1	331205	922916	1975	216	772	25	150	El Dorado

Table 1.--*Location and description of public-supply wells in Union County, Arkansas*--Continued

Well site number (fig.2)	Owner of well	Owner's well number	Location: USGS well number (land-net location)	Location: Latitude	Location: Longitude	Year well drilled	Altitude of land surface above sea level (feet)	Depth of well below land surface (feet)	Length of screen (feet)	Well discharge 1989 (gal/min)	Aquifer
28	Lawson-Urban Water Assoc.	2	17S13W31BAD1	331203	922908	1984	215	771	20	150	El Dorado
29	Marysville Water Assoc.	--	17S17W30DCD1	331300	925356	1976	280	690	30	100	El Dorado
30	Mount Holly Water Works	2	16S18W35BBB1	331808	925638	1972	235	480	40	100	El Dorado
31	do.	3	16S18W34ABC2	331805	925709	1980	248	465	58	60	El Dorado
32	New Hope Water Assoc.	1	19S17W16ABB1	330455	925152	1983	240	595	70	150	El Dorado
33	do.	2	19S17W09DAC1	330509	925138	1987	220	586	40	185	El Dorado
34	New London Water Assoc.	1	17S12W32BBC1	331203	922218	1976	230	822	51	150	El Dorado
35	do.	2	17S12W32BBB1	331204	922221	1986	220	828	50	175	El Dorado
36	Norphlet Water Works	2	16S15W20DAA1	331900	923956	1964	190	603	53	340	El Dorado
37	do.	3	16S15W21CCB1	331842	923950	1983	140	665	41	235	El Dorado
38	Old Union Water Assoc.	--	17S14W16CBD1	331421	923332	1989	270	700	100	280	El Dorado
39	Parkers Chapel Water Assoc.	1	18S16W12ACB1	331024	924229	1968	303	797	42	210	El Dorado
40	do.	2	18S16W11DAB1	331011	924317	1976	270	767	50	220	El Dorado
41	Smackover Water Works	5	16S16W02ABC1	332205	924330	1954	116	552	60	250	El Dorado
42	do.	6	16S16W02BAA1	332211	924337	1958	117	553	50	440	El Dorado
43	do.	7	16S16W01DDD1	332115	924213	1974	112	470	40	300	El Dorado
44	do.	8	16S16W01DBC1	332131	924230	1974	119	473	40	300	El Dorado
45	Strong Water Works	1	18S12W32AAD1	330642	922125	1947	115	430	70	80	Greensand
46	do.	2	18S12W32ABC1	330643	922153	1956	112	400	40	35	Greensand
47	do.	3	18S12W33BBB1	330652	922119	1971	112	466	30	185	Greensand
48	do.	4	18S12W32ACD1	330633	922139	1978	145	312	25	35	Greensand
49	do.	5	18S12W33CCC1	330607	922121	1983	135	290	40	85	Greensand
50	do.	6	18S12W32CBD1	330619	922214	1985	150	310	50	85	Greensand
51	Wesson-Newell Water Assoc.	1	18S16W29AAA1	330807	924613	1976	225	636	40	165	El Dorado

[1]Approximately.

Data from these wells and the following equations were used to help provide an overview of the susceptibility of the aquifers to surface contamination. Average vertical travel time through a confining unit can be computed (Vecchioli, 1989) using the equation:

$$t_v = \frac{nl}{\frac{K_v}{b}\Delta h} \tag{1}$$

derived from Darcy's Law, where

t_v is average vertical travel time, in days, through the confining unit;

n is effective porosity (dimensionless), of the confining unit;

l is distance, in feet, between the bottom of the overlying aquifer and the top of the underlying aquifer;

K_v is vertical hydraulic conductivity, in feet/day, of the confining unit;

Δh is head difference, in feet, between the potentiometric surface of the overlying and underlying aquifers; and

b is thickness, in feet, of the confining unit; for computation of average vertical travel time through a confining unit, distance (l) is the same as thickness (b).

Thus, equation 1 becomes:

$$t_v = \frac{nb^2}{K_v \Delta h} \tag{2}$$

The average velocity of lateral ground-water movement in an aquifer can be computed (Lohman, 1972) using a version of Darcy's Law:

$$v = \frac{365 K_h \frac{dh}{dl}}{n} \tag{3}$$

where v is average velocity of ground-water movement, in feet per year

365 is a constant representing the number of days in a year;

K_h is horizontal hydraulic conductivity of ground water, in feet per day;

$\frac{dh}{dl}$ is hydraulic gradient of ground water along a flow path (dimensionless); and

n is porosity (dimensionless).

A discussion on the parameters used in equations 2 and 3 is presented in a subsequent section of this report. The values for these parameters and their sources are also discussed later in the report.

Well-Numbering System

The well-numbering system used in this report is based upon the location of the wells according to the Federal land survey used in Arkansas. The component parts of a well number are the township number, the range number, the section number, and three letters which indicate, respectively, the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section in which the well is located. The letters are assigned counterclockwise, beginning with "a" in the northeast quarter or quarter-quarter or quarter-quarter-quarter section in which the well is located. For example, well 01SO3WO4BBD16 (fig. 3) is located in Township 1 South, Range 3 West, and in the southeast quarter of the northwest quarter of the northwest quarter of section 4. This well is the 16th well in this quarter-quarter-quarter section of section 4 from which data were collected.

Acknowledgments

The authors wish to thank personnel of the municipalities and rural water associations in Union County for the data they provided and for assistance in measuring water levels. The study also benefited greatly from data provided by the Arkansas Department of Health, Arkansas Water Well Construction Commission, Arkansas Oil and Gas Commission, Arkansas Department of Pollution Control and Ecology, and Mr. William R. Gaunt of Gaunt and Associates. Historic water-level and borehole geophysical data, collected in cooperation with the Arkansas Geological Commission, were invaluable in establishing the basic hydrogeologic framework for the study.

HYDROGEOLOGIC SETTING

Geologic Units

The sediments of Tertiary age that constitute the formations within the Claiborne Group (table 2) are as much as 1,360 ft thick in Union County. The Claiborne Group consists of, in ascending order, the Cane River Formation, Sparta Sand, Cook Mountain Formation, and Cockfield Formation. These formations generally are composed of interbedded sequences of sand and clay. The sand beds in the Cockfield Formation and Sparta Sand contain most of the fresh ground water in Union County. All geologic units below the Sparta Sand contain saline water. The Cane River and Cook Mountain Formations are regional confining units. Alluvial and terrace deposits of Quaternary age underlie bottomlands and flood plains of most streams throughout Union County. These deposits, consisting of clay, silt, sand, and gravel, overlie Cockfield and Cook Mountain deposits.

The Cockfield Formation, the Cook Mountain Formation, and Quaternary alluvial and terrace deposits crop out in Union County (fig. 4). The Cockfield Formation is present at land surface throughout most of Union County. The Cook Mountain Formation, which underlies the Cockfield, is exposed at land surface only in the northern and northwestern parts of the county.

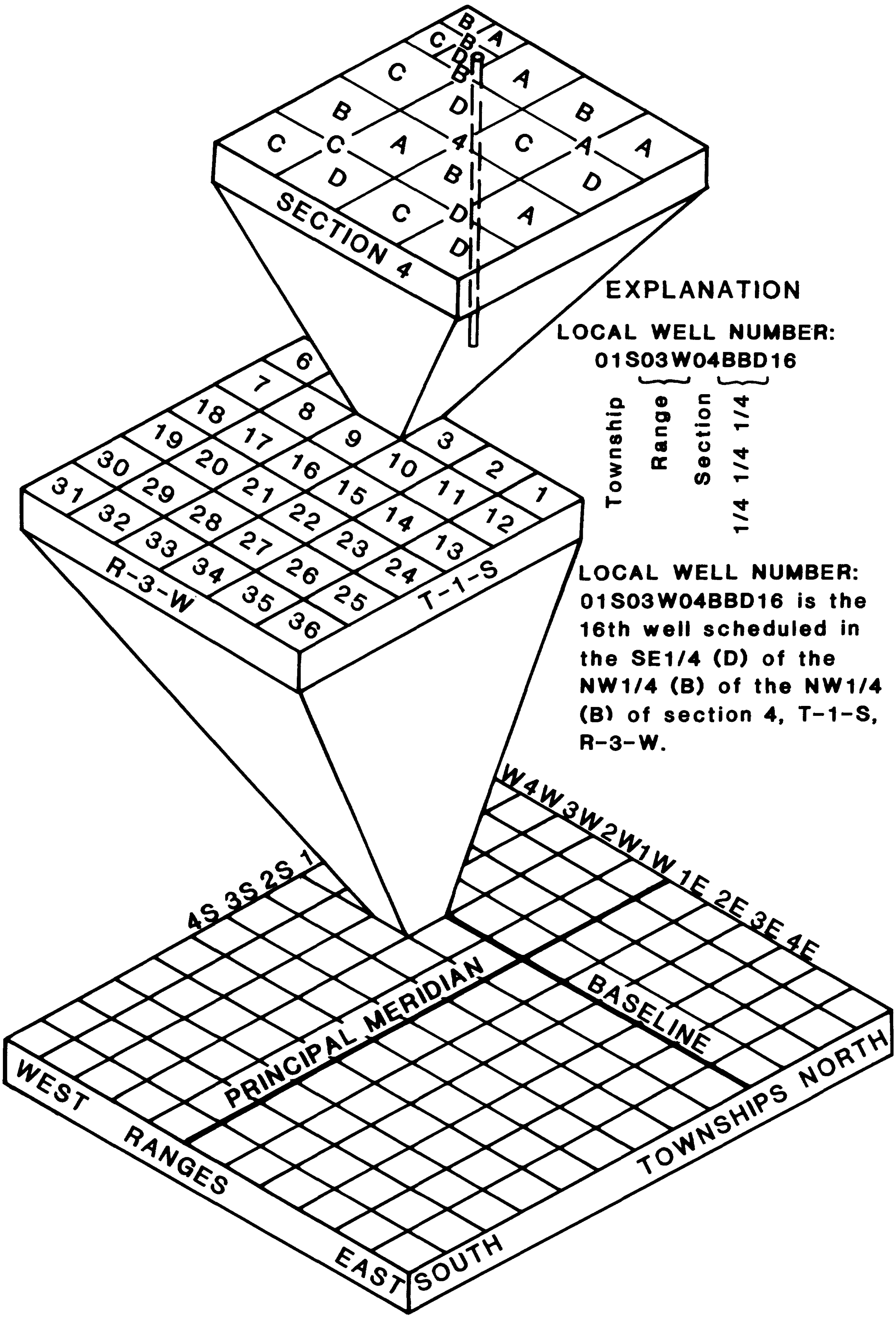


Figure 3.--Well-numbering system.

Table 2.--*Description of hydrogeologic units in the study area*

System	Series	Group	Formation	Hydrogeologic unit	Hydrogeologic properties
Quaternary	Holocene and Pleistocene		Alluvial and terrace deposits		Clay, silt, sand, and gravel. Present only in bottomlands of most streams. Generally not used. As much as 100 feet thick.
Tertiary	Eocene	Claiborne	Cockfield Formation	Cockfield aquifer	Lignitic sand with interbedded clay. Principal aquifer for rural domestic supply. Water with-drawals approximately 0.5 million gallons per day. Approximately 200 feet thick where present.
			Cook Mountain Formation	Cook Mountain confining unit	Clay with interbedded fine sand. Not an aquifer. Thickness ranges from 50 to 200 feet.
			Sparta Sand	Greensand aquifer	Thinly bedded fine glauconitic sand with interbedded clay. Source of municipal and industrial water supply principally in southeast part of county. Water withdrawals approximately 0.5 million gallons per day. Approximately 200 feet thick.
				Middle confining unit	Clay and silt. Not an aquifer. Thickness ranges from 40 to 160 feet.
				El Dorado aquifer	Thickly bedded medium to coarse sand. Source of municipal and industrial water supply throughout county. Water with-drawals approximately 14 million gallons per day. Approximately 300 feet thick.
			Cane River Formation	Cane River confining unit	Clay and silty clay. Not an aquifer. Approximately 300 feet thick.

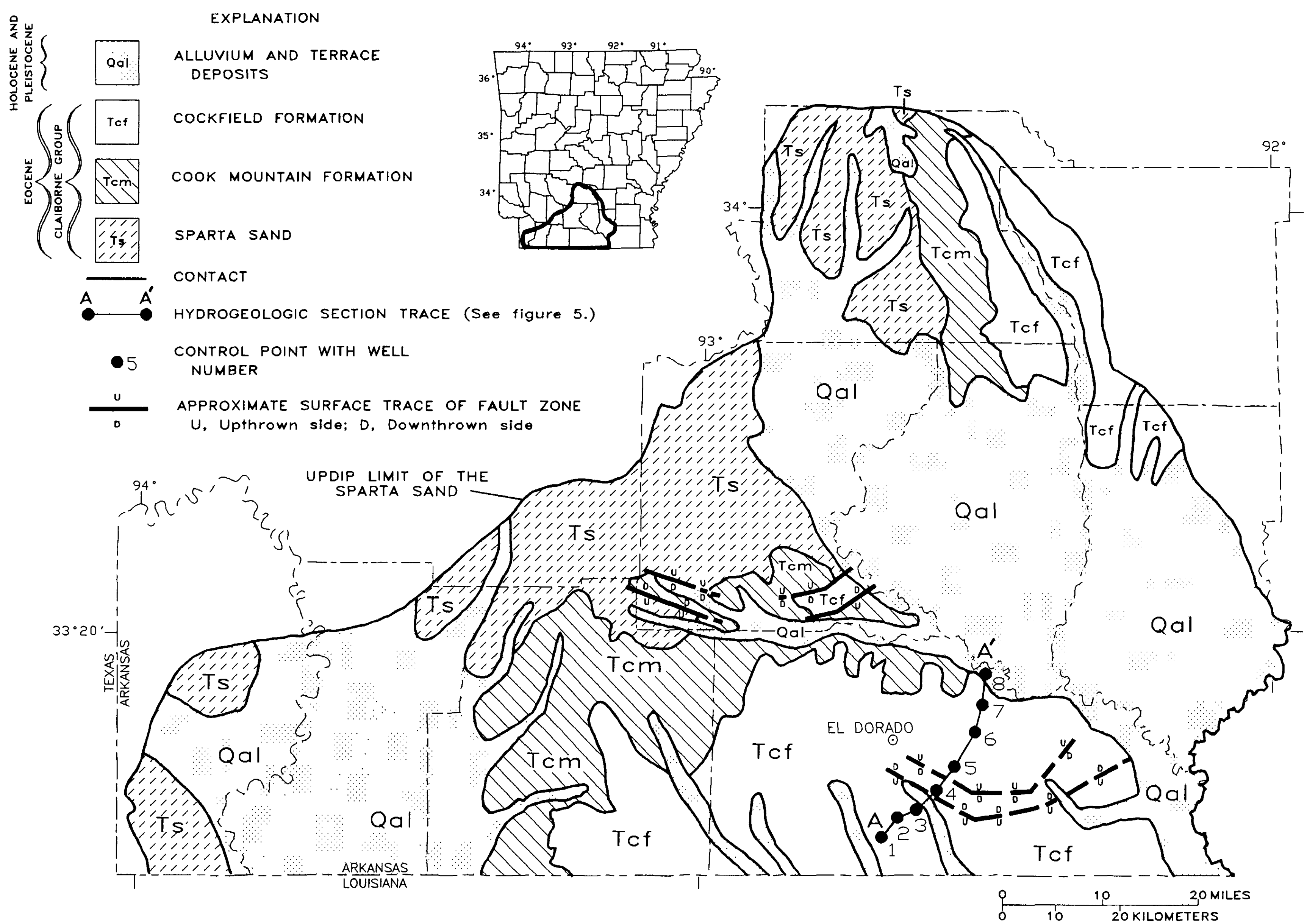


Figure 4.--Generalized geologic map of southern Arkansas (modified from Hosman, 1982 and Broom and others, 1984).

Quaternary alluvial and terrace deposits are present primarily in the bottomlands of the Ouachita River and its major tributaries in the northern and eastern parts of the county. The nearest outcrops of the Sparta Sand are about 4 mi west and 3 mi northwest of the northwest corner of Union county, in Columbia and Ouachita Counties, respectively (fig. 4).

A generalized south-north hydrogeologic section through the center of Union County (fig. 5) depicts the vertical extent of formations within the Claiborne Group. The formations are continuous over the study area except southeast of El Dorado where a structural feature known as a graben is present (fig. 4). Within the graben the geologic section between two parallel fault planes has been offset (Broom and others, 1984). The formations within the graben are about 200 ft lower than the same formations outside of the graben (fig. 5).

In Union County, the Cockfield Formation is about 200 ft thick and generally consists of discontinuous fine- to medium-grained sand, which is interbedded with silt, clay, and lignite. Sand beds in the Cockfield are as much as 100 ft thick. The Cockfield aquifer, which is delimited by the Cockfield Formation, generally is unconfined in the study area. Water withdrawals from the Cockfield aquifer in Union County in 1985 were 0.461 Mgal/d (Holland, 1987). Withdrawals were predominantly from domestic wells; however, one shallow public-supply well (site 20) in the town of Felsenthal also is completed in the Cockfield aquifer. Water levels in the Cockfield aquifer generally fluctuate 3 ft or less annually and have no long-term changes (Fitzpatrick and others, 1990). Recharge to the Cockfield aquifer is mostly local where it occurs by infiltration of rainfall on the outcrop area (fig. 4). Based on soil characteristics, the Cockfield has moderate recharge potential (Louisiana Geological Survey, 1989). Most of the discharge from the Cockfield aquifer is to streams and to evapotranspiration (Broom and others, 1984).

The Cook Mountain Formation, which crops out in the northern and northwestern parts of the county (fig. 4), is a confining unit between the overlying aquifer in the Cockfield Formation and the underlying aquifer of the Sparta Sand. Locally, the Cook Mountain Formation consists of clay and silty clay with minor amounts of very fine sand in places (Broom and others, 1984). Thickness of the Cook Mountain Formation is variable and ranges from 50 to 200 ft in Union County.

The Sparta Sand in Union County is about 600 ft thick and consists of sand, silt, and clay beds. The beds commonly are irregular, discontinuous, and of local extent. The Sparta Sand generally is divisible into three distinct hydrogeologic units in Union County (table 2 and fig. 5). The names of these units are of local usage. The upper 200 ft is composed of thin-bedded, very fine- to fine-grained glauconitic sand with clay and is known locally as the Greensand aquifer. The middle 100 ft consists of clay and silt and is termed the middle confining unit. The lower 300 ft is composed of thick-bedded, medium- to coarse-grained sand and is known locally as the El Dorado aquifer. Comparison of water-level hydrographs from wells completed in the Greensand aquifer with those from wells completed in the El Dorado aquifer supports the concept that the two aquifers function somewhat independently (Broom and others, 1984). Recharge to the aquifer occurs predominantly as infiltration of precipitation in areas of outcrop (fig. 4). Based on soil characteristics, the Sparta Sand has moderate to high recharge potential where it crops out (Louisiana Geological Survey, 1989). Discharge occurs by withdrawal from wells and by subsurface discharge to adjacent units.

The Greensand aquifer is overlain by the Cook Mountain confining unit and underlain by the middle confining unit of the Sparta Sand (fig. 5). The aquifer dips regionally from an altitude

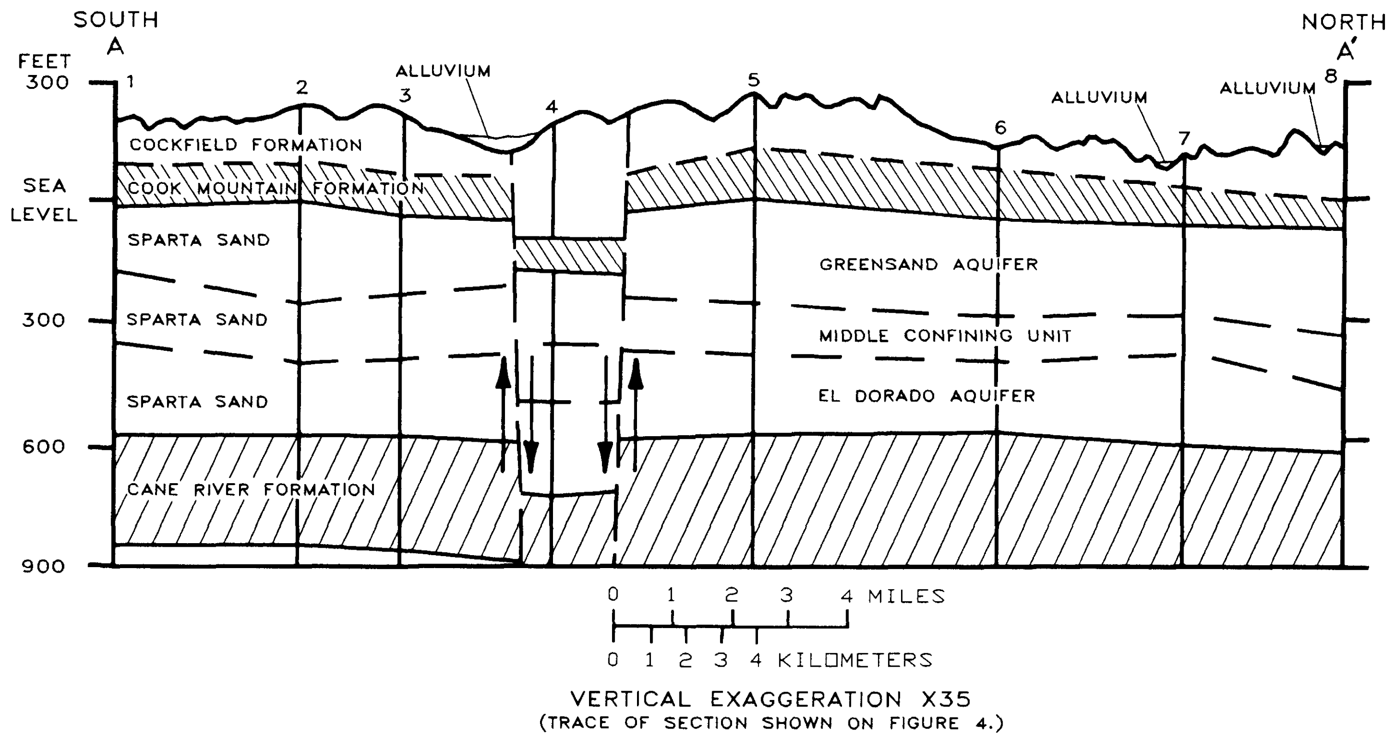


Figure 5.--South-north hydrogeologic section through center of Union County (modified from Broom and others, 1984).

of about 150 ft above sea level in the northwestern corner of the county to about 250 ft below sea level in the southeastern corner (Broom and others, 1984). In the southeastern corner of Union County the Greensand aquifer is the main source of water for municipal and industrial supplies; water in underlying sand beds is saline. Water withdrawal from the Greensand aquifer totaled about 0.5 Mgal/d in 1982 (Broom and others, 1984). Broom and others (1984, plates 2, 4, and 5) reported that the Greensand aquifer is partly in contact with the Cockfield aquifer across the fault planes of the graben (fig. 5).

The middle confining unit generally consists of clay and silt. However, in some areas of Union County, the middle confining unit contains sand that makes the unit difficult to distinguish from the Greensand and El Dorado aquifers. The unit was first described by Broom and others (1984).

The El Dorado aquifer is overlain by the middle confining unit of the Sparta Sand and underlain by the Cane River Formation (fig. 5). Regionally, the El Dorado aquifer dips southeastward. The top of the aquifer ranges from an altitude of about 200 ft below sea level in the northwestern part of the county to about 800 ft below sea level in the southeastern part (Broom and others, 1984). Withdrawals from the aquifer increased from less than 0.5 Mgal/d in 1921 to about 16 Mgal/d in 1982 (Broom and others, 1984). Broom and others (1984, plates 2 and 5) reported that the El Dorado aquifer is partly in contact with the Greensand aquifer across the fault planes of the graben.

Ground-Water Flow System

The ground-water flow system in Union County is complex. The Cockfield aquifer generally is not stressed by withdrawals in Union County. The flow of water in the Cockfield aquifer generally is from highlands in interstream areas toward the lower lying major streams that drain Union County. Water movement in the Cockfield aquifer, as indicated by contours of the potentiometric surface (lateral water movement is about perpendicular to the contours), generally is in the direction of land slope and toward streams draining the area (fig. 6). Thus, water in the Cockfield aquifer generally moves northward toward Smackover Creek in the northern part of Union County, eastward toward the Ouachita River in the eastern part of the county, and toward the major streams in the southern part of the county (fig. 6).

The Greensand aquifer is moderately stressed by withdrawals in Union County. The generalized potentiometric surface of the Greensand aquifer (fig. 7) shows that water in this aquifer flows generally southward. However, the lack of control points (water wells for water-level measurements) preclude a more exact representation of the flow system, particularly in the vicinity of the public-supply wells, where ground-water flow direction and rate of movement are affected by ground-water withdrawals.

The El Dorado aquifer is heavily stressed by withdrawals in Union County. The generalized potentiometric surface of the El Dorado aquifer (fig. 8) shows that water in this aquifer is moving toward the center of a cone of depression located at El Dorado, Arkansas. However, this is only a very simplistic part of a complex flow system for two reasons. First, major cones of depression also have developed in areas to the west and south of Union County. These cones of depression are coalescing because of the large withdrawal of water from aquifers in the Sparta

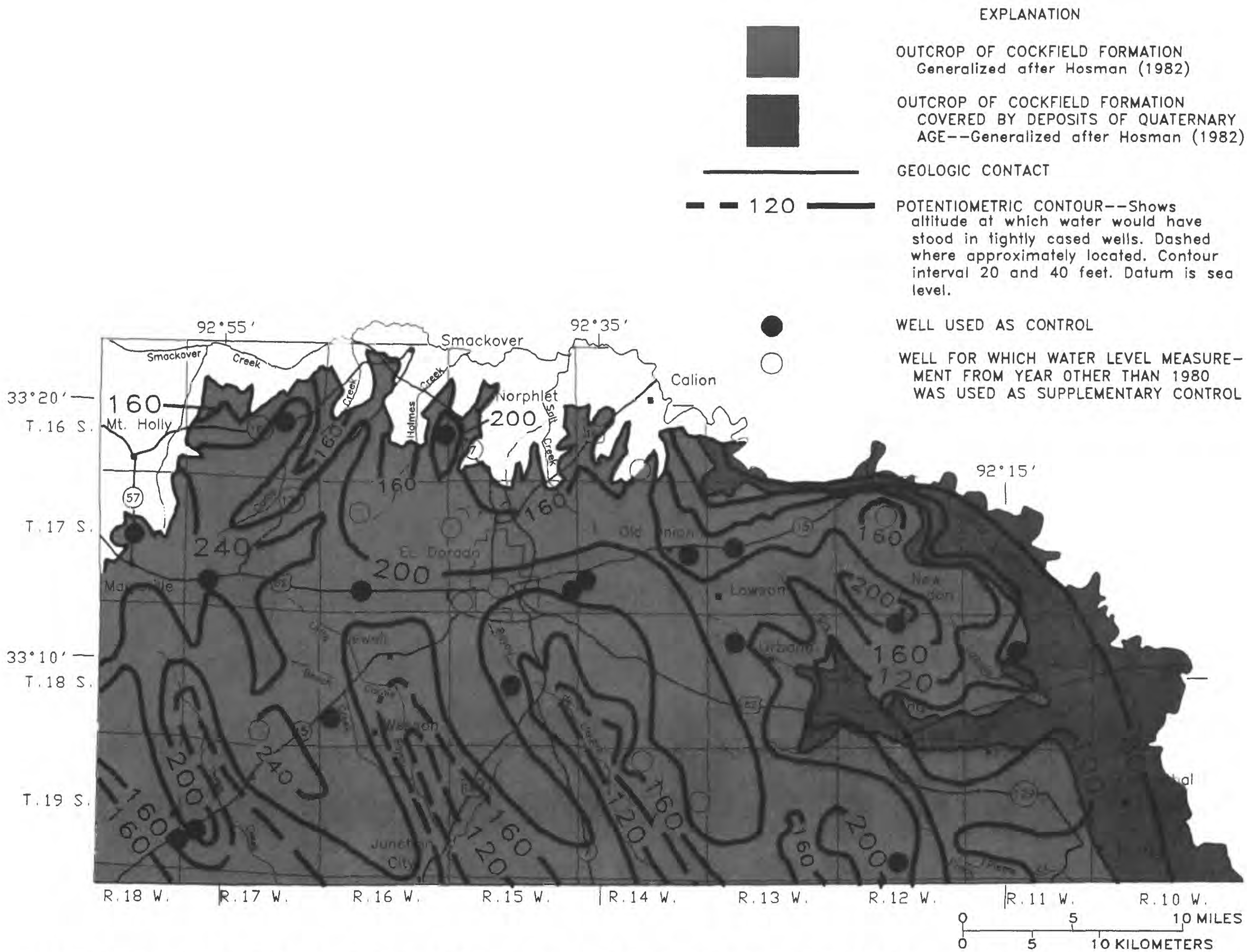


Figure 6.--Generalized potentiometric surface of the Cockfield aquifer, Union County, Arkansas, spring 1980 (modified from Ackerman, 1987).

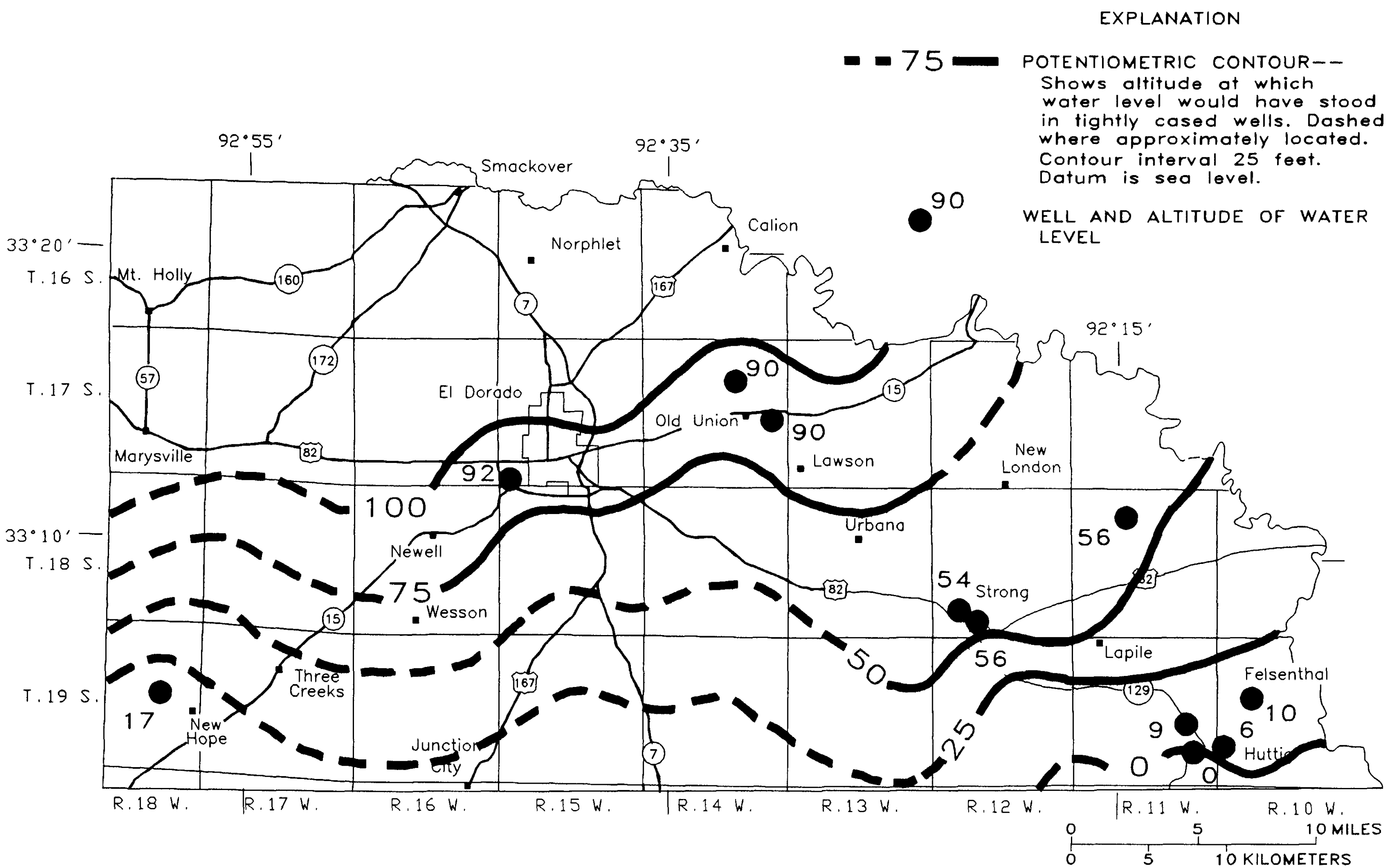


Figure 7.--Generalized potentiometric surface of the Greensand aquifer, Union County, Arkansas, 1982 (modified from Broom and others, 1984).

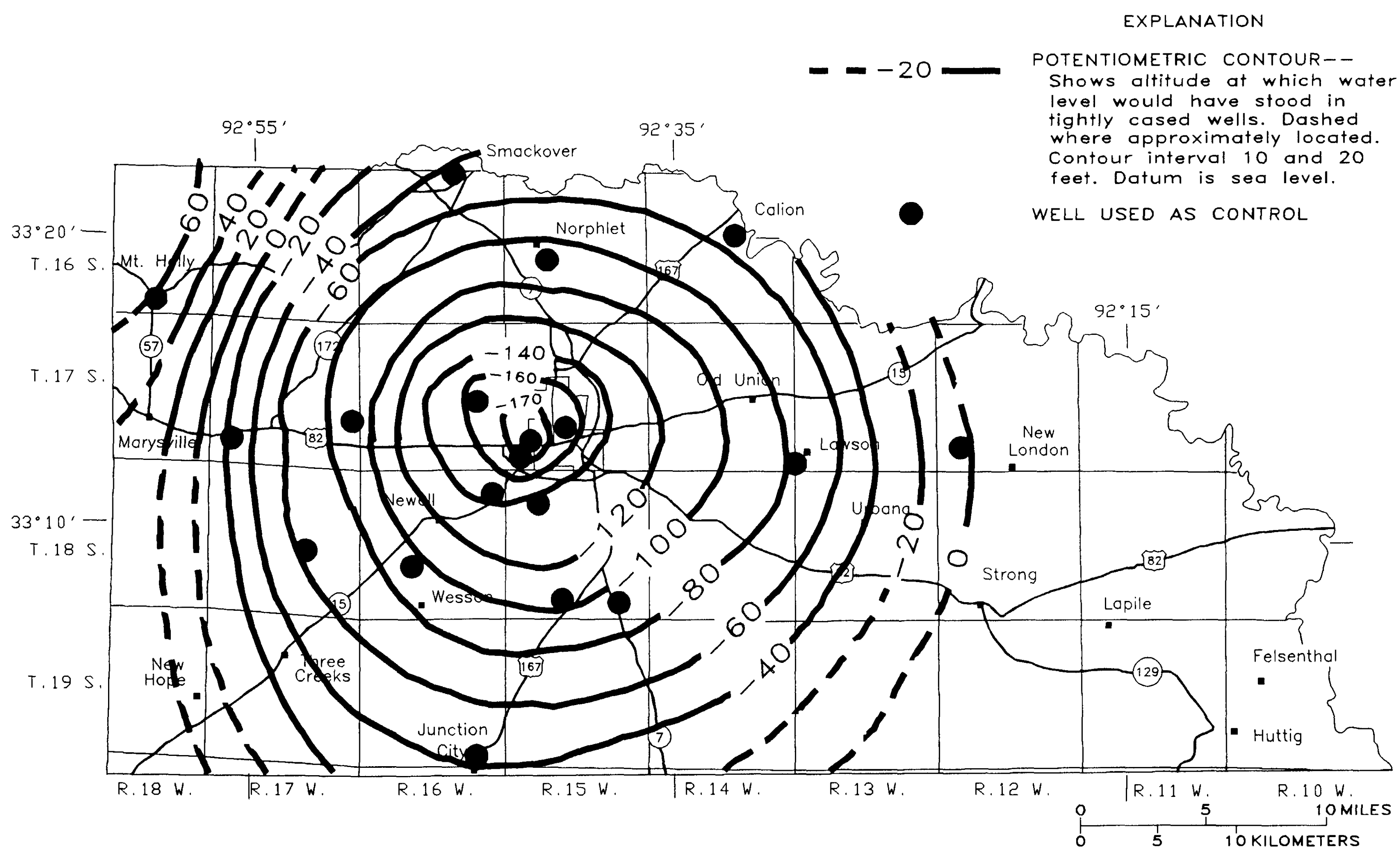


Figure 8.--Generalized potentiometric surface of the El Dorado aquifer, Union County, Arkansas, spring 1990.

Sand. Second, the lack of control points precludes a more exact representation of the flow of water in the El Dorado aquifer in Union County. Near El Dorado, Arkansas, where numerous industrial and public-supply wells withdraw a large quantity of ground water from the El Dorado aquifer, the cone of depression cannot be accurately represented and probably is in a constant state of flux because of the spatial and temporal changes in ground-water withdrawals in this area.

Although the horizontal direction and rate of movement of ground water in the aquifers are difficult to determine because of the lack of water-level and aquifer-test data, especially in the vicinity of public-supply wells, the vertical flow rates of water between aquifers are even more difficult to ascertain. Because of the hydraulic head differential, or difference in altitude of the potentiometric surfaces, between aquifers, water in the Cockfield aquifer has the potential to move downward to the Greensand aquifer and from there downward to the El Dorado aquifer in Union County. Although the direction of water movement between aquifers probably can be determined, the rate of flow is difficult to estimate because the rate of movement of water between aquifers is dependent not only on the head difference between the two aquifers but also on the thickness, effective porosity, and vertical hydraulic conductivity of the confining unit. Because of the varying thickness of confining units in Union County, a borehole geophysical log is needed to more accurately determine confining unit thickness at a local scale. Similarly, porosity and vertical hydraulic-conductivity values of confining units in Union County are unknown.

In summary, an accurate determination of the horizontal direction and rate of movement of ground water in aquifers, especially at a local scale, necessitates the acquisition of site-specific hydrogeologic and aquifer-characteristic data. An accurate determination of the vertical flow of water between aquifers at a site is complicated by the need for representative confining unit hydraulic characteristic data. Although data were not available to accurately describe local horizontal and vertical flow regimes in Union County, ranges of horizontal and vertical flow rates and travel times based on generalized hydrogeologic and lithologic data available for the study area, may be useful to managers, planners, and regulators charged with the development and protection of the ground-water resource.

SOURCES OF POTENTIAL CONTAMINATION

Identifying existing potential contaminant sources can be helpful to local officials charged with monitoring and protecting aquifers and ground water. The city of El Dorado and surrounding area has been substantially affected by urban growth and industrial activities. The major industry in the area is the petrochemical industry. In this study, only major sources of potential contamination were located. Many smaller potential contaminant sources probably exist in the study area but these have not been accurately located or described in this study.

The State of Arkansas conducted a Surface Impoundment Assessment in 1978-79 to locate all surface impoundments holding liquid waste in the State. The degree to which these impoundments are potential hazards to ground water in Union County is unknown; however, 23 impoundments related to industrial and municipal activities are known to exist (fig. 9) (Chesney, 1979). The majority of these industrial impoundments are concentrated in and around the city of El Dorado. In addition, millions of barrels of brine have been pumped and held in surface impoundments before being released to streams or injection wells during the more than 60 years

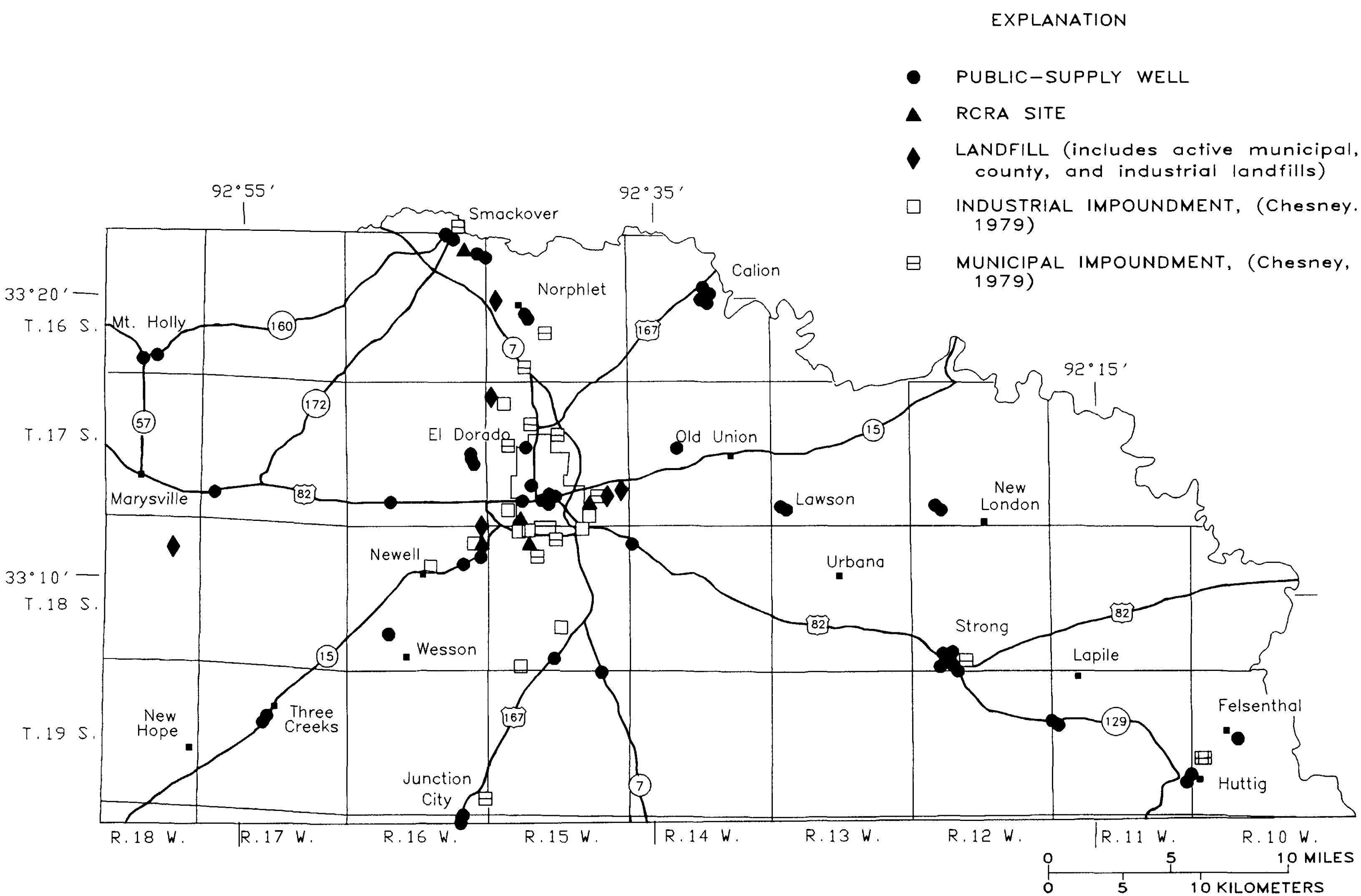


Figure 9.--Locations of potential ground-water contamination sources and public-supply wells in Union County, Arkansas.

of oil development in Union County. Numerous oil and brine impoundments exist in each of more than 50 oil and gas fields in Union County. Impoundments related to oil and gas operations are too numerous to show in figure 9.

There are six active municipal, county, and industrial landfills in Union County (fig. 9). Complete information as to the quantity or kinds of wastes that have been stored in these landfills is not available. Included among the landfills and surface impoundments are several sites known to contain hazardous wastes including five sites that are regulated as part of the Resources Conservation and Recovery Act (RCRA) (fig. 9).

Subsurface injection of wastes into saline zones can also pose a threat to aquifers and to freshwater supplies. In Union County there are 9 Class I injection wells, more than 300 Class II injection wells, and 36 Class V injection wells. Class I wells are used for disposal of industrial or municipal wastes beneath a formation that contains, within 1/4 mile, an underground source of drinking water. Class II wells are used by the petroleum industry to inject fluids that are brought to the surface in connection with conventional oil or natural gas production. Class V wells are those wells not included in the other classes. In the study area, Class V wells are predominately used by the chemical industry in relation to bromide production. The locations of Class I and Class V waste-disposal wells and public-supply wells are shown in figure 10. Class V well locations were obtained from the Arkansas Oil and Gas Commission and are located to the nearest quarter of a mile.

SUSCEPTIBILITY OF AQUIFERS TO CONTAMINATION

An overview of the susceptibility of aquifers in Union County to contamination from surface sources is based partly on estimates of travel times of water through confining units, travel times from recharge areas to points of withdrawal from the aquifer, and the occurrence of ground-water flow through natural or manmade breaches in the confining units. Except for the latter situation, the analytical techniques previously described will be used to compute the estimated vertical movement through confining units and lateral movement through aquifers under present (1990) conditions.

Vertical Movement Through Confining Units

The computation of vertical movement, or travel time, through a confining unit requires water levels or potentiometric surfaces (heads) for aquifers both above and below the confining unit. The relation of water levels and other components of equation 2 are generalized on a schematic hydrogeologic section (fig. 11). For this study, Cockfield water-table altitudes in Union County for 1990 were estimated from a 1980 potentiometric surface map (fig. 6) by Ackerman (1987a). Greensand aquifer heads for 1990 were estimated from a 1982 potentiometric surface map (fig. 7) by Broom and others (1984). These estimates of 1990 heads were considered representative because water-level data from files of the U.S. Geological Survey indicate no measurable long-term change in water levels in the Cockfield and Greensand aquifers between 1972 and 1990. Water-level data collected after 1980 are available in U.S. Geological Survey reports (Edds,

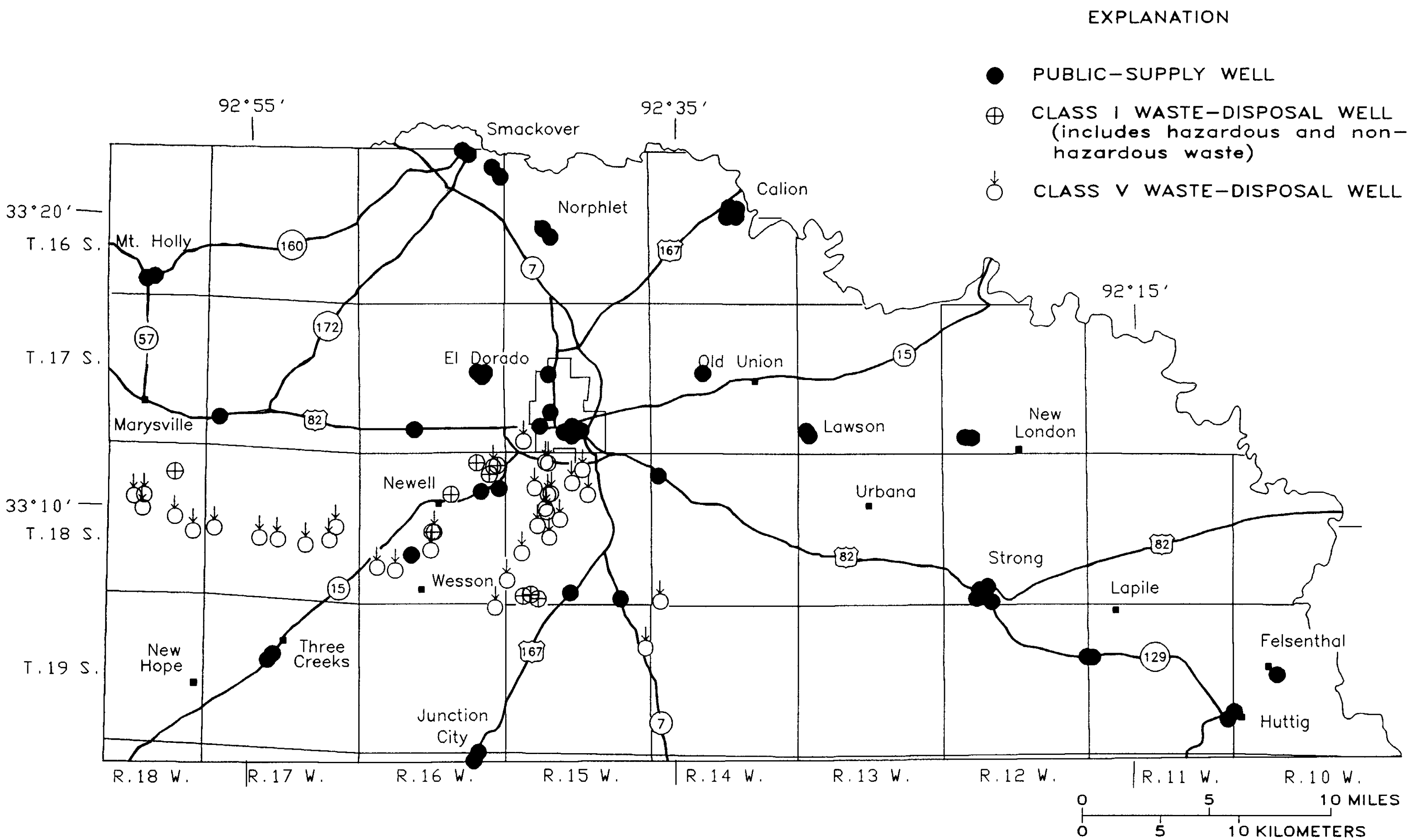
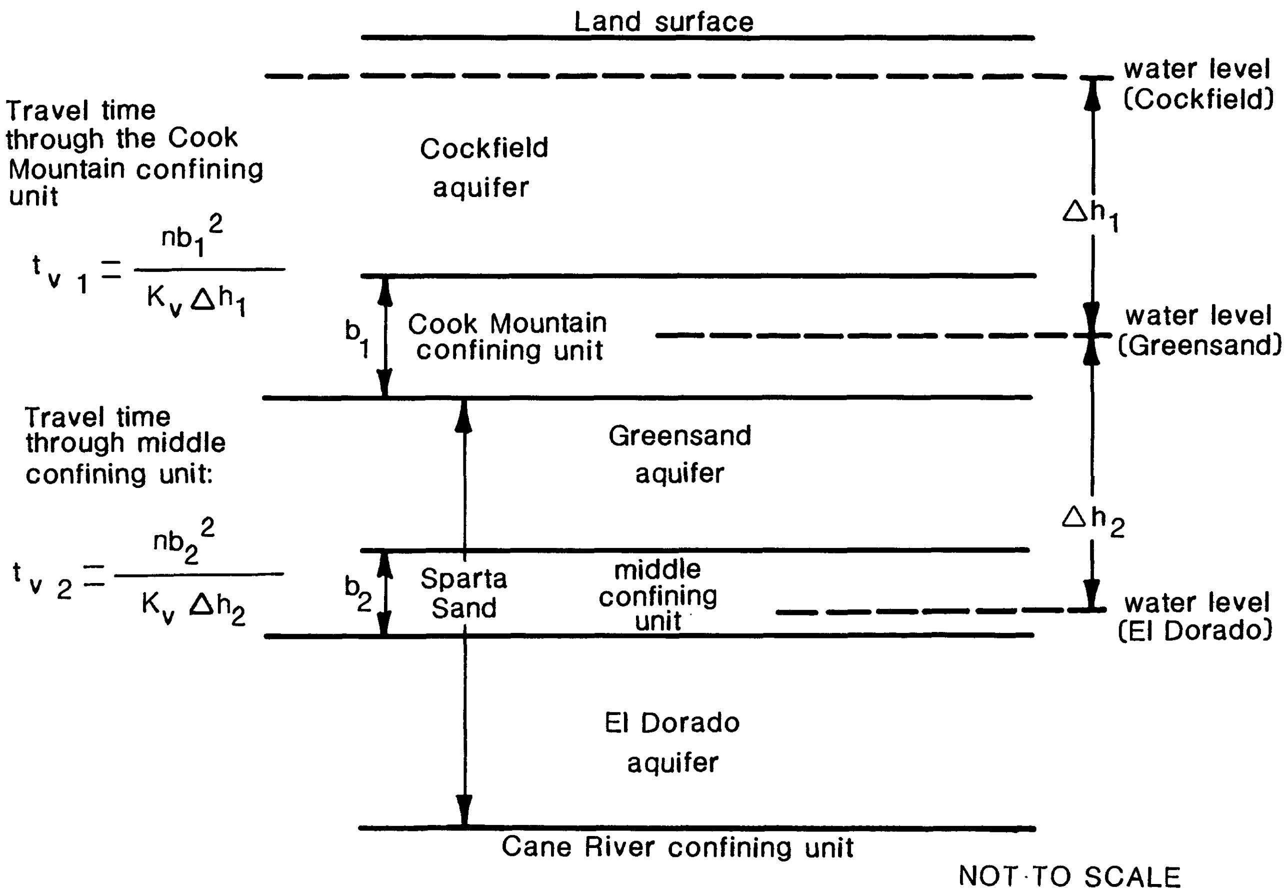


Figure 10.--Locations of waste-disposal wells and public-supply wells in Union County, Arkansas.



EXPLANATION

$$t_v = \frac{nb^2}{K_v \Delta h}$$

t_v - vertical travel time, in days, through Cook Mountain confining unit or through middle confining unit of the Sparta Sand;

n - porosity (dimensionless) of confining unit;

K_v - vertical hydraulic conductivity of confining unit, in ft/d;

Δh - head difference, in feet between the potentiometric surface of the Greensand aquifer and the water table in the Cockfield Formation, or between the potentiometric surface of the El Dorado aquifer and the potentiometric surface of the Greensand aquifer; and

b - thickness, in feet, of the confining unit.

Figure 11.--Schematic hydrogeologic section showing components of equation 2 needed to compute travel time through Cook Mountain and middle confining unit.

1981, 1982, 1983, 1984; Edds and Spencer, 1985; Edds and Remsing; 1986; Freiwald and Plafcan, 1987; Westerfield and Plafcan, 1988; and Westerfield and Gonthier, 1990). Heads in the El Dorado aquifer were estimated from a potentiometric surface map constructed from 1990 data (fig. 8). The estimated head difference, Δh, for computing vertical flow through the Cook Mountain and the middle confining units, respectively, was obtained by subtracting the altitude of the Greensand potentiometric surface from the altitude of the water table in the Cockfield Formation, or by subtracting the altitude of the El Dorado potentiometric surface from the altitude of the Greensand potentiometric surface. Because water-level data were not available for pumping conditions, the value of Δh represents static water-level conditions only and does not account for the additional head differences caused by pumping. Taking into account the drawdowns of the potentiometric surface during pumping may increase to some degree the value of Δh, which in turn may locally decrease vertical travel times.

Thickness values (b) for the Cook Mountain and middle confining units were obtained from borehole geophysical logs, if available in the general area, or otherwise from data reported by Broom and others (1984) and Fitzpatrick and others (1990). Generally, the thickness of the confining unit is the aggregate thickness of clay and very fine-grained beds that separate the overlying aquifer from the underlying aquifer. This is best determined by obtaining a geophysical well log at the site of investigation. If a geophysical well log is not available, then the thickness of the confining unit will have to be estimated as best possible, with the understanding that this could introduce error into the computed time-of-travel.

A vertical hydraulic-conductivity value of 0.0003 ft/d is considered representative of the Cook Mountain and the middle confining units (Arthur and Taylor, 1990; Williamson and others, 1990). An effective porosity value of 0.35 is considered representative of the Cook Mountain and the middle confining units (Freeze and Cherry, 1979).

Some of the data needed to estimate average vertical travel time at public-supply well sites in Union County are listed in table 3. Readers are reminded, however, that the data in table 3 are based, in part, on regionalized or generalized values for hydrologic and lithologic characteristics. Where more site specific or more current data are available, these data should be used in place of the data in table 3 to estimate average vertical travel times using equation 2.

The potential for the travel of contaminants through the Cook Mountain and middle confining units was evaluated based on estimations of the vertical-travel time of water. According to hydrostatic head data (as expressed by potentiometric surfaces in figures 6-8), downward leakage of water and contaminants through both the Cook Mountain and middle confining units is possible. However, computed travel times indicate that water moves vertically through the confining units very slowly, provided these units are not breached. Computed average vertical travel times through the Cook Mountain confining unit based on hydraulic and hydrogeologic conditions observed at public-supply wells ranged from about 70 to 1,000 years. Computed average vertical travel times through the middle confining unit ranged from about 35 to 600 years. These travel times are based on 1990 hydrostatic head data and, therefore, will change as head in the wells rises or falls. Large ground-water withdrawals in the El Dorado well field has caused a large cone of depression to develop with the center of the cone at El Dorado (fig. 8). Head differences across the middle confining unit in the Sparta Sand are greatest at the center of this cone (table 3). If pumpage around El Dorado were to be redistributed, then the head differential at the center of the cone probably would decrease and vertical-travel time would increase somewhat. The thickness of the Cook Mountain and middle confining units at all public-supply wells

Table 3.--*Selected data needed to estimate average vertical-travel time through confining units at public-supply wells in Union County, Arkansas*

[Δh_1, difference between water table in the Cockfield aquifer and the potentiometric surface of the Greensand aquifer, in feet; Δh_2, difference between the potentiometric surfaces of the Greensand and El Dorado aquifers, in feet; fig., figure; Assoc., Association; --, no data; do., ditto]

Well site number (fig. 2)	Owner of well	Owner's well number	Aquifer	Potentiometric surface, in feet above or below (-) sea level: Cockfield aquifer	Greensand aquifer	El Dorado aquifer	Thickness, in feet: Cook Mountain confining unit (b_1)	Middle confining unit (b_2)	Δh_1	Δh_2
1	Batts-Lapile Water Assoc.	1	Greensand	100	25	--	[1]130	--	75	--
2	do.	2	Greensand	100	25	--	[1]130	--	75	--
3	Calion Water Works	1	El Dorado	[2]87	64	-47	[1]55	[1]50	[2]23	111
4	do.	2	El Dorado	[2]87	64	-47	[1]55	[1]65	[2]23	113
5	Crabapple Point Water System	1	Greensand	[2]87	64	--	[3]55	--	[2]23	--
6	do.	2	Greensand	[2]87	64	--	[3]55	--	[2]23	--
7	El Dorado Water Works	10A	El Dorado	200	90	-165	[3]100	[3]70	110	255
8	do.	11	El Dorado	200	90	-165	[3]100	[3]70	110	255
9	do.	12	El Dorado	200	90	-165	[3]100	[3]70	110	255
10	do.	13	El Dorado	200	90	-171	[3]100	[3]70	110	261
11	do.	14	El Dorado	200	90	-170	[3]100	[3]70	110	260
12	do.	15	El Dorado	200	90	-160	[3]100	[3]70	110	250
13	do.	16	El Dorado	190	100	-160	[3]95	[3]75	90	260
14	do.	17	El Dorado	200	90	-169	[3]80	[3]55	110	259
15	do.	18	El Dorado	200	90	-169	[1]80	[1]55	110	259
16	do.	19	El Dorado	200	90	-169	[3]80	[3]55	110	259
17	Faircrest Water Assoc.	1	El Dorado	190	45	-115	[3]100	[3]160	145	160
18	do.	2	El Dorado	160	45	-86	[3]100	[3]160	115	131
19	Felsenthal Water Assoc.	1	Greensand	56	12	--	[3]120	--	44	--
20	do.	2	Cockfield	56	--	--	--	--	--	--
21	Huttig Water Works	1	Greensand	90	5	--	[3]120	--	85	--
22	do.	2	Greensand	90	4	--	[3]120	--	86	--
23	Highway 82 Water Assoc.	--	El Dorado	220	[4]115	-120	[3]100	[3]60	105	235
24	Johnson Township Water Assoc.	--	El Dorado	180	75	-120	[1]160	[1]138	105	195

Table 3.--*Selected data needed to estimate average vertical-travel time through confining units at public-supply wells in Union County, Arkansas*--Continued

Well site number (fig. 2)	Owner of well	Owner's well number	Aquifer	Potentiometric surface, in feet above or below (-) sea level: Cockfield aquifer	Greensand aquifer	El Dorado aquifer	Thickness, in feet: Cook Mountain confining unit (b_1)	Middle confining unit (b_2)	Δh_1	Δh_2
25	Junction City Water Works	1	El Dorado	160	25	-45	[3]80	[3]50	135	70
26	do.	2	El Dorado	160	25	-45	[3]80	[3]50	135	70
27	Lawson-Urbana Water Assoc.	1	El Dorado	180	75	-78	[3]100	[3]60	105	153
28	do.	2	El Dorado	180	75	-75	[3]100	[3]60	105	150
29	Marysville Water Assoc.	--	El Dorado	240	[4]110	-22	[3]180	[3]40	130	132
30	Mount Holly Water Works	2	El Dorado	--	--	55	--	[3]60	--	--
31	do	3	El Dorado	--	--	60	--	[3]60	--	--
32	New Hope Water Assoc.	1	El Dorado	200	45	-30	[3]110	[3]50	155	75
33	do.	2	El Dorado	200	45	-35	[3]110	[3]50	155	80
34	New London Water Assoc.	1	El Dorado	200	75	-4	[3]55	[3]120	125	79
35	do.	2	El Dorado	200	75	-6	[1]55	[1]120	125	81
36	Norphlet Water Works	2	El Dorado	--	--	-85	--	[3]50	--	--
37	do.	3	El Dorado	--	--	-90	--	[3]50	--	--
38	Old Union Water Assoc.	--	El Dorado	200	90	-100	[1]130	[1]50	110	190
39	Parkers Chapel Water Assoc.	1	El Dorado	200	90	-151	[3]100	[3]80	110	241
40	do.	2	El Dorado	200	90	-139	[3]100	[3]80	110	229
41	Smackover Water Works	5	El Dorado	--	--	-41	--	[3]70	--	--
42	do.	6	El Dorado	--	--	-40	--	[3]70	--	--
43	do.	7	El Dorado	--	--	-50	--	[3]70	--	--
44	do.	8	El Dorado	--	--	-45	--	[3]70	--	--
45	Strong Water Works	1	Greensand	100	50	--	[3]110	--	50	--
46	do.	2	Greensand	100	34	--	[3]110	--	66	--
47	do.	3	Greensand	100	50	--	[3]110	--	50	--
48	do.	4	Greensand	100	56	--	[3]110	--	44	--

Table 3.--*Selected data needed to estimate average vertical-travel time through confining units at public-supply wells in Union County, Arkansas*--Continued

Well site number (fig. 2)	Owner of well	Owner's well number	Aquifer	Potentiometric surface, in feet above or below(-) sea level: Cockfield aquifer	Greensand aquifer	El Dorado aquifer	Thickness, in feet: Cook Mountain confining unit (b_1)	Middle confining unit (b_2)	Δh_1	Δh_2
49	do.	5	Greensand	100	50	--	[3]110	--	50	--
50	do.	6	Greensand	100	53	--	[3]110	--	47	--
51	Wesson-Newell Water Assoc.	1	El Dorado	180	85	-95	[3]90	--	95	180

[1]Data based on geophysical log of the well.
[2]Alluvial deposits replace Cockfield aquifer.
[3]Data based on nearby geophysical well log.
[4]Estimated.

completed in either the Greensand or El Dorado aquifers indicate that these aquifers may be substantially protected from surface contaminants by confining units (assuming no breaches in these confining units have occurred.).

Lateral Movement Through Aquifers

Porosity, horizontal hydraulic-conductivity and hydraulic-gradient values necessary to compute the average velocity of ground-water movement through aquifers can be derived from various sources. A porosity value of 0.30, is considered representative of the Sparta Sand (Freeze and Cherry, 1979). For their ground-water flow model analysis, Fitzpatrick and others (1990) delineated four zones of uniform horizontal hydraulic conductivity for the Sparta aquifer from the recharge area to the city of El Dorado. These values of horizontal hydraulic conductivity range from 1 to 15 ft/d. Hosman and others (1968) reported a hydraulic conductivity value for the Sparta Sand in Union County of 10.7 ft/d. Hydraulic-gradient values for 1990 were estimated from a 1986 potentiometric surface map of the Sparta aquifer (Edds and Fitzpatrick, 1989). Hydraulic gradients in the Sparta aquifer in and around Union County have not changed measurably in the past 10 years (Ackerman, 1987b). Various combinations of hydraulic-gradient and horizontal hydraulic-conductivity values were then substituted into equation 3 to compute the average velocity of lateral ground-water movement in the Sparta aquifer (table 4).

The recharge areas of aquifers are the areas most susceptible to the introduction of contaminants into the ground-water flow system from the land surface. From the recharge area a contaminant could move down-gradient, and adversely affect the quality of ground water at points of discharge. The Cockfield Formation crops out and is recharged throughout most of Union County and is, therefore, susceptible to contamination from surface sources in the county (fig. 4). The Sparta Sand crops out and is recharged northwest of Union County (fig. 4), and is most susceptible to contamination from surface sources in that area.

The potential for contamination of the Greensand and El Dorado aquifers by contaminants originating in the recharge area, was evaluated on the basis of estimated ground-water velocities. Computed velocities indicate that water within the Sparta Sand not proximate to pumped wells moves slowly, ranging from approximately 1 to 70 ft/yr, depending on horizontal hydraulic conductivity and hydraulic gradient (table 4). Estimated travel times of ground water from recharge areas to public-supply wells in the Greensand and El Dorado aquifers is on the order of several thousand years. However, the movement of contaminants in ground water is controlled by a number of factors described previously, in addition to the rate of ground-water flow. Therefore, the travel times for ground water can only provide an approximation of actual contaminant travel times.

Table 4.--***Average velocities of lateral ground-water movement in the Sparta aquifer based on various combinations of horizontal hydraulic conductivity and hydraulic gradient***

[Average velocities in feet per year; ft/d, feet per day; ft/mi, feet per mile]

Horizontal hydraulic conductivity (ft/d)	Average velocity in feet per year, for indicated hydraulic gradient in foot per foot (and feet per mile)			
	0.00051 (2.7 ft/mi)	0.00126 (6.7 ft/mi)	0.00189 (10.0 ft/mi)	0.00379 (20.0 ft/mi)
[1]1	0.62	1.53	2.30	4.61
[1]2	1.24	3.07	4.60	9.22
[1]8	4.96	12.26	18.40	36.89
[2]10.7	6.64	16.40	24.60	49.34
[1]15	9.31	23.00	34.49	69.17

[1]Calibrated horizontal hydraulic conductivity used in the ground-water flow model of the Sparta aquifer in or around Union County (Fitzpatrick and others, 1990).

[2]Horizontal hydraulic conductivity value of the Sparta aquifer in Union County (Hosman and others, 1968).

Movement Through Natural and Manmade Breaches in the Confining Units

Although analytical techniques indicate that the Greensand and El Dorado aquifers generally are protected from surface contamination by confining units, natural and manmade breaches in the confining units could allow a surface contaminant to move relatively quickly into the aquifer. A natural breach in the confining unit could be caused by fractures related to faulting and jointing. An area of particular concern is in the vicinity of a graben located just southeast of the city of El Dorado (fig. 4). In this area hydraulic connection may exist between juxtaposed aquifers above and below the confining units as reported by Broom and others (1984) and Hosman (1982). If this connection exists, the movement of contaminants from relatively shallow to relatively deep aquifers could be facilitated and the susceptibility of the fresh ground-water flow system and of nearby supply wells to surface contamination enhanced.

Manmade breaches in the confining units such as abandoned wells, injection wells, and open boreholes are ubiquitous in many parts of the study area. However, documentation of aquifer contamination from such sources is rare. Data describing the location, construction, and current condition of abandoned wells is sparse and the potential for contamination can only be surmised based on proximity to active public-supply wells. More than 7,500 oil, gas, and related wells are known to have been drilled in Union County prior to 1981 (fig. 12). Aquifers underlying, and hence public-supply wells in, the towns of Smackover, Norphlet, Parkers Chapel, El Dorado, and Old Union are located within known oil fields where abandoned wells are concentrated.

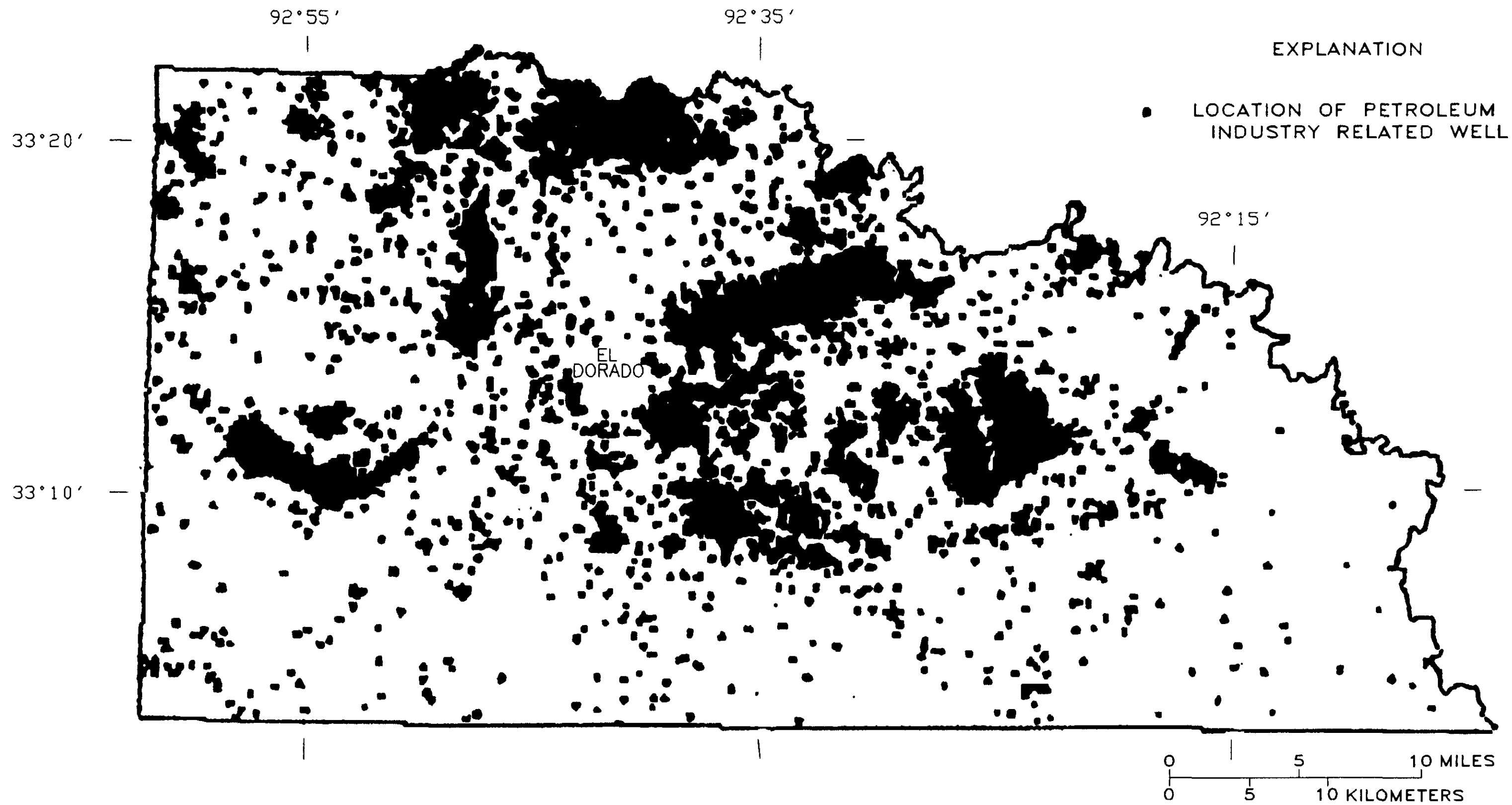


Figure 12.--Distribution of petroleum-industry related wells installed prior to 1981, Union County, Arkansas.

Susceptibility of Public-Supply Wells

Susceptibility of public-supply wells in Union County to contamination from surface sources may be highly variable because of the spatial variability of hydraulic and hydrogeologic characteristics and proximity to potential sources of contamination. In addition, natural and man-made breaches in confining units may enhance the susceptibility of the aquifers and hence the susceptibility of many wells in Union County to contamination.

Several well sites may be particularly susceptible to surface contamination. The well at site 20 near Felsenthal may be susceptible to surface contamination because the well is located in the flood plain of the Ouachita River and is completed in the Cockfield aquifer at a relatively shallow depth of 206 ft. The lithologic character of the sediments in this area is not well known but an areally extensive confining clay that would impede the downward movement of water and contaminant has not been identified using available data. However, interbedded clay within the Cockfield Formation may impede the movement of a contaminant to some degree. The vertical movement of water is from the alluvium toward the Cockfield aquifer, as indicated by water-level measurements, which indicate a hydraulic separation to some degree between the alluvium and the Cockfield aquifer.

Similar conditions occur at well sites 5 and 6 near Calion. These wells are located in the flood plain of the Ouachita River and are completed in the Greensand aquifer at a depth of only 130 ft. In this area, the Cockfield Formation and part of the Cook Mountain Formation have been eroded leaving about 40 ft of alluvium overlying about 55 ft of the Cook Mountain confining unit. The length of the screen is unknown, but the top of the screen probably is about 15 to 25 ft below the top of the Greensand aquifer. Differences in water levels between the alluvium and the Greensand aquifer indicate that the direction of vertical movement of water is toward the Greensand aquifer.

SUMMARY

In an effort to provide an overview of the susceptibility of aquifers in Union County, Arkansas, to contamination from potential surface sources, hydrogeologic conditions were determined at 51 public-supply well sites and potential contaminant sources were located. The city of El Dorado and surrounding area has been affected by urban growth and industrial activities. The major industry in Union County is the petrochemical industry. Major sources of potential contamination in Union County include numerous surface waste impoundments, 6 active landfills, and more than 300 injection wells. The overview of the susceptibility of aquifers to contamination from potential surface sources was partly based on the computation of the vertical movement of ground water through confining units and of the lateral movement of ground water through aquifers from areas of recharge to points of withdrawal.

The sediments of Tertiary age that comprise the formations within the Claiborne Group are as much as 1,360 ft thick in Union County. The Claiborne Group consists of, in ascending order, the Cane River Formation, Sparta Sand, Cook Mountain Formation, and Cockfield Formation. All geologic units below the Sparta Sand contain saline water. The sand beds in the Cockfield and Sparta Sand contain most of the freshwater in Union County. The Sparta Sand contains two aquifers in Union County, known locally as the Greensand aquifer and the El Dorado aquifer. Fifty of the public-supply wells in Union County are completed in one of these two aquifers. The Cane River and Cook Mountain Formations are regional confining units. Alluvial and terrace deposits of Quaternary age occur in bottomlands of most streams throughout Union County and overlie Cockfield and Cook Mountain deposits. The Cockfield Formation is present at land surface throughout most of Union County. The Cook Mountain Formation is present at land surface only in the northern and northwestern parts of the county. The nearest outcrops of the Sparta Sand are about 4 mi west and 3 mi northwest of the northwest corner of Union County, in Columbia and Ouachita Counties, respectively.

The Cockfield aquifer generally is not stressed by withdrawals in Union County. The flow of water in this aquifer generally is in the direction of land slope and toward streams draining the area. The Greensand aquifer is moderately stressed by withdrawals in Union County. The direction of ground-water flow in this aquifer generally is southward. The El Dorado aquifer is heavily stressed by withdrawals in Union County. The generalized potentiometric surface of the El Dorado aquifer shows that water in the aquifer in Union County is moving toward the center of a cone of depression at El Dorado, Arkansas. Major cones of depression also have developed in the Sparta aquifer in areas to the west and south of Union County. These cones of depression are coalescing because of the withdrawal of large quantities of water from these aquifers. Only a generalized concept of the cone of depression and of the direction and rate of ground-water movement in the El Dorado aquifer is available in Union County because of the lack of control and because of the spatial and temporal variations in withdrawals from this aquifer in the El Dorado area.

Analytical techniques based on modification of Darcy's Law were used to estimate vertical-travel times through confining units (assuming no breaches in the unit). Average vertical travel time for ground water to move downward through the Cook Mountain confining unit to the Greensand aquifer ranged from about 70 to 1,000 years based on an estimated vertical hydraulic-conductivity value of 0.0003 ft/d, clay thicknesses that ranged from 55 to 180 ft, an effective porosity value of 0.35, and head differences between the aquifers. Average vertical travel time for ground water to move downward through the middle confining unit of the Sparta Sand to the El Dorado aquifer ranged from about 35 to 600 years based on an estimated vertical hydraulic-conductivity value of 0.0003 ft/d, clay thicknesses that ranged from 40 to 160 ft, an effective porosity value of 0.35, and head differences between the aquifers. Average lateral velocities of ground-water movement within the Sparta Sand in and around Union County were about 1 to 70 ft/yr based on horizontal hydraulic-conductivity values that ranged from 1 to 15 ft/d and on hydraulic-gradient values that ranged from 2.7 to 20 ft/mi. These computations provide only a general estimate of travel time based on reported ranges of aquifer characteristics. Travel times computed in this manner may differ substantially from travel times at specific sites. Where more site-specific hydrologic and lithologic data are available, these data can be used with equations presented in this report to more accurately estimate travel times.

Although analytical techniques indicate that aquifers in Union County generally are protected from surface contamination, natural and manmade breaches in confining units could allow a surface contaminant to bypass the confining unit and pass directly into the aquifer. A natural breach caused by faulting is of particular concern in the vicinity of a graben located just southeast of the city of El Dorado; however, manmade breaches in confinement such as abandoned wells, injection wells, and open boreholes are the primary threat to public-supply wells. More than 7,500 oil, gas, and related wells that penetrated the confining units were drilled in Union County prior to 1981.

One well near Felsenthal and two wells near Calion possibly are more susceptible to contamination than most other public-supply wells in Union County because these wells are relatively shallow and are located in the flood plain of the Ouachita River. However, all public-supply wells in Union County are probably susceptible to some degree to contamination from surface sources because of natural or manmade breaches in the confining units.

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