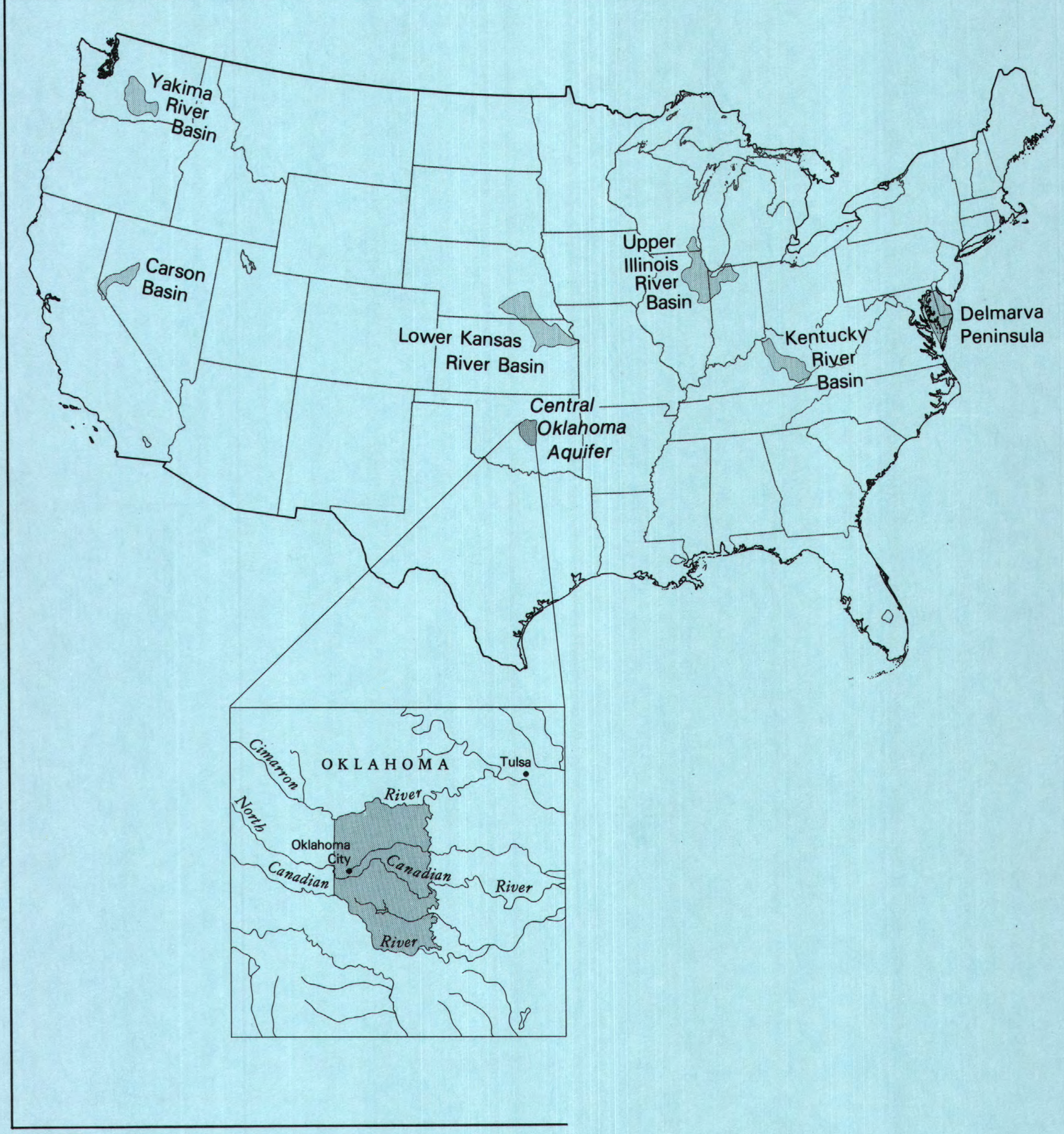
GROUND-WATER-QUALITY ASSESSMENT OF THE CENTRAL OKLAHOMA AQUIFER, OKLAHOMA -- ANALYSIS OF AVAILABLE WATER-QUALITY DATA THROUGH 1987



U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

U.S. GEOLOGICAL SURVEY
Open-File Report 88—728

NATIONAL WATER - QUALITY ASSESSMENT PROGRAM

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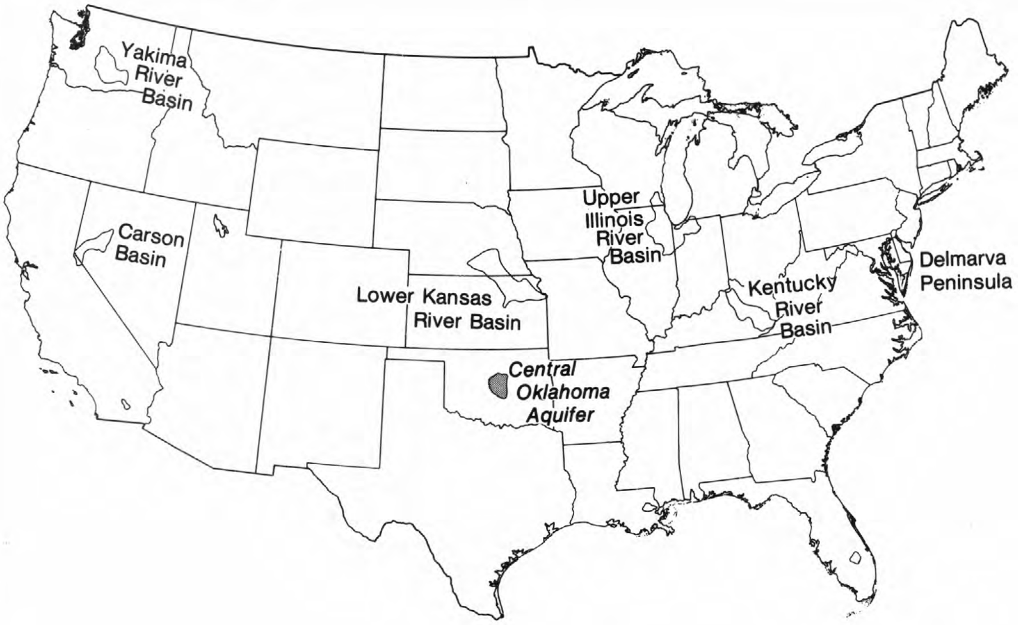

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1989

DEPARTMENT OF THE INTERIOR
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FOREWORD

One of the great challenges faced by water-resources scientists is providing reliable water-quality information to guide the management and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resources agencies and by academic institutions. Many of these organizations are collecting water-quality data for a host of purposes, including compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research to advance our understanding of water-quality processes. In fact, during the past two decades, tens of billions of dollars have been spent on water-quality data-collection programs. Unfortunately, the utility of these data for present and future regional and national assessments is limited by such factors as the areal extent of the sampling network, the frequency of sample collection, the varied collection and analytical procedures, and the types of water-quality characteristics determined.

To address this deficiency, the Congress appropriated funds for the U.S. Geological Survey, beginning in 1986, to test and refine concepts for a National Water-Quality Assessment (NAWQA) Program that, if fully implemented, would:

1. Provide a nationally consistent description of water-quality conditions for a large part of the Nation's water resources;
2. Define long-term trends (or lack of trends) in water quality; and
3. Identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends.

As presently envisioned, a full-scale NAWQA Program would be accomplished through investigations of a large set of major river basins and aquifer systems that are distributed throughout the Nation and that account for a large percentage of the Nation's population and freshwater use. Each investigation would be conducted by a small team that is familiar with the river basin or aquifer system. Thus, the investigations would take full advantage of the region-specific knowledge of persons in the areas under study.

Four surface-water projects and three ground-water projects are being conducted as part of the pilot program to test and refine the assessment methods and to help determine the need for and the feasibility of a full-scale program. An initial activity of each pilot project is to compile, screen, and interpret available data to provide an initial description of water-quality conditions and trends in the study area. The results of this analysis of available data are presented in individual reports for each project.

The pilot studies depend heavily on cooperation and information from many Federal, State, interstate, and local agencies. The assistance and suggestions of all are gratefully acknowledged.

Philip Cohen

Philip Cohen
Chief Hydrologist

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CONVERSION FACTORS AND ABBREVIATIONS

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

Multiply inch-pound units	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter (m^3)
foot (ft)	0.3048	meter (m)
gallon per minute (gal /min)	0.06308	liter per second (L/s)
inch (in.)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

°F = 1.8 (°C) + 32

ADDITIONAL ABBREVIATIONS

meq/L	milliequivalents per liter	pCi/L	picocuries per liter
mg/L	milligrams per liter	MCL	maximum contaminant level
μg/L	micrograms per liter	SMCL	secondary maximum contaminant level

Sea Level: In this report "sea level" refers to the 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 "Sea Level Datum of 1929."

GROUND-WATER-QUALITY ASSESSMENT OF THE CENTRAL OKLAHOMA AQUIFER, OKLAHOMA -- ANALYSIS OF AVAILABLE WATER-QUALITY DATA THROUGH 1987

By David L. Parkhurst, Scott C. Christenson, and Jamie L. Schlottmann

EXECUTIVE SUMMARY

Beginning in 1986, the Congress annually has appropriated funds for the U.S. Geological Survey to test and refine concepts for a National Water-Quality Assessment (NAWQA) Program. The long-term goals of a full-scale program would be to:

(1) Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's surface- and ground-water resources;

(2) Define long-term trends (or lack of trends) in water quality; and

(3) Identify, describe, and explain, as possible, the major factors that affect the observed water-quality conditions and trends.

The results of the NAWQA Program will be made available to water managers, policy makers, and the public, and will provide an improved scientific basis for evaluating the effectiveness of water-quality management programs.

At present (1988), the assessment program is in a pilot phase in seven project areas throughout the country that represent diverse hydrologic environments and water-quality conditions. The Central Oklahoma aquifer project is one of three pilot ground-water projects. One of the initial activities performed by each pilot project was to compile, screen, and interpret the large amount of water-quality data available within each study unit.

The purpose of this report is to assess the water quality of the Central Oklahoma aquifer using the information available through 1987. The scope of the work includes compiling data from Federal, State, and local agencies; evaluating the suitability of the information for conducting a regional water-quality assessment; mapping regional variations in major-ion chemistry; calculating summary statistics of the available water-quality data; producing maps to show the location and number of samples that exceeded water-quality standards; and performing contingency-table analyses to determine the relation of geologic unit and depth to the occurrence of chemical constituents that exceed water-quality standards. This report provides an initial description of water-quality conditions in the Central Oklahoma aquifer study unit. No attempt was made in this report to determine the causes for regional variations in major-ion chemistry or to examine the reasons that some chemical constituents exceed water-quality standards.

Description of the Study Unit

The Central Oklahoma aquifer underlies about 3,000 square miles of central Oklahoma and is used extensively for municipal, industrial, commercial, and domestic water supplies. Between 1970 and 1985, the quantity of ground water withdrawn from the Central Oklahoma aquifer approximately doubled. While uses other than public supply were approximately constant, water use for public supplies tripled from about 10 thousand acre-feet during 1970 to about 30 thousand acre-feet during 1985.

The Central Oklahoma aquifer underlies all or parts of Cleveland, Lincoln, Logan, Oklahoma, Payne, and Pottawatomie Counties. Much of the population resides in the major cities in the central part of the study unit, including Oklahoma City, Norman, Midwest City, Edmond, and Moore. Although about one third of the study unit is urban and suburban, the dominant land use is agriculture and there are large areas of deciduous forest.

The Central Oklahoma aquifer consists of those geologic units that yield substantial volumes of water to wells from the extensive, continuous flow system underlying Cleveland, Lincoln, Logan, Oklahoma, Payne, and Pottawatomie Counties. Ground water in this flow system originates as recharge from precipitation on the aquifer and circulates in the Quaternary-age alluvium and terrace deposits along major streams; the Permian-age Garber Sandstone and Wellington Formation; and the Permian-age Chase, Council Grove, and Admire Groups (undifferentiated in this report). The El Reno and Hennessey Groups overlie the aquifer in the western part of the study unit, with the Hennessey Group forming a confining unit. The Vanoss Formation is a

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confining unit that underlies the aquifer and crops out in the eastern part of the study unit.

Sources of Water-Quality Data

The majority of the water-quality data for the Central Oklahoma aquifer study unit for this report were obtained from six Federal, State, and local agencies: the Association of Central Oklahoma Governments, the Oklahoma State Department of Health, the Oklahoma Water Resources Board, the U.S. Department of Defense, the U.S. Department of Energy, and the U.S. Geological Survey. Some additional chemical analyses were obtained from municipalities and consulting firms. A total of 4,439 analyses from 1,604 wells and 409 distribution systems were assembled for this report. Maps presented in the report show the sampling locations for each agency. A table shows the number of sites sampled and the number of chemical analyses provided by each agency.

Analyses that could be associated with an individual well were stored in the U.S. Geological Survey's National Water Information System (NWIS) data base. Data associated with water-distribution systems or site-specific contamination studies were not entered in the NWIS data base. Data that could not be associated with a known geographic location were not considered in this report.

The available chemical analyses of water from the study unit are not ideal for conducting a water-quality assessment. Each agency has sampled for different purposes and, accordingly, has analyzed different constituents using different sampling techniques and analytical methods. The lack of consistency in sampling techniques and analytical methods makes it difficult to combine data from different agencies. Although wells sampled by some of the agencies were evenly distributed areally, none of the data were evenly distributed vertically. Except for the Department of Defense data from wells near Tinker Air Force Base, there are virtually no analyses available for organic compounds in the study unit.

Analysis of Available Water-Quality Data

The available data were used to determine regional variations in major-ion chemistry for the shallow and deep zones of the study unit; to calculate summary statistics for each constituent for which data were available; to map and tabulate the occurrence of constituents that exceeded water-quality standards; and to evaluate the relation of geologic unit and depth to the occurrence of constituents that exceed water-quality standards.

Regional Variations in Major-Ion Chemistry

Water composition was examined in shallow and deep zones of the study unit. There are distinct spatial patterns in water composition in the shallow zone that are related to geologic units. The chemical composition of water in the alluvium and terrace deposits is variable and may contain large concentrations of any or all of the major ions: sodium, calcium, magnesium, bicarbonate, chloride, or sulfate. The predominant ions in water in the El Reno Group and the shallow part of the Garber Sandstone and Wellington Formation generally are calcium, magnesium, and bicarbonate. Water in the Hennessey, Chase, Council Grove, and Admire Groups and in the Vanoss Formation commonly contains large concentrations of sodium, sulfate, and chloride in addition to calcium, magnesium, and bicarbonate. Deep wells generally are completed in the Garber Sandstone and Wellington Formation. Water from these deep wells has large concentrations of calcium, magnesium, and bicarbonate or sodium and bicarbonate. Large concentrations of sulfate and chloride are common in some parts of the deep Garber Sandstone and Wellington Formation. Sodium chloride brines are found below freshwater throughout the study unit.

Comparison of Selected Inorganic Constituents to Water-Quality Standards

The U.S. Environmental Protection Agency has set two types of drinking-water standards: the MCL (maximum contaminant level), which is a primary standard for the protection of human health, and the SMCL (secondary maximum contaminant level), which is a recommended standard based on aesthetic reasons related to public acceptance of drinking water. MCL's or SMCL's are established for 20 inorganic constituents considered in this study.

Nitrate, arsenic, chromium, selenium, and residual-alpha radioactivity (gross alpha particle activity, excluding radon and uranium) concentrations exceeded the MCL's in some ground-water samples from the study unit. Sulfate, chloride, manganese, and dissolved-solids concentrations and pH values exceeded the SMCL's in some ground-water samples. Total iron concentrations exceeded the SMCL in some ground-water samples, but dissolved iron concentrations rarely exceeded the SMCL. Although no standard currently (1988) exists for uranium, it is a potential concern to health. Concentrations of uranium in ground water in the study unit commonly exceeded 10 picocuries per liter or 15 micrograms per liter. The available analyses indicate that concentrations of fluoride, barium, cadmium, copper, lead, mercury, silver, zinc, and radium-226 rarely exceed the MCL's or SMCL's in ground water from the study unit.

The following table was derived from the data that were selected for contingency-table analysis as described below. The table shows the overall percentage of the selected analyses that exceeded the water-quality standards. Dissolved and total concentration data were combined for the percentages shown in the table. Because the maximum concentration was selected to represent a well or distribution system, the table shows the percentage of wells and distribution systems that have had at least one analysis that exceeded a standard for a constituent.

Constituent	Type of standard	Percentage of analyses that exceeded the standard
Nitrate	MCL	8.6
Arsenic	MCL	4.3
Chromium	MCL	6.8
Selenium	MCL	12.5
Residual-alpha radioactivity[1]	MCL	12.2
pH less than 6.5	SMCL	10.0
pH greater than 8.5	SMCL	3.5
Sulfate	SMCL	9.6
Chloride	SMCL	6.9
Dissolved solids	SMCL	37.9
Iron	SMCL	4.1
Manganese	SMCL	5.3

[1] The term residual-alpha radioactivity is used for gross alpha radioactivity excluding radon and uranium.

A contingency-table analysis was used to examine the relation between geohydrologic categories and the occurrence of constituents at concentrations that exceeded the water-quality standards. The chemical analyses were grouped into geohydrologic categories, which were defined by geologic unit and, for the Garber Sandstone and Wellington Formation, by well depth or sampling depth. For a given geohydrologic category, if there were more than one analysis from a well or distribution system for a constituent, the maximum concentration was selected to represent that well or distribution system in that geohydrologic category.

The contingency-table statistics indicated that the proportion of analyses that exceeded the water-quality standard was significantly different among geohydrologic categories for most constituents. The following conclusions were drawn from the available data and the contingency-table statistics. The word "common" is used to describe situations where approximately 10 percent or more of the data exceeded a water-quality standard.

(1) Ground-water concentrations of nitrate commonly exceed the 10-milligrams-per-liter MCL in most parts of the study unit except at depths greater than 300 feet in the Garber Sandstone and Wellington Formation.

(2) Ground-water concentrations of arsenic commonly exceed the 50-micrograms-per-liter MCL at depths greater than 300 feet in the Garber Sandstone and Wellington Formation, but rarely exceed the MCL in the rest of the study unit.

(3) Ground-water concentrations of chromium commonly exceed the 50-micrograms-per-liter MCL at depths greater than 300 feet in the Garber Sandstone and Wellington Formation, but rarely exceed the MCL in the rest of the study unit.

(4) Ground-water concentrations of selenium commonly exceed the 10-micrograms-per-liter MCL at depths greater than 100 feet in the Garber Sandstone and Wellington Formation, but rarely exceed the MCL in other parts of the study unit.

(5) No data were available for residual-alpha radioactivity for many parts of the study unit. In the limited data that were available, concentrations exceeded the MCL most frequently in ground-water samples from the Chase, Council Grove, and Admire Groups.

(6) Ground-water pH values commonly exceed 8.5, the upper limit of the SMCL for pH, at depths greater than 300 feet in the Garber Sandstone and the Wellington Formation and in the Vanoss Formation. Ground-water pH values less than 6.5, the lower limit of the SMCL for pH, commonly occur in most parts of the study unit except at depths greater than 300 feet in the Garber Sandstone and Wellington Formation.

(7) Ground-water concentrations of sulfate commonly exceed the 250-milligrams-per-liter SMCL in most parts of the study unit and concentrations greater than the SMCL are most common in ground water from the Hennessey Group.

(8) Ground-water concentrations of chloride greater than the 250-milligrams-per-liter SMCL occur throughout the study unit.

(9) Ground-water concentrations of dissolved solids greater than the 500-milligrams-per-liter SMCL commonly occur throughout the study unit.

(10) Concentrations of total iron greater than the 300-micrograms-per-liter SMCL are common in water from wells in the study unit; but concentrations of dissolved iron rarely exceed the SMCL.

(11) Concentrations of manganese commonly exceed the 50-micrograms-per-liter SMCL in ground water from alluvium and terrace deposits.

(12) Concentrations of uranium that exceed 10 picocuries per liter or 15 micrograms per liter are common in most parts of the study unit. Large concentrations of uranium occur most frequently in the Hennessey Group; at depths greater than 100 feet in the Garber Sandstone and Wellington Formation; and in the Chase, Council Grove, and Admire Groups.

Organic Compounds

The presence of synthetic organic compounds indicates that some ground water has been contaminated at Tinker Air Force Base. No data for organic compounds were available for any part of the study unit other than the area within and around Tinker Air Force Base. Therefore, at the present time (1988), it cannot be determined whether contamination by organic compounds is a common problem in the study unit.

INTRODUCTION

Beginning in 1986, the Congress annually has appropriated funds for the U.S. Geological Survey to test and refine concepts for a National Water-Quality Assessment (NAWQA) Program. The long-term goals of a full-scale program would be to:

(1) Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's surface- and ground-water resources;

(2) Define long-term trends (or lack of trends) in water quality; and

(3) Identify, describe, and explain, as possible, the major factors that affect the observed water-quality conditions and trends.

The results of the NAWQA Program will be made available to water managers, policy makers, and the public, and will provide an improved scientific basis for evaluating the effectiveness of water-quality management programs. A description of the concepts for a NAWQA Program is provided by Hirsch and others (1988).

The NAWQA Program is organized into study units based on known hydrologic systems. For ground water, the study units are large parts of aquifers or aquifer systems, and for surface water the study units are major river basins. The study units are large, involving areas of a few thousand to several tens of thousands of square miles.

At present (1988), the assessment program is in a pilot phase in seven project areas throughout the country that represent diverse hydrologic environments and water-quality conditions. Pilot project areas focusing primarily on ground water include the Carson basin in Nevada and California, the Central Oklahoma aquifer in Oklahoma, and the Delmarva Peninsula in Delaware, Maryland, and Virginia. Pilot project areas focusing primarily on surface water include the Yakima River basin in Washington, the lower Kansas River basin in Kansas and Nebraska, the Kentucky River basin in Kentucky, and the upper Illinois River basin in Illinois, Indiana, and Wisconsin.

Because the NAWQA Program is national in scope, common approaches, methods, and reporting will be used by the pilot projects. The national scope is critical to assure consistent and comparable information that can be integrated and analyzed in a national context. Each project, however, will be designed to investigate the water-quality problems of the individual study unit. Thus, in the design of the NAWQA Program, each project will consider the unique geohydrologic conditions and land use in the study unit.

The Central Oklahoma aquifer was selected for study in the pilot NAWQA Program because it is a major source for water supplies in central Oklahoma and because it has several known or suspected water-quality problems. These problems include: arsenic, chromium, and selenium concentrations in excess of public drinking-water standards; large gross alpha particle activity concentrations; contamination by synthetic organic compounds; and contamination by oil-field brines and drilling fluids. The aquifer also was chosen because it underlies large urban areas, and the effects of an urban environment on regional ground-water quality have not been studied extensively.

The objectives of the Central Oklahoma aquifer project are to: (1) Investigate regional ground-water quality throughout the aquifer, emphasizing the occurrence and distribution of potentially toxic substances in ground water, including trace elements, organic compounds, and radioactive constituents; (2) describe the relation of ground-water quality to hydrogeologic and other pertinent factors; and (3) provide a general description of the location, nature, and causes of selected water-quality problems within the study unit.

One of the initial activities performed by each pilot project was to compile, screen, and interpret the large amount of water-quality data available within each study unit. These data were collected by different agencies for widely different purposes. This preliminary water-quality assessment will help to establish priorities and to formulate plans for subsequent project field activities, as well as to provide the foundation for detailed regional assessments of ground-water quality within each study unit.

Purpose and Scope

The purpose of this report is to assess the water quality of the Central Oklahoma aquifer using the information available through 1987. The scope of the work includes compiling data from Federal, State, and local agencies, evaluating the suitability of the information for conducting a regional water-quality assessment, mapping regional variations in major-ion chemistry, calculating summary statistics of the available water-quality data, producing maps to show the location and number of samples that exceeded water-quality standards, and performing contingency-table analyses to determine the relation of geologic unit and depth to the occurrence of chemical constituents that exceed water-quality standards. The report provides an initial description of water-quality conditions in the Central Oklahoma aquifer. No attempt was made in this report to determine the causes for regional variations in major-ion chemistry or to examine the reasons that some chemical constituents exceed water-quality standards.

Acknowledgments

The data that are discussed in this report were provided to the U.S. Geological Survey by several agencies. The NAWQA project team would like to thank Judith Duncan, Rocky McElvany, and Mark Kurklin of the Oklahoma State Department of Health, Suzanne Moore and Larry Pinkston of the Association of Central Oklahoma Governments, and Duane Smith of the Oklahoma Water Resources Board for their efforts in providing data.

DESCRIPTION OF THE STUDY UNIT

The Central Oklahoma aquifer underlies about 3,000 mi^2 (square miles) of central Oklahoma (fig. 1), where the aquifer is used extensively for municipal, industrial, commercial, and domestic water supplies. Most of the usable ground water within the aquifer is in the Garber Sandstone and the Wellington Formation. Substantial quantities of usable ground water also are present in the Chase, Council Grove, and Admire Groups, which underlie the Garber Sandstone and Wellington Formation, and in alluvium and terrace deposits, which are associated with the major streams in the study unit.

The water quality of the Central Oklahoma aquifer is affected by geohydrologic and water-quality conditions in geologic units adjacent to the aquifer. Therefore, for this report the study unit is larger than the Central Oklahoma aquifer (the term "study unit" is used throughout this report instead of the more conventional "study area," because depth as well as areal extent must be considered in the discussion of water quality in the Central Oklahoma aquifer). The study unit defined for this report is bounded by 34° 45′ and 36° north latitude, and 96° 45′ and 97° 45′ west longitude (fig. 1).

Location and Physiography

The Central Oklahoma aquifer underlies all or parts of Cleveland, Logan, Lincoln, Oklahoma, Payne, and Pottawatomie Counties (fig. 2). The aquifer is within the Osage Plains section of the Central Lowland province of the Interior Plains division of the United States (Fenneman, 1946). The eastern part of the study unit is characterized by low hills, generally covered with blackjack and post oaks, with relief of 30 to 200 feet. The western part of the study unit is characterized by a gently rolling grass-covered plain with relief of less than 100 feet. Elevations within the study unit generally are higher in the west than in the east. The highest elevation is about 1,400 feet above sea level in the western part of the study unit along the drainage divide between the Canadian and North Canadian Rivers; the lowest elevation is about 800 feet above sea level along the Cimarron River in Payne County.

The major streams in the study unit are the Cimarron River, the Deep Fork, the North Canadian River, the Little River, and the Canadian River (fig 2). These streams, which flow from west to east across the study unit, have formed broad, flat alluvial valleys. The Little River is a tributary to the Canadian River, and the Deep Fork is a tributary to the North Canadian River. The headwaters of the Little River and the Deep Fork are within the study unit.

The average annual temperature in the study unit is about 16 °C. The average annual precipitation is approximately 33 inches, most of which falls from April through October.

Population and Land Use

There are five counties that account for most of the area of the study unit of the Central Oklahoma aquifer project: Cleveland, Lincoln, Logan, Oklahoma, and Pottawatomie. In 1986, the combined population of these five counties was 915,000 (Oklahoma Employment Security Commission, 1987). Much of the population resides in the major cities in the west-central

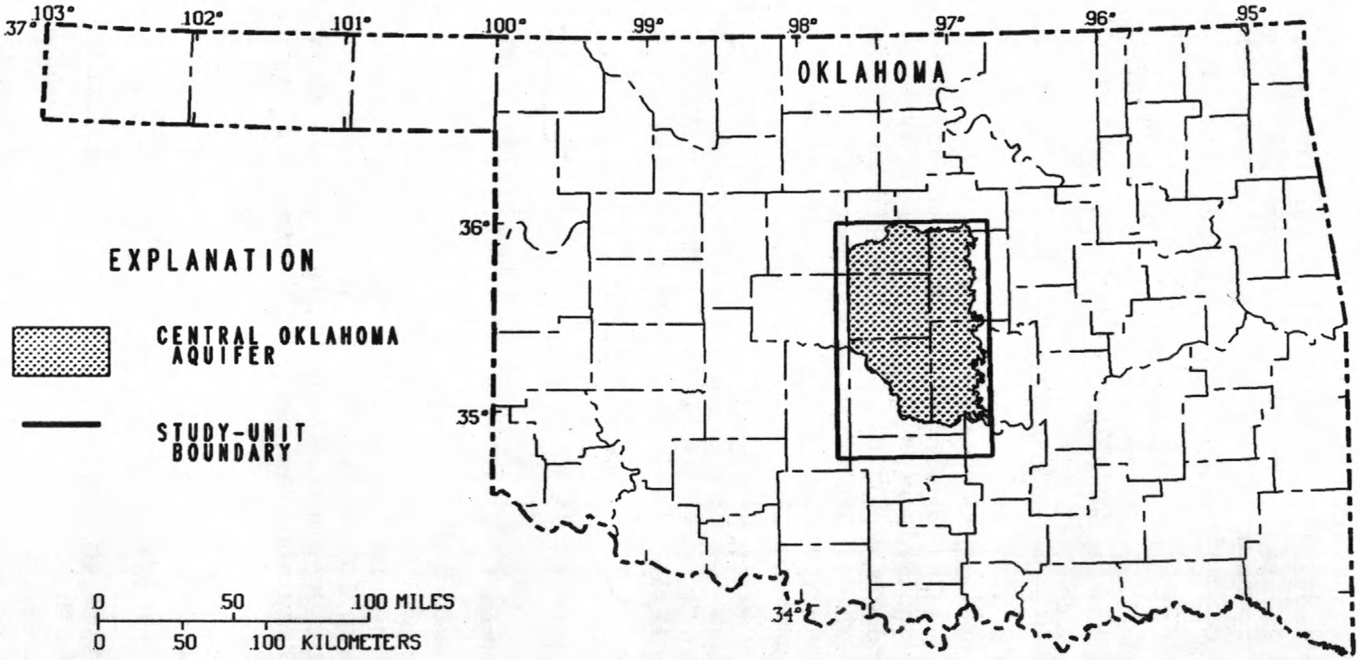

Figure 1. – Location of the Central Oklahoma aquifer and the study unit.

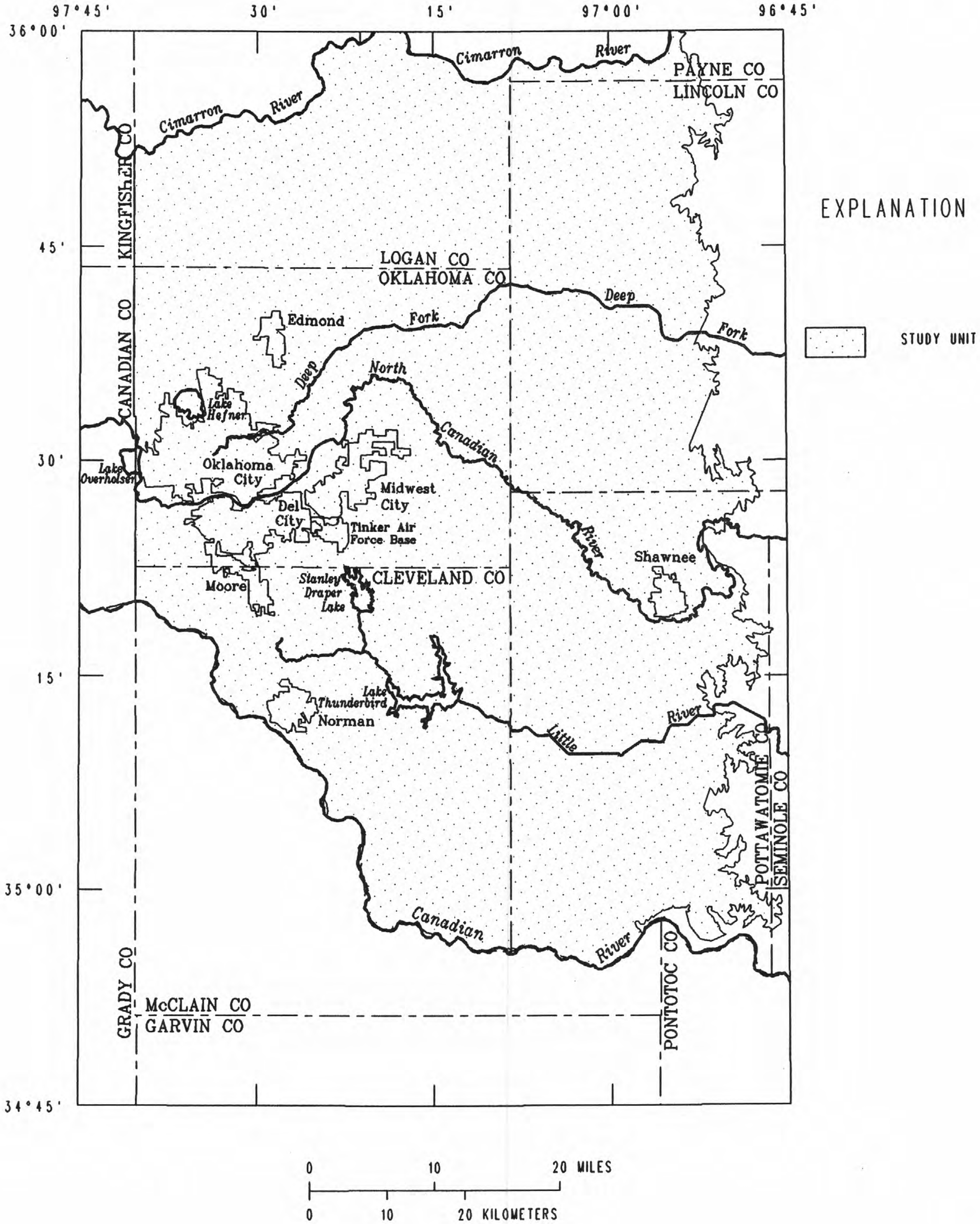

Figure 2.—Geographic features of the study unit.

part of the study unit, including Oklahoma City, Norman, Midwest City, Edmond, and Moore. Oklahoma City has the largest population of any city in Oklahoma, with a population of 434,200 in 1986. In 1986, the populations of the larger communities in the study unit (over 25,000 residents) were:

Oklahoma City	434,200	Moore	42,100
Norman	78,300	Shawnee	27,500
Midwest City	53,700	Del City	26,400
Edmond	51,200		

Although Oklahoma City covers a large area and is surrounded by numerous other communities, the dominant land use in the study unit is agricultural. Much of the agricultural land is devoted to raising livestock, although grain crops (principally wheat and sorghum) are grown in the area. Land use is approximately evenly divided between agriculture and deciduous forest in the eastern part of the study unit. These forests are known locally as the "Cross Timbers" and consist of post oak and blackjack.

The other significant land use within the study unit is urban development. In 1975, Oklahoma City was the second largest city in the United States in terms of land area, covering 635 mi^2 (Morris, 1977). Other cities that have areas of more than 20 mi^2 include Norman (174 mi^2), Edmond (64.3 mi^2), Shawnee (32.9 mi^2), Midwest City (24.7 mi^2), and Moore (21.8 mi^2).

Hydrogeologic Setting

The Central Oklahoma aquifer consists of those geologic units that yield substantial volumes of water to wells from the extensive, continuous flow system centered around Cleveland, Lincoln, Logan, Oklahoma, and Pottawatomie Counties. Ground water in this flow system originates as recharge from precipitation on the aquifer and circulates in the Permian-age Garber Sandstone and Wellington Formation; the Permian-age Chase, Council Grove, and Admire Groups; and Quaternary-age alluvium and terrace deposits along major streams (fig. 3). Because most deep wells in central Oklahoma are completed in the Garber Sandstone and the Wellington Formation, the Central Oklahoma aquifer commonly has been referred to as the "Garber-Wellington aquifer," but this terminology is imprecise because: (1) The Garber Sandstone and Wellington Formation are not an aquifer outside of central Oklahoma because of a decrease in transmissivity; and (2) the water in the Chase, Council Grove, and Admire Groups, and in the overlying alluvium and terrace deposits is part of the same flow system. Therefore, for purposes of the NAWQA Program, the term "Central Oklahoma aquifer" is used. The stratigraphic relation of the geologic units within the study unit is shown in table 1.

The Cimarron River defines the northern boundary of the Central Oklahoma aquifer because: (1) The aquifer is less permeable north of the river; (2) there are few (if any) large-capacity wells completed in the aquifer north of the river; and (3) it is expected that the river is a significant boundary to ground-water flow with very little ground-water underflow from one side of the river to the other. For similar reasons, the Canadian River defines the southern boundary of the Central Oklahoma aquifer.

The western boundary of the Central Oklahoma aquifer is considered to be where freshwater circulation in the aquifer becomes negligible. An increase in dissolved-solids concentration to greater than 5,000 mg/L (milligrams per liter) in the western part of the study unit is thought to be an indication of a decrease in the circulation of ground water. The position of the western extent of ground water containing less than 5,000 mg/L dissolved solids is not defined precisely but occurs at approximately the Oklahoma-Canadian County line (Hart, 1966). For this report, the Oklahoma-Canadian County line is defined to be the western boundary of the Central Oklahoma aquifer. The eastern boundary of the aquifer is the eastern limit of the outcrop of the Chase, Council Grove, and Admire Groups.

The lower boundary of the Central Oklahoma aquifer is defined as the lower limit of ground water containing less than 5,000 mg/L dissolved solids. This increase in dissolved-solids concentration at depth is referred to as the base of freshwater. The base of the freshwater is deepest in south-central Oklahoma County near Midwest City, where the depth to the

Table 1.—*Correlation of major chronostratigraphic units, geologic units, and geohydrologic categories in central Oklahoma*

Erathem	System	Geologic unit	Geohydrologic category
Cenozoic	Quaternary	Alluvium	Alluvium-Terrace
		Terrace deposits	
Paleozoic	Permian	El Reno Group	El Reno
		Hennessey Group	Hennessey
		Garber Sandstone	Garber-Wellington Shallow Medium-depth Deep
		Wellington Formation	
		Chase Group	Chase-Admire
		Council Grove Group	
		Admire Group	
	Pennsylvanian	Vanoss Formation	Vanoss

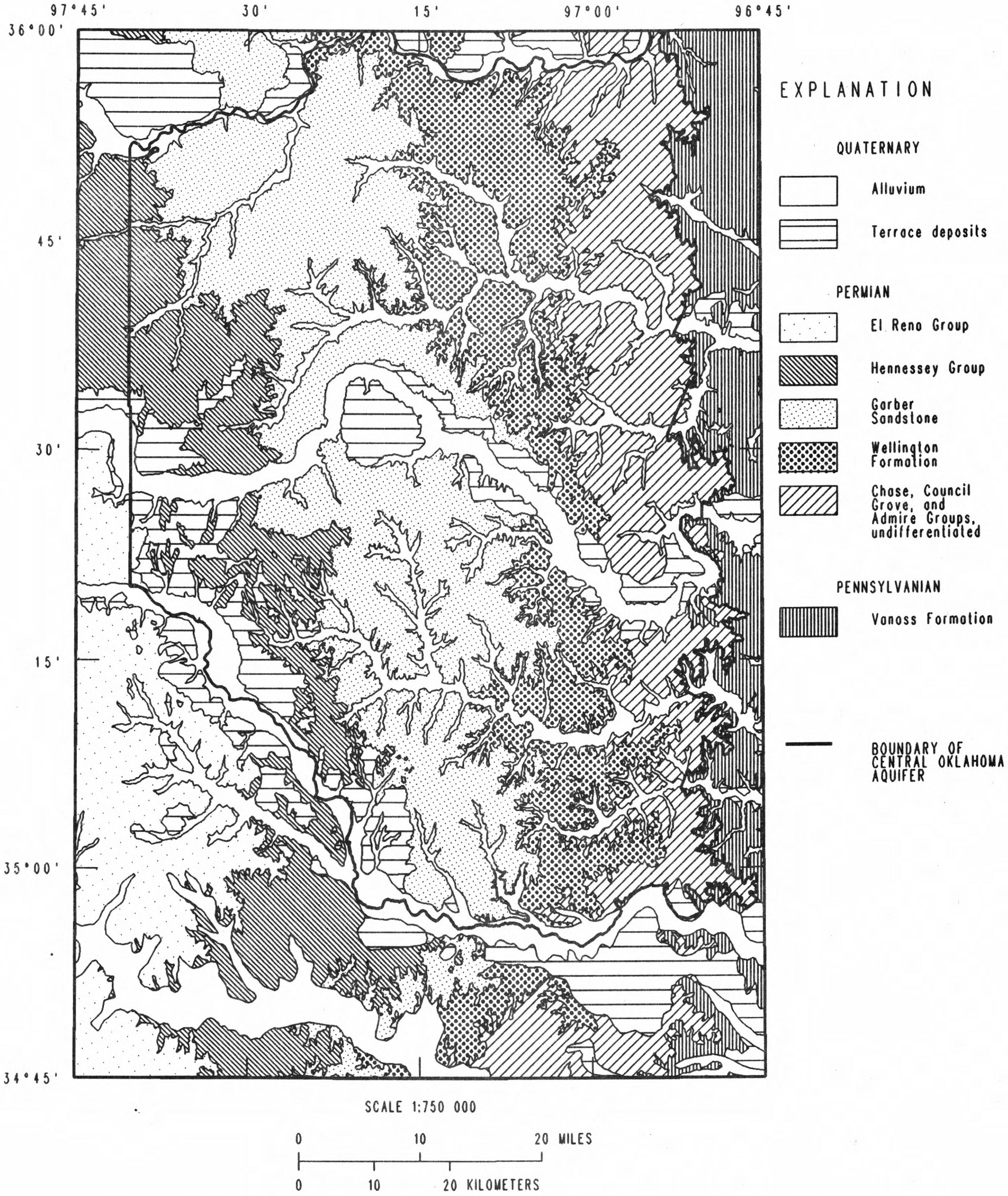

Figure 3. – Geologic map of central Oklahoma (modified from Bingham and Moore, 1975, and Hart, 1974).

base of freshwater is about 1,000 feet. To the north, south, and east, the base of the freshwater slopes upward gradually, until the base of freshwater is only about 100 feet below land surface at the boundaries of the aquifer. To the west, the base of freshwater rises gradually to approximately the Oklahoma-Canadian County line. At that line, the depth to the base of freshwater decreases abruptly from about 800 feet to about 200 feet (Hart, 1966).

Alluvium deposited by streams is the youngest geologic deposit in the study unit. The alluvium is constantly being eroded, transported, and deposited by streams. Alluvium is present along most of the perennial streams in the study unit. The most extensive alluvial deposits are present along the North Canadian and Canadian Rivers, where the alluvium is as much as 3 miles wide. The alluvium consists of lenticular beds of unconsolidated clay, silt, sand, and gravel. The thickness of the alluvium ranges from 0 to about 100 feet. Where the alluvium is thickest and contains beds of gravel, wells yield as much as 700 gal/min (gallons per minute) (Bingham and Moore, 1975).

Terrace deposits associated with streams in the study unit are older alluvial deposits that occur where erosion has deepened the stream valleys and left the terrace deposits topographically above the present-day alluvium. Terrace deposits along the Cimarron, North Canadian, and Canadian Rivers are as much as 8 miles wide. Like the alluvium, the terrace deposits consist of lenticular beds of unconsolidated clay, silt, sand, and gravel. Thickness of the terrace deposits in the study unit ranges from 0 to 100 feet. Wells completed in the most productive terrace deposits may yield up to 300 gal/min (Bingham and Moore, 1975).

Beneath the alluvium and terrace deposits are consolidated geologic units of Permian age. These strata generally are red or reddish-brown in color, and thus generally are referred to as "red beds." The regional dip is to the west at about 50 feet per mile.

The youngest consolidated geologic unit in the study unit is the El Reno Group. The El Reno Group consists of red-brown fine-grained sandstone with some mudstone conglomerates and shales. The El Reno Group generally yields sufficient amounts of water for domestic and stock wells. The El Reno Group is not considered to be part of the Central Oklahoma aquifer because it is separated from the aquifer by the Hennessey Group, which is a confining layer. The El Reno Group is discussed in this report because some wells within the study unit are completed in the El Reno Group.

Stratigraphically below the El Reno Group are rocks of the Hennessey Group. The Hennessey Group is present in the western one-third of the study unit, but has been removed by erosion in the eastern two-thirds. The Hennessey Group consists of reddish-brown shales and mudstones with a few thin beds of very fine-grained sandstone. Because the Hennessey Group is composed mainly of shale and mudstone, it has small transmissivity and, thus, is a confining layer. Even though it has little transmissivity, a few small-yield wells, for domestic and stock use, are completed in the Hennessey Group. Because the Hennessey Group is a confining layer, it is not considered to be part of the Central Oklahoma aquifer but is discussed in this report because some wells within the study unit are completed in the Hennessey Group.

Stratigraphically below the Hennessey Group are the Garber Sandstone and the Wellington Formation. In central Oklahoma, the Garber Sandstone and the Wellington Formation have similar lithologies. Therefore, these two geologic units are not differentiated in this report. These units consist of lenticular beds of fine-grained, cross-bedded sandstone interbedded with siltstone and shale. The sand grains are predominantly quartz, and the sandstone is friable. In southeastern Oklahoma County, about 75 percent of the total thickness of the sequence is sandstone. In all directions from southeastern Oklahoma County, the percentage of sandstone decreases and the percentage of siltstone and shale increases. For example, in southern Cleveland County, only 25 percent of the total thickness is sandstone (Wood and Burton, 1968). The Garber Sandstone and Wellington Formation are at the surface in the central part of the study unit, but have been removed by erosion in the east. Where a full section of the Garber Sandstone and Wellington Formation is present their combined thickness ranges from 800 to 1,000 feet. Shallow wells are completed in either the Garber Sandstone or Wellington Formation, but wells with the largest yields are completed in both geologic units. A few wells completed in both units yield as much as 600 gal/min, but because the sandstone is fine-grained, maximum well yields generally range from 100 to 300 gal/min.

The Chase, Council Grove, and Admire Groups (undifferentiated in this report) of Permian age consist of beds of fine-grained, cross-bedded sandstone, shale, and thin limestone. In surface exposures in the eastern part of the study unit, these Groups appear to have similar lithologies. East of their outcrop these geologic units have been removed by erosion. Where complete sections are present, the combined thickness of these Groups ranges from 300 to 600 feet.

In the central part of the study unit, wells are completed in the Wellington Formation and in one or more of the underlying Chase, Council Grove, and Admire Groups. East of the outcrop of the Wellington Formation, wells that are completed only in the Chase, Council Grove, and Admire Groups generally yield 10 to 50 gal/min, with a few wells yielding as much as 100 gal/min. Bingham and Moore (1975) referred to the Chase, Council Grove, and Admire Groups as the "Oscar Group," and assigned it to the Pennsylvanian System. Although data from Bingham and Moore (1975) are cited frequently, the term "Oscar Group" is not used in this report. A recently published correlation chart by Lindberg (1987) refers to Bingham and Moore's Oscar Group as the Permian-age Chase, Council Grove, and Admire Groups. This terminology follows the usage of the U.S. Geological Survey and is used in this report.

The Vanoss Formation is the only Pennsylvanian-age geologic unit in the study unit and is the oldest geologic unit considered in this report. The Vanoss Formation underlies the Chase, Council Grove, and Admire Groups and is found along the eastern boundary of the study unit. The Vanoss Formation consists mainly of shale and a few thin, fine-grained sandstone beds. The Vanoss generally does not yield substantial volumes of water to wells and is considered to be a confining layer. The Vanoss Formation is not considered to be part of the Central Oklahoma aquifer but is discussed in this report because some wells within the study unit are completed in the Vanoss Formation.

Water Use

Reported water use from the Central Oklahoma aquifer during 1985 was about 40 thousand acre-ft (acre-feet) of water (fig. 4). During 1985, about 73 percent of the reported water use from the Central Oklahoma aquifer was for public supplies (James Schuelein, Oklahoma Water Resources Board, written commun., 1986). All the major communities in central Oklahoma, except Oklahoma City, rely either entirely on ground water from the Central Oklahoma aquifer or on a mixture of ground-water and surface-water supplies (Oklahoma City relies on surface water for water supply). During 1985, the second largest use of water from the Central Oklahoma aquifer was industrial, which accounted for about 15 percent of the total.

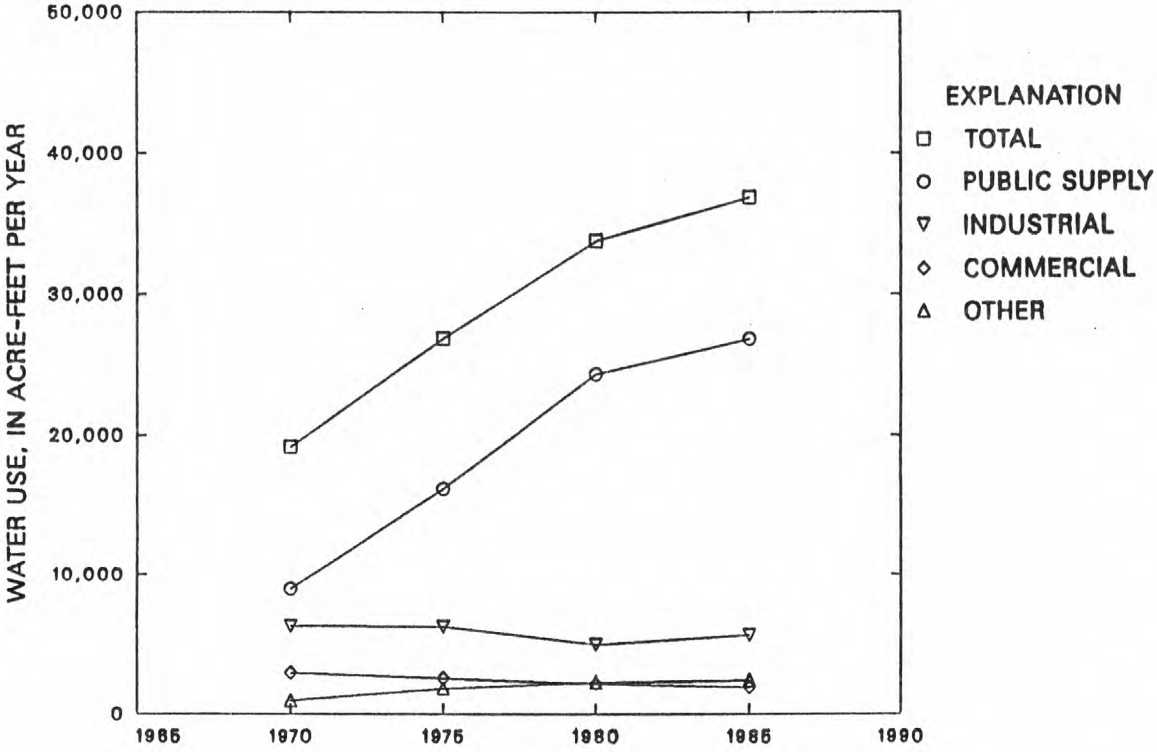

Figure 4. – Reported water use from the Central Oklahoma aquifer.

Commercial water use and irrigation each accounted for about 5 percent of the total water use during 1985. All other uses combined were less than 2 percent of the total.

Between 1970 and 1985, the quantity of ground water withdrawn from the Central Oklahoma aquifer approximately doubled. While uses other than public supply stayed approximately the same, water use for public supplies tripled from about 10 thousand acre-ft during 1970 to about 30 thousand acre-ft during 1985.

SOURCES OF WATER-QUALITY DATA

Water-quality data for the Central Oklahoma aquifer were available from six Federal, State, and local agencies: the Association of Central Oklahoma Governments, the Oklahoma State Department of Health, the Oklahoma Water Resources Board, the U.S. Department of Defense, the U.S. Department of Energy, and the U.S. Geological Survey. Some additional chemical analyses were obtained from municipalities and consulting firms. A total of 4,439 analyses from 1,604 wells and 409 distribution systems were compiled for this report. Some wells were sampled by more than one agency, and some individual wells from distribution systems also were sampled. Table 2 presents a summary of the data obtained from each agency showing the number of analyses and the number of sites sampled for each constituent.

Analyses that could be associated with an individual well were stored in the U.S. Geological Survey's National Water Information System (NWIS) data base. Data associated with water-distribution systems were not entered in the NWIS data base. Any data that could not be associated with a known geographic location were not considered in this report.

Association of Central Oklahoma Governments

The Association of Central Oklahoma Governments is an association of municipalities in Canadian, Cleveland, Logan, and Oklahoma Counties. Because many municipalities in those counties rely on ground water from the Central Oklahoma aquifer, these municipalities have recognized the importance of collecting water-quality data. Therefore, the Association, in conjunction with the U.S. Environmental Protection Agency, developed a research project "for the protection, development, and management of the Garber-Wellington Aquifer located in central Oklahoma" (Gates and others, 1983). The municipalities that make up the Association operate public water systems and must comply with laws concerning public supplies. These municipalities must ensure that the water they distribute complies with standards for each constituent set by the U.S. Environmental Protection Agency (table 4). Water-quality data collected by the Association generally include chemical constituents which are regulated.

The Association provided 582 analyses from 188 wells in Cleveland, Logan, and Oklahoma Counties (fig. 5). The analyses predominantly were for samples from municipal wells. Some analyses were from test holes sampled at several depths during drilling. The constituents analyzed included some major elements, selected trace elements, and gross-alpha and gross-beta radioactivity. The samples were collected between 1979 and 1987 and were analyzed by the Oklahoma State Department of Health. The data, obtained on magnetic tape, were checked against original laboratory sheets. Municipal well locations were compiled by personnel from the NAWQA project and the latitude and longitude coordinates of the well locations were used to store the Association's data in the NWIS data base.

Oklahoma State Department of Health

The Oklahoma State Department of Health has broad authority stemming from its mandate to safeguard the health of the State's people. The Department of Health has jurisdiction in any situation that could contaminate or has contaminated a drinking-water source. The Department of Health has approval and regulatory authority for all public water supplies. Many of the water-quality data from the Department of Health are from water samples that were taken from public water-supply distribution systems. Within the Department of Health, data are collected and analyzed by both the Environmental Laboratory and the Radiochemistry Laboratory.

The Department of Health Environmental Laboratory supplied 1,658 analyses from 401 distribution systems (fig. 6) in Cleveland, Lincoln, Logan, Oklahoma, and Pottawatomie Counties. These numbers exclude: (1) Any distribution system that derived all or part of its water from surface-water sources, (2) any ground-water distribution system that was designated as obtaining water from an aquifer other than the Central Oklahoma aquifer, and (3) any distribution system that lacked adequate location information for the well field. In general, the analyses from the distribution systems could not be identified with a single well and therefore were not entered into the NWIS data base. The samples were collected between 1978 and 1987, and were analyzed for inorganic constituents regulated by the U.S. Environmental Protection Agency.

The Department of Health Radiochemistry Laboratory provided 374 analyses of radioactive constituents from 85 distribution systems in Cleveland, Lincoln, Logan, Oklahoma, and Pottawatomie Counties (fig. 7). The Radiochemistry Laboratory

Table 2.—*Compilation of the number of analyses and the number of sites sampled for each chemical constituent from Federal, State, and local sources of chemical data*

[ACOG, Association of Central Oklahoma Governments; DOD, Department of Defense; NURE, National Uranium Resource Evaluation; OSDHEL, Oklahoma State Department of Health Environmental Laboratory; OSDHRL, Oklahoma State Department of Health Radiochemistry Laboratory; OWRB, Oklahoma Water Resources Board; USGS, U.S. Geological Survey; Other, includes analyses from individual municipalities and consulting companies. -, indicates no data were available. Constituents and properties: µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter]

Constituents and properties	ACOG		DOD		NURE		OSDHEL		OSDHRL		OWRB		USGS		Other	
	Number of		Number of		Number of		Number of		Number of		Number of		Number of		Number of	
	Analyses	Sites	Analyses	Sites	Analyses	Sites	Analyses	Sites	Analyses	Sites	Analyses	Sites	Analyses	Sites	Analyses	Sites
Properties and major ions																
Specific conductance (µS/cm at 25 °C)	410	178	230	187	510	510	-	-	-	-	-	-	578	534	140	22
pH, field (standard units)	-	-	230	187	509	509	-	-	-	-	-	-	463	431	137	22
pH, laboratory (standard units)	427	180	-	-	-	-	280	122	-	-	154	103	-	-	14	11
Temperature, water (°C)	-	-	-	-	508	508	-	-	-	-	-	-	407	392	-	-
Oxygen, dissolved (mg/L as O_2)	-	-	-	-	509	509	-	-	-	-	-	-	-	-	-	-
Hardness, total (mg/L as $CaCO_3$)	429	180	23	20	-	-	280	122	-	-	156	104	447	399	146	28
Calcium, total (mg/L as Ca)	-	-	14	14	-	-	87	83	-	-	154	103	-	-	-	-
Calcium, dissolved (mg/L as Ca)	-	-	5	5	478	478	-	-	-	-	-	-	310	276	132	17
Magnesium, total (mg/L as Mg)	-	-	14	14	-	-	-	-	-	-	154	103	-	-	-	-
Magnesium, dissolved (mg/L as Mg)	-	-	5	5	478	478	-	-	-	-	-	-	310	276	132	17
Sodium, total (mg/L as Na)	-	-	14	14	-	-	288	118	-	-	153	102	-	-	-	-
Sodium, dissolved (mg/L as Na)	16	2	5	5	478	478	-	-	-	-	-	-	171	163	126	11
Sodium plus potassium, dissolved (mg/L as Na)	-	-	-	-	-	-	-	-	-	-	-	-	229	211	11	11
Potassium, total (mg/L as K)	-	-	5	5	-	-	-	-	-	-	-	-	-	-	-	-
Potassium, dissolved (mg/L as K)	-	-	5	5	178	178	-	-	-	-	-	-	126	121	126	11
Bicarbonate (mg/L as HCO_3)	-	-	14	14	-	-	-	-	-	-	-	-	397	357	11	11
Carbonate (mg/L as CO_3)	-	-	14	14	-	-	-	-	-	-	-	-	362	323	11	11
Alkalinity, total (mg/L as $CaCO_3$)	16	2	-	-	481	481	280	122	-	-	156	104	438	400	126	11
Alkalinity, hydroxyl (mg/L as $CaCO_3$)	-	-	9	9	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate, dissolved (mg/L as SO_4)	429	180	119	113	480	480	280	122	-	-	156	104	454	405	151	33
Chloride, dissolved (mg/L as Cl)	429	180	119	113	-	-	297	124	-	-	156	104	470	415	151	33
Fluoride, total (mg/L as F)	-	-	-	-	-	-	306	124	-	-	156	104	-	-	-	-
Fluoride, dissolved (mg/L as F)	16	2	5	5	-	-	-	-	-	-	-	-	168	157	126	11
Bromide, dissolved (mg/L as Br)	-	-	-	-	-	-	-	-	-	-	-	-	29	27	-	-
Iodide, dissolved (mg/L as I)	-	-	-	-	-	-	-	-	-	-	-	-	6	6	-	-
Silica, total (mg/L as SiO_2)	-	-	5	5	-	-	-	-	-	-	-	-	-	-	-	-
Silica, dissolved (mg/L as SiO_2)	-	-	-	-	-	-	-	-	-	-	-	-	114	98	137	22
Dissolved solids, residue at 180 °C (mg/L)	-	-	-	-	-	-	-	-	-	-	-	-	329	300	-	-
Dissolved solids, residue at 105 °C (mg/L)	16	2	-	-	-	-	275	116	-	-	156	104	-	-	-	-
Solids, total dissolved (mg/L)	-	-	5	5	-	-	-	-	-	-	-	-	-	-	-	-

Table 2.—*Compilation of the number of analyses and the number of sites sampled for each chemical constituent from Federal, State, and local sources of chemical data*—Continued

Constituents and properties	ACOG		DOD		NURE		OSDHEL		OSDHRL		OWRB		USGS		Other	
	Number of Analyses	Number of Sites	Number of Analyses	Number of Sites	Number of Analyses	Number of Sites	Number of Analyses	Number of Sites	Number of Analyses	Number of Sites	Number of Analyses	Number of Sites	Number of Analyses	Number of Sites	Number of Analyses	Number of Sites
Nutrients																
Nitrogen, nitrate, total (mg/L as N)	16	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrogen, nitrate, dissolved (mg/L as N)	-	-	-	-	-	-	-	-	-	-	-	-	332	302	-	-
Nitrogen, nitrite, dissolved (mg/L as N)	-	-	-	-	-	-	-	-	-	-	-	-	4	4	-	-
Nitrogen, nitrite plus nitrate, total (mg/L as N)	20	20	-	-	-	-	1,477	401	-	-	155	103	-	-	126	11
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	-	-	5	5	-	-	-	-	-	-	-	-	33	33	-	-
Phosphorus, total (mg/L as P)	-	-	-	-	-	-	-	-	-	-	-	-	8	7	-	-
Phosphorus, dissolved (mg/L as P)	-	-	-	-	507	507	-	-	-	-	-	-	-	-	-	-
Phosphorus, dissolved orthophosphate (mg/L as P)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	126	11
Trace elements																
Aluminum, dissolved (μg/L as Al)	-	-	-	-	507	507	-	-	-	-	-	-	4	4	-	-
Arsenic, total (μg/L as As)	117	87	218	191	-	-	324	118	-	-	112	95	-	-	18	3
Arsenic, dissolved (μg/L as As)	-	-	160	145	509	509	-	-	-	-	-	-	2	2	-	-
Barium, total (μg/L as Ba)	-	-	226	191	-	-	311	118	-	-	119	96	-	-	-	-
Barium, dissolved (μg/L as Ba)	-	-	160	145	507	507	-	-	-	-	-	-	-	-	-	-
Beryllium, dissolved (μg/L as Be)	-	-	-	-	507	507	-	-	-	-	-	-	-	-	-	-
Boron, dissolved (μg/L as B)	-	-	-	-	507	507	-	-	-	-	-	-	122	113	-	-
Cadmium, total (μg/L as Cd)	11	2	218	191	-	-	299	122	-	-	110	95	-	-	-	-
Cadmium, dissolved (μg/L as Cd)	-	-	160	145	-	-	-	-	-	-	-	-	7	7	-	-
Chromium, total (μg/L as Cr)	334	166	218	191	-	-	361	122	-	-	113	96	-	-	22	7
Chromium, dissolved (μg/L as Cr)	27	5	160	145	507	507	-	-	-	-	-	-	6	6	126	11
Chromium, hexavalent (μg/L as Cr)	16	11	14	14	-	-	-	-	-	-	-	-	-	-	-	-
Chromium, dissolved, hexavalent (μg/L as Cr)	-	-	9	9	-	-	-	-	-	-	-	-	-	-	-	-
Chromium, trivalent (μg/L as Cr)	-	-	13	13	-	-	-	-	-	-	-	-	-	-	-	-
Cobalt, dissolved (μg/L as Co)	-	-	-	-	507	507	-	-	-	-	-	-	-	-	-	-
Copper, total recoverable (μg/L as Cu)	-	-	-	-	-	-	280	120	-	-	121	97	-	-	-	-
Copper, dissolved (μg/L as Cu)	-	-	-	-	507	507	-	-	-	-	-	-	7	7	-	-
Iron, total (μg/L as Fe)	8	8	32	32	-	-	280	122	-	-	151	103	60	57	-	-
Iron, dissolved (μg/L as Fe)	-	-	18	18	507	507	-	-	-	-	-	-	29	28	126	11
Lead, total (μg/L as Pb)	1	1	218	191	-	-	303	122	-	-	112	96	-	-	-	-
Lead, dissolved (μg/L as Pb)	-	-	160	145	-	-	-	-	-	-	-	-	6	6	-	-
Lithium, dissolved (μg/L as Li)	-	-	-	-	507	507	-	-	-	-	-	-	17	17	-	-
Manganese, total (μg/L as Mn)	11	11	32	32	-	-	276	118	-	-	116	96	-	-	-	-
Manganese, dissolved (μg/L as Mn)	-	-	18	18	507	507	-	-	-	-	-	-	11	11	119	11
Mercury, total recoverable (μg/L as Hg)	-	-	218	191	-	-	288	118	-	-	-	-	-	-	-	-
Mercury, dissolved (μg/L as Hg)	-	-	160	145	-	-	-	-	-	-	-	-	2	2	-	-
Molybdenum, dissolved (μg/L as Mo)	-	-	-	-	507	507	-	-	-	-	-	-	-	-	-	-

Table 2.—*Compilation of the number of analyses and the number of sites sampled for each chemical constituent from Federal, State, and local sources of chemical data*—Continued

Constituents and properties	ACOG Number of Analyses	 Sites	DOD Number of Analyses	 Sites	NURE Number of Analyses	 Sites	OSDHEL Number of Analyses	 Sites	OSDHRL Number of Analyses	 Sites	OWRB Number of Analyses	 Sites	USGS Number of Analyses	 Sites	Other Number of Analyses	 Sites
Trace elements—Continued																
Nickel, total (μg/L as Ni)	-	-	218	191	-	-	-	-	-	-	-	-	-	-	-	-
Nickel, dissolved (μg/L as Ni)	-	-	160	145	507	507	-	-	-	-	-	-	-	-	-	-
Niobium, dissolved (μg/L as Nb)	-	-	-	-	507	507	-	-	-	-	-	-	-	-	-	-
Scandium dissolved (μg/L as Sc)	-	-	-	-	507	507	-	-	-	-	-	-	-	-	-	-
Selenium, total (μg/L as Se)	348	168	218	191	-	-	389	119	-	-	111	95	-	-	31	16
Selenium, dissolved (μg/L as Se)	27	5	160	145	509	509	-	-	-	-	-	-	2	2	126	11
Silver, total (μg/L as Ag)	-	-	218	191	-	-	289	118	-	-	-	-	-	-	-	-
Silver, dissolved (μg/L as Ag)	-	-	160	145	507	507	-	-	-	-	-	-	-	-	-	-
Strontium, dissolved (μg/L as Sr)	-	-	-	-	178	178	-	-	-	-	-	-	17	17	-	-
Tin, dissolved (μg/L as Sn)	-	-	-	-	178	178	-	-	-	-	-	-	-	-	-	-
Titanium, dissolved (μg/L as Ti)	-	-	-	-	507	507	-	-	-	-	-	-	-	-	-	-
Vanadium, dissolved (μg/L as V)	-	-	-	-	507	507	-	-	-	-	-	-	-	-	-	-
Yttrium, total (μg/L as Y)	-	-	-	-	507	507	-	-	-	-	-	-	-	-	-	-
Zinc, total (μg/L as Zn)	-	-	218	191	-	-	278	120	-	-	121	97	-	-	-	-
Zinc, dissolved (μg/L as Zn)	-	-	160	145	507	507	-	-	-	-	-	-	7	7	-	-
Zirconium, dissolved (μg/L as Zr)	-	-	-	-	507	507	-	-	-	-	-	-	-	-	-	-
Radionuclides																
Alpha radioactivity, total (pCi/L)	107	107	112	108	-	-	-	-	399	99	-	-	-	-	8	8
Beta radioactivity, total (pCi/L)	-	-	112	108	-	-	-	-	-	-	-	-	-	-	8	8
Beta, gross total as Sr/Y-90 (pCi/L)	107	107	-	-	-	-	-	-	399	99	-	-	-	-	-	-
Ra-226, total (pCi/L)	-	-	23	23	-	-	-	-	244	75	-	-	-	-	-	-
Ra-228, total (pCi/L)	-	-	32	32	-	-	-	-	-	-	-	-	-	-	-	-
Ra-226 + Ra-228 (pCi/L)	-	-	36	36	-	-	-	-	-	-	-	-	-	-	-	-
Thorium, dissolved (μg/L as Th)	-	-	-	-	507	507	-	-	-	-	-	-	-	-	-	-
Uranium, natural, total (pCi/L as U)	-	-	-	-	-	-	-	-	141	49	-	-	-	-	-	-
Uranium, natural, dissolved (μg/L as U)	-	-	-	-	509	509	-	-	-	-	-	-	-	-	-	-
Organic compounds																
Carbon, organic, total (mg/L as C)	-	-	180	178	-	-	-	-	-	-	-	-	-	-	-	-
Carbon, organic, dissolved (mg/L as C)	-	-	-	-	-	-	-	-	-	-	-	-	15	15	-	-
Cyanide, total (mg/L as CN)	-	-	115	114	-	-	-	-	-	-	-	-	-	-	-	-
Selected synthetic organic compounds	-	-	289	192	-	-	1	1	-	-	-	-	-	-	-	-

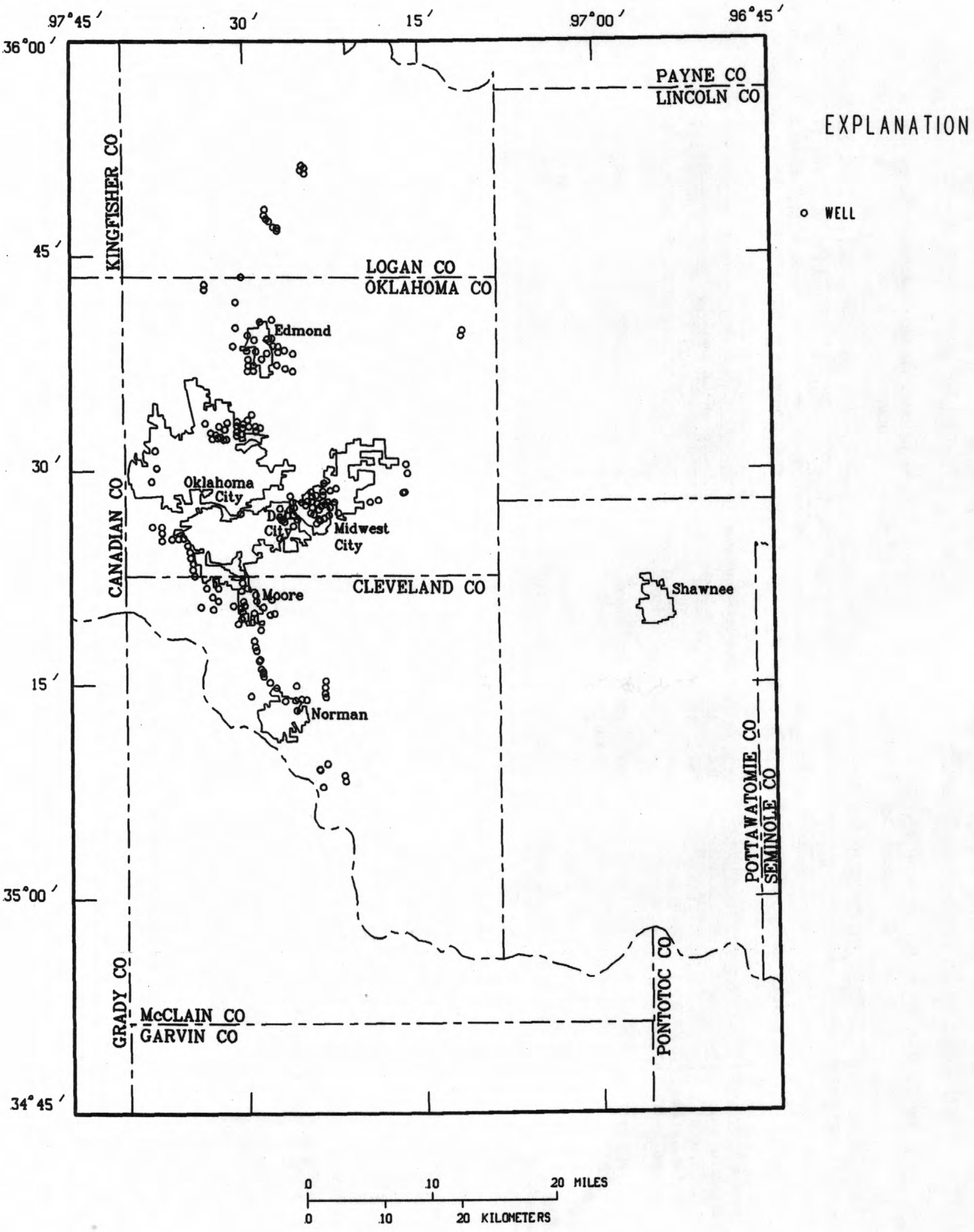

Figure 5.—Locations of wells sampled by the Association of Central Oklahoma Governments.

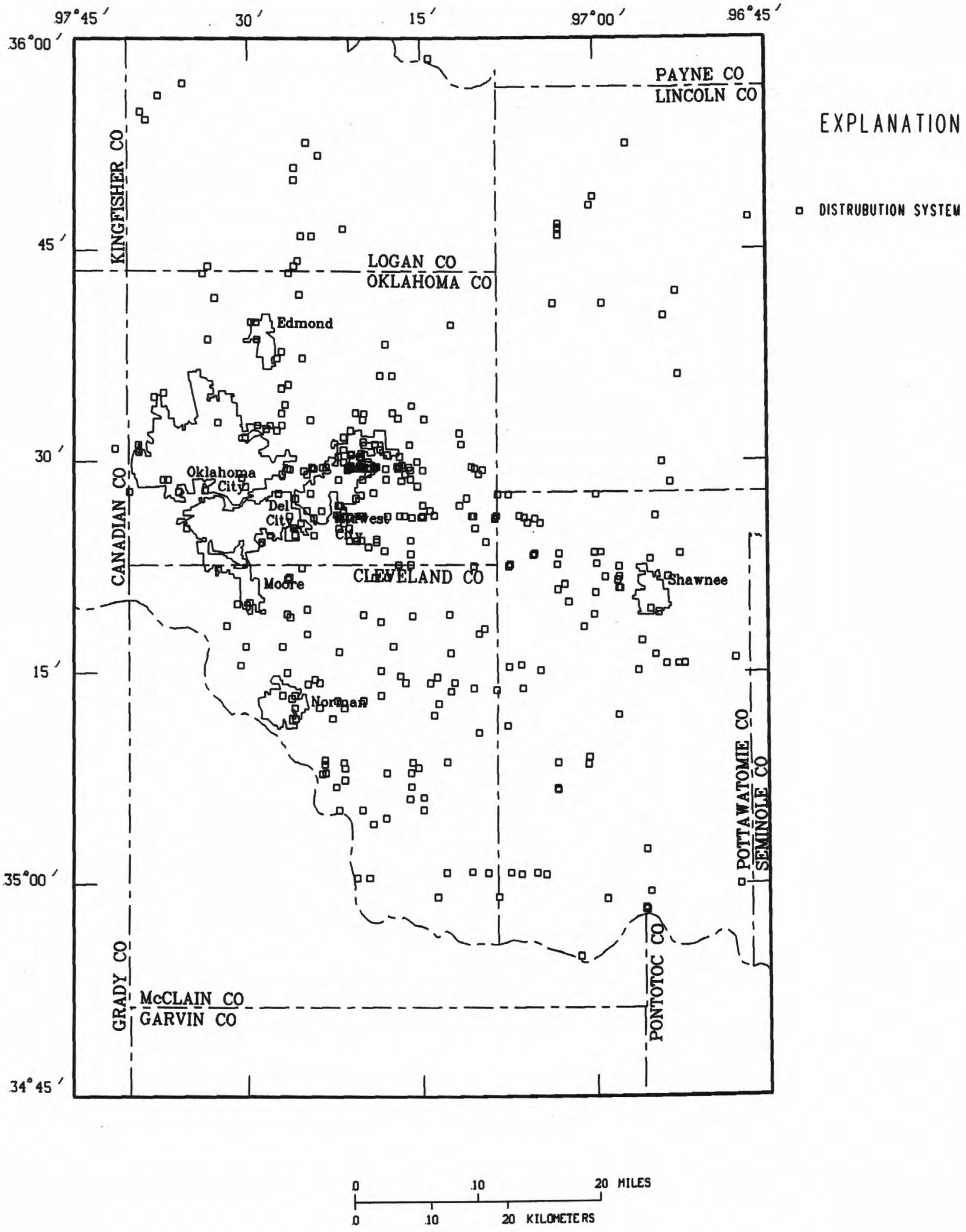

Figure 6.—Locations of distribution systems sampled by the Oklahoma State Department of Health Environmental Laboratory.

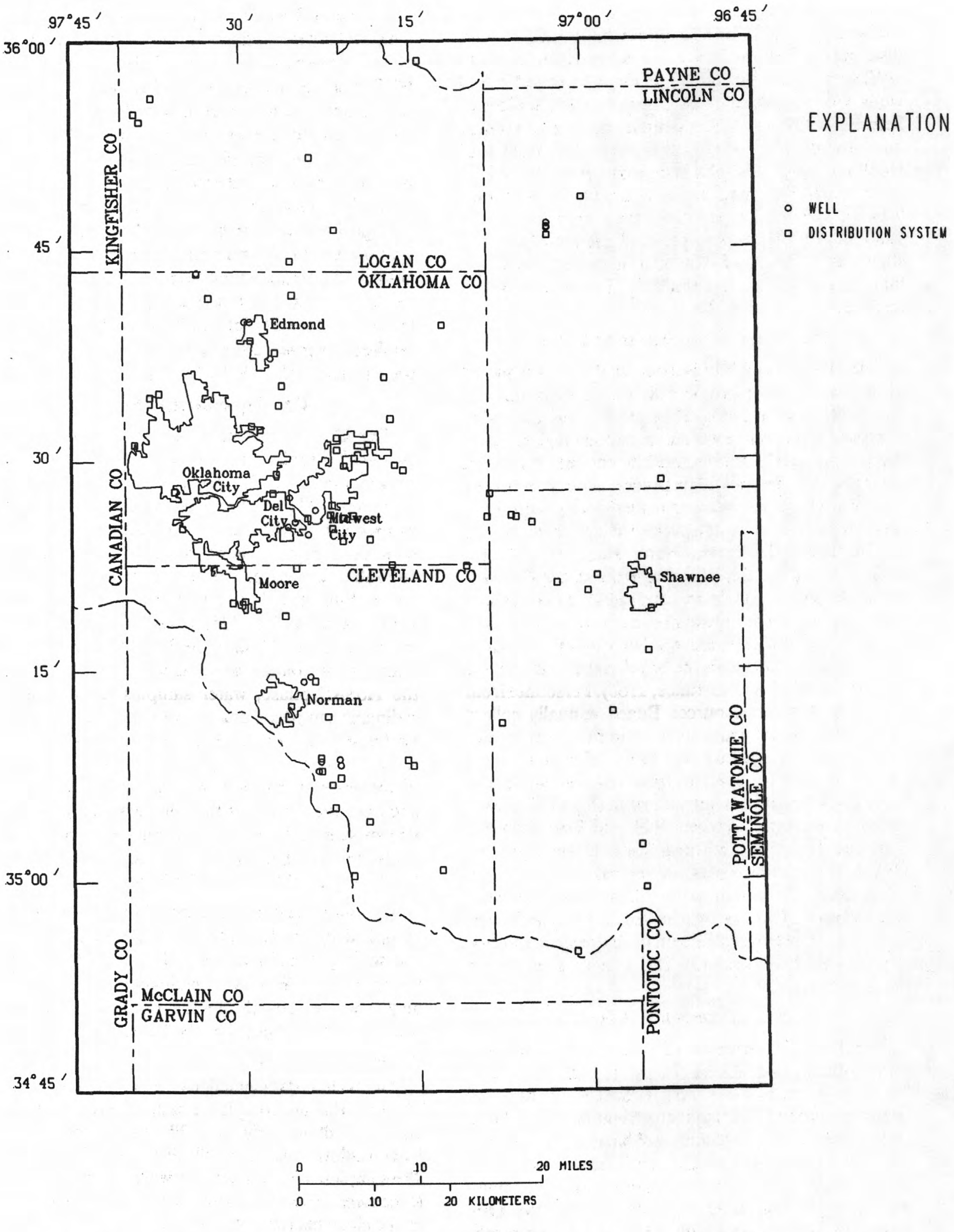

Figure 7.—Locations of wells and distribution systems sampled by the Oklahoma State Department of Health Radiochemistry Laboratory.

provided an additional set of 25 analyses taken from individual wells in the same 5 counties. The distribution-system data were not entered into the NWIS data base but the 25 analyses from individual wells were entered. The samples were collected between 1981 and 1987. Samples for radiochemical constituents were screened by the Department of Health using gross-alpha and gross-beta radioactivity analyses. If the gross-alpha radioactivity exceeded 5 pCi/L (picocuries per liter), then radium-226 was analyzed. If the gross-alpha radioactivity (plus the standard deviation of the counting error) was larger than 15 pCi/L, then uranium alpha radioactivity was analyzed.

Oklahoma Water Resources Board

The Oklahoma Water Resources Board is required by statute "to develop statewide and local plans to assure the best and most effective use and control of water to meet both the current and long range needs of the people of Oklahoma; and to cooperate in such planning with any public or private agency, entity, or person interested in water, and are directed to prepare such plans for consideration and approval by the Legislature" (Oklahoma Water Resources Board, 1979). As part of this planning process, the Ground-water Division of the Board "is dedicated to establishing standards for underground waters that will preserve, protect and improve their quality and assure that the waters will attain the beneficial uses described for them" (Whitlow and Vance, 1986). Personnel from Okahoma Water Resources Board annually collect samples of ground water to assist in the development of ground-water quality standards. The Board provided 156 chemical analyses from 104 wells within the Central Oklahoma aquifer study unit (fig. 8). The samples were collected between 1983 and 1986 and were analyzed by the Oklahoma State Department of Health for major elements and several trace elements. These data, obtained on magnetic tape, were checked against original laboratory sheets. Latitude and longitude coordinates were derived from the legal descriptions of sampling locations. The data were entered in the NWIS data base.

U.S. Department of Defense

The U.S. Department of Defense has engaged frequently in operations that deal with toxic and hazardous materials. The U.S. Department of Defense has begun a program to "identify the locations and contents of past toxic and hazardous material disposal and spill sites and to eliminate the hazards to public health in an environmentally responsible manner" (U.S. Geological Survey, 1988). Under this program the U.S. Army Corps of Engineers currently (1988) is conducting a study at Tinker Air Force Base in central Oklahoma.

A total of 289 samples from 192 sites related to the Tinker study were obtained through the U.S. Environmental Protection Agency's STORET (STOrage and RETrieval) database (fig. 9). The samples were collected between March of 1986 and June of 1987 and were analyzed for an extensive suite of inorganic, radioactive, and organic constituents. The inorganic and radioactive constituent data were not considered in the following discussion because they are from a site-specific contamination study (it was felt that analyses from such a contamination study would bias the data). The organic constituent data were considered in the discussion of organic constituents because these were the only data available in the study unit on synthetic organic compounds. None of these data were stored in the NWIS data base.

U.S. Department of Energy

The U. S. Department of Energy established the National Uranium Resource Evaluation (NURE) Program in 1973. The objectives of the NURE Program were: (1) To provide a comprehensive in-depth assessment of the Nation's uranium resources for national energy planning, and (2) to identify areas favorable for the occurrence of uranium resources throughout the United States (Union Carbide Corporation, 1978). One phase of the NURE Program was the Hydrogeochemical and Stream Sediment Reconnaissance Survey (HSSRS). During the HSSRS phase, water samples from wells and sediment samples from streams were collected and analyzed for a comprehensive suite of inorganic chemical constituents. The results of the chemical analyses of the water samples were used in this report. In addition, the results of the chemical analyses of the stream sediments for the Central Oklahoma aquifer study unit were examined by Mosier and Bullock (1988) as part of the NAWQA Program.

Although the data from the NURE Program were compiled by the Department of Energy, these data are commonly referred to as "NURE data." Use of the term "NURE data" is maintained in this report, and refers specifically to the chemical analyses of water samples collected by the Department of Energy for the NURE Program.

The NURE data included one sample from each of 510 wells that are completed in the Central Oklahoma aquifer study unit (fig. 10). The samples were taken from shallow wells, generally less than 100 feet deep. The samples were collected between January 1977 and December 1978. Analyses were performed for all major elements (except chloride) and a large suite of trace elements, in addition to uranium and thorium.

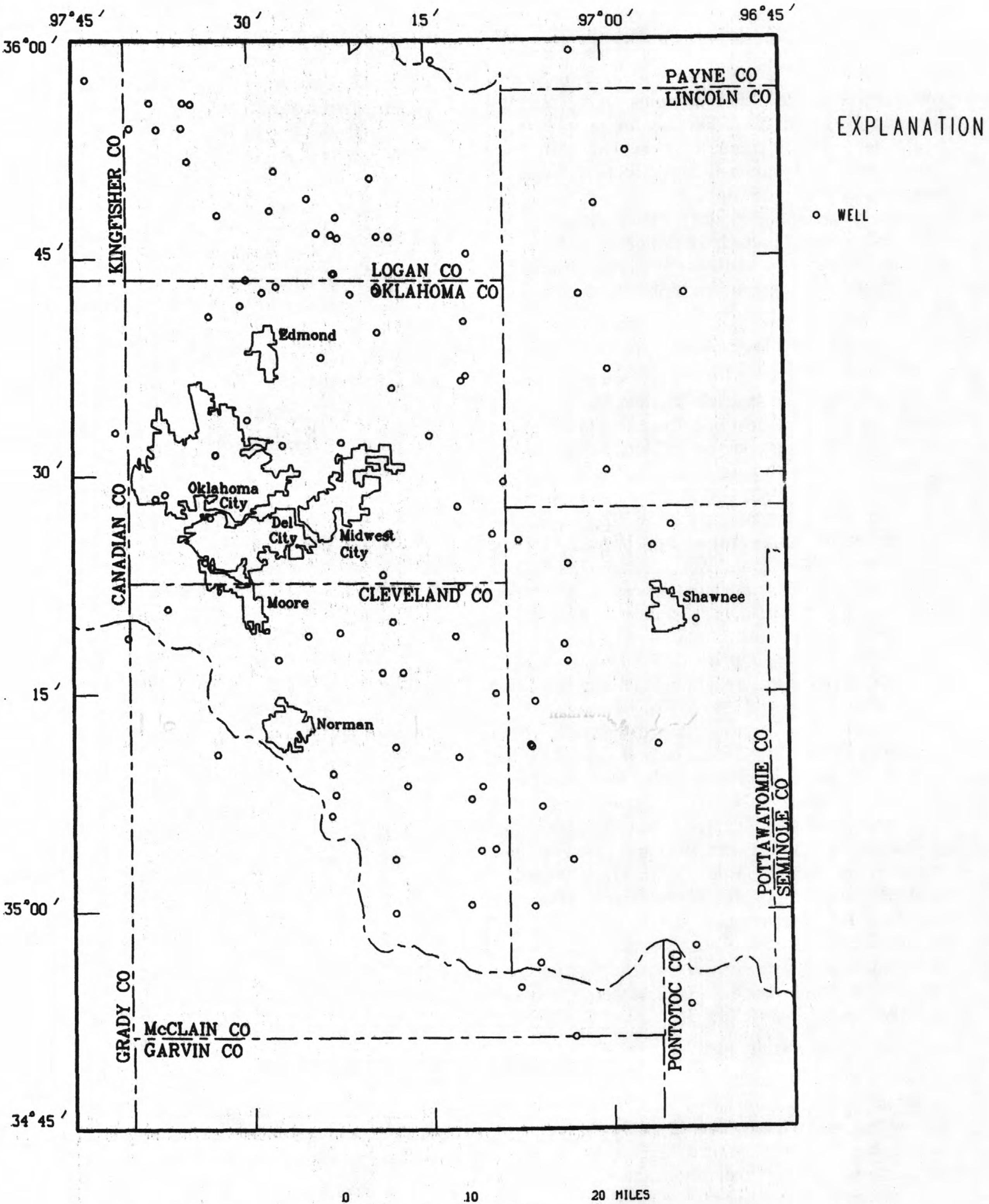

Figure 8.—Locations of wells sampled by the Oklahoma Water Resources Board.

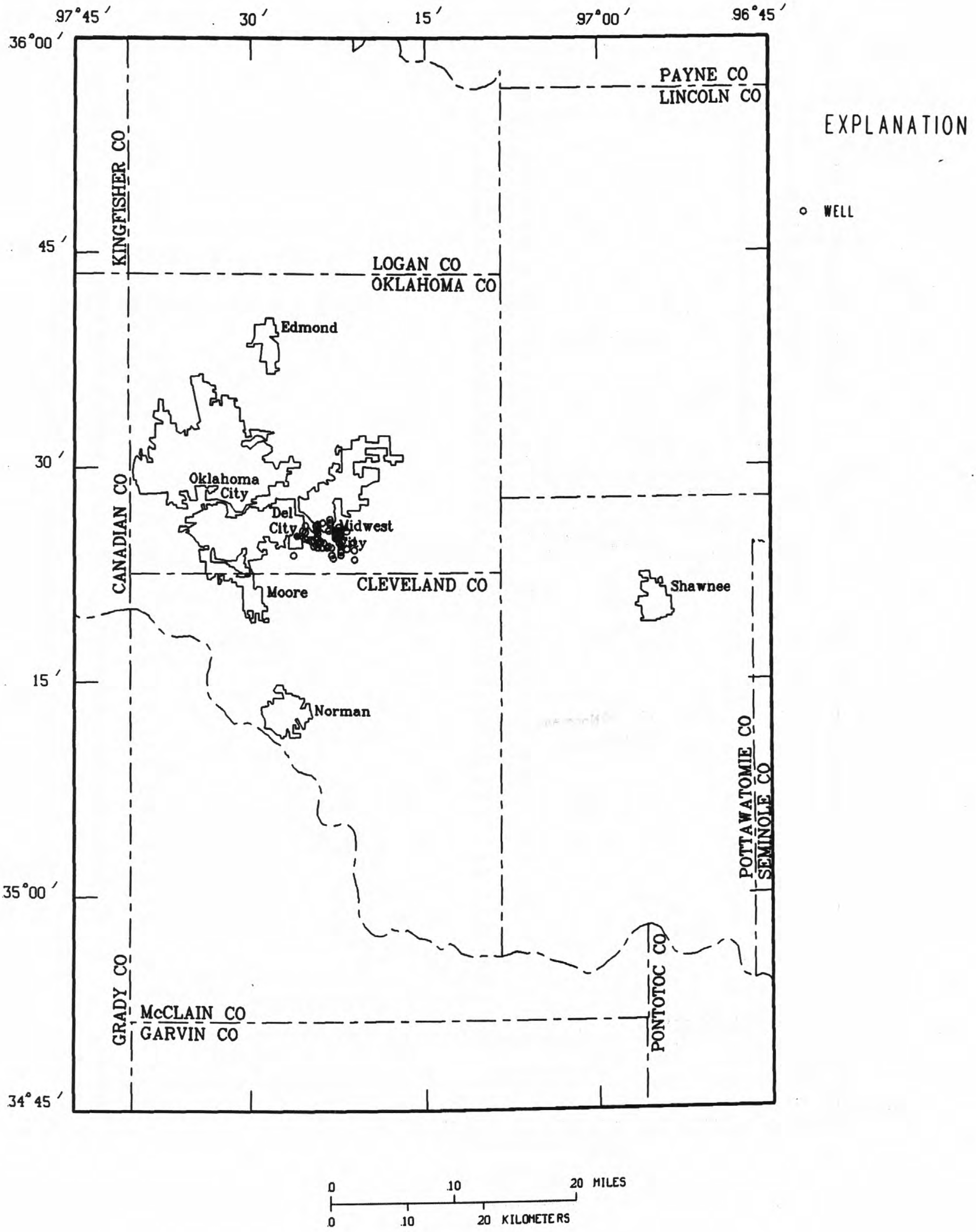

Figure 9.—Locations of wells sampled by the U.S. Department of Defense.

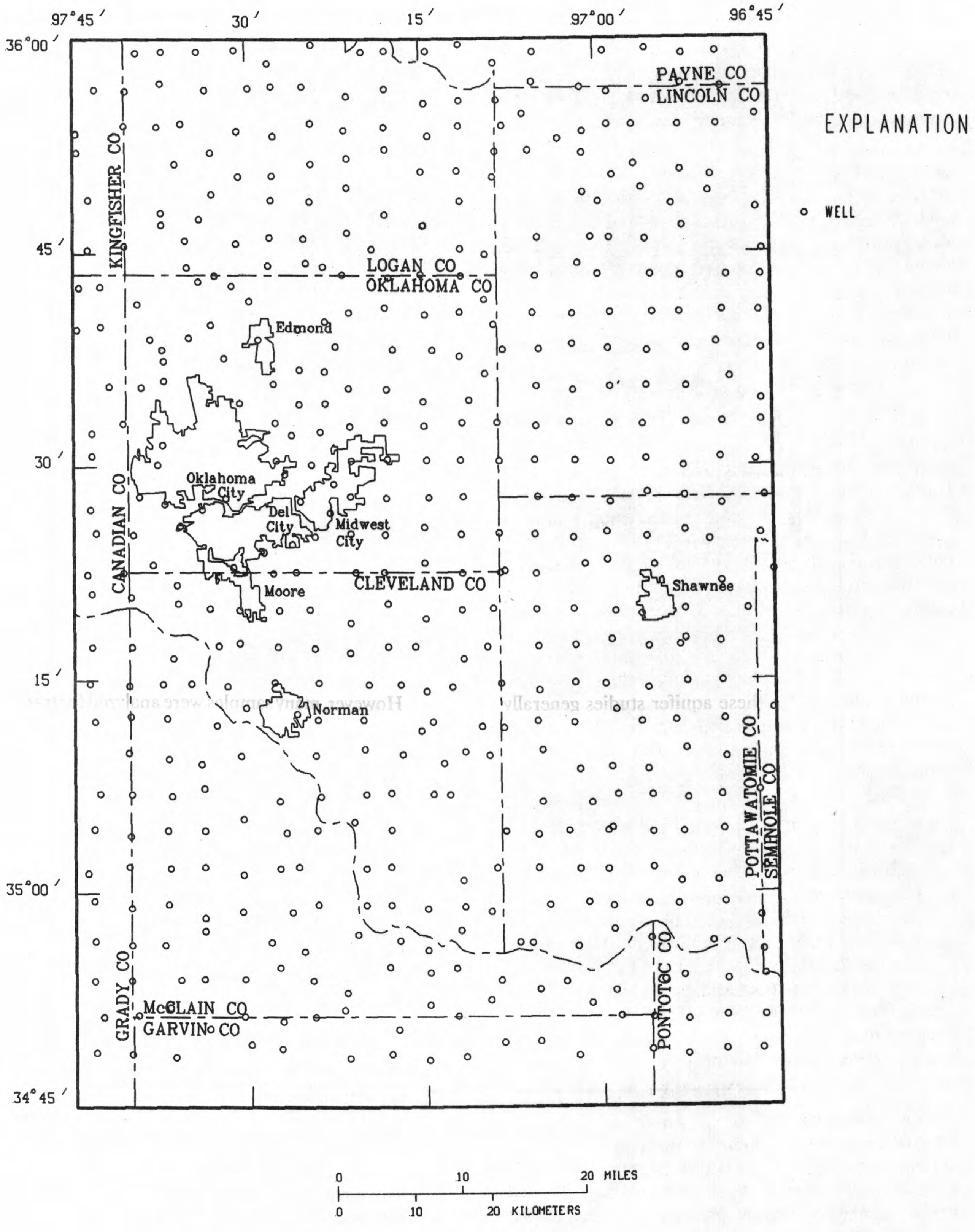

Figure 10.–Locations of wells sampled by the U.S. Department of Energy.

The sampling program in the study unit was carried out under the direction of the Oklahoma Geological Survey and the samples were analyzed by the Oak Ridge National Laboratory. The data were obtained on magnetic tape from the U.S. Geological Survey's Earth Resources Observation Systems Data Center.

Personnel from the U.S. Geological Survey attempted to locate all 510 of the wells sampled by the NURE Program. Most of the NURE sites were found and at each site the latitude, longitude, and legal description of the well location was determined. At about 250 of the sites the well depth and water level were measured, and the geologic unit in which the well is completed was determined. All 510 analyses were entered in the NWIS data base after a limited amount of data checking.

U.S. Geological Survey

The mission of the U.S. Geological Survey is to provide geologic, topographic, and hydrologic information that contributes to the wise management of the Nation's natural resources (U.S. Geological Survey, 1986). Among many activities that are undertaken to accomplish its mission, the U.S. Geological Survey collects and analyzes data on the quantity and quality of surface water and ground water. Many of the water samples collected by the U.S. Geological Survey in central Oklahoma were collected as part of studies of specific aquifers, especially studies of the alluvium and terrace deposits along the North Canadian River. The samples collected for these aquifer studies generally were analyzed for major elements, and the analyses were used to determine the suitability of water for water supplies and irrigation.

The U.S. Geological Survey has collected and analyzed samples in the study unit since 1941. A total of 650 samples from 588 wells were collected by the U.S. Geological Survey in the study unit and the results of the chemical analyses of these samples are stored in the NWIS data base (fig. 11). For the most part, the samples were analyzed in U.S. Geological Survey laboratories in Oklahoma City, Salt Lake City, or Denver. The analyses were checked against laboratory data sheets when available. The well-location data were checked and, if necessary, updated to agree with the latest location information for the study unit.

Data From Other Sources

Some 178 analyses from 40 wells were obtained from other sources, including municipalities and consulting firms. For almost all of these wells, several samples were collected at different depths as the well was being drilled. The samples were analyzed by private laboratories or by the Oklahoma State Department of Health. The data were checked and entered into the NWIS data base.

GENERAL SUITABILITY OF DATA FOR REGIONAL WATER-QUALITY ASSESSMENT

An ideal water-quality assessment of a ground-water resource requires that the chemical data be evenly distributed areally and vertically; the sampled wells be completed in distinct geologic units; consistent sampling procedures and analytical methods be used; and chemical analyses be made for a wide range of inorganic and organic constituents. The following discussion examines the suitability of the data from each agency relative to requirements for an ideal assessment:

(1) Association of Central Oklahoma Governments: Chemical analyses obtained from the Association of Central Oklahoma Governments generally were performed on water from public-supply wells. Because public-supply wells are clustered near municipalities, these analyses are not evenly distributed areally. Municipal wells generally are completed to maximize the well's yield, therefore the wells tend to be open to all transmissive hydrogeologic units instead of distinct hydrogeologic units.

Water samples collected by the Association generally were not filtered and were acidified with nitric acid. The samples were analyzed by the Oklahoma State Department of Health, therefore the analytical methods were the same as those used by that agency (discussed below). However, many samples were analyzed for trace elements only, so the suite of constituents was not consistent with those of the Department of Health. Some samples were collected and analyzed for gross-alpha and gross-beta radioactivity. No data on organic constituents were available from the Association.

(2) Oklahoma State Department of Health: Most of the samples obtained from the Oklahoma State Department of Health were from water distribution systems, not individual wells. Many of the analyses represent groups of wells, thus it is frequently impossible to assign distinct locations to these analyses. Because most of the Department of Health data are from public-supply systems, the data are clustered near municipalities and are not evenly distributed areally.

Most of the chemical analyses performed by the Department of Health include major ions and some trace constituents. Samples to be analyzed for major ions are not acidified and are refrigerated; samples to be analyzed for trace constituents are acidified with nitric acid.

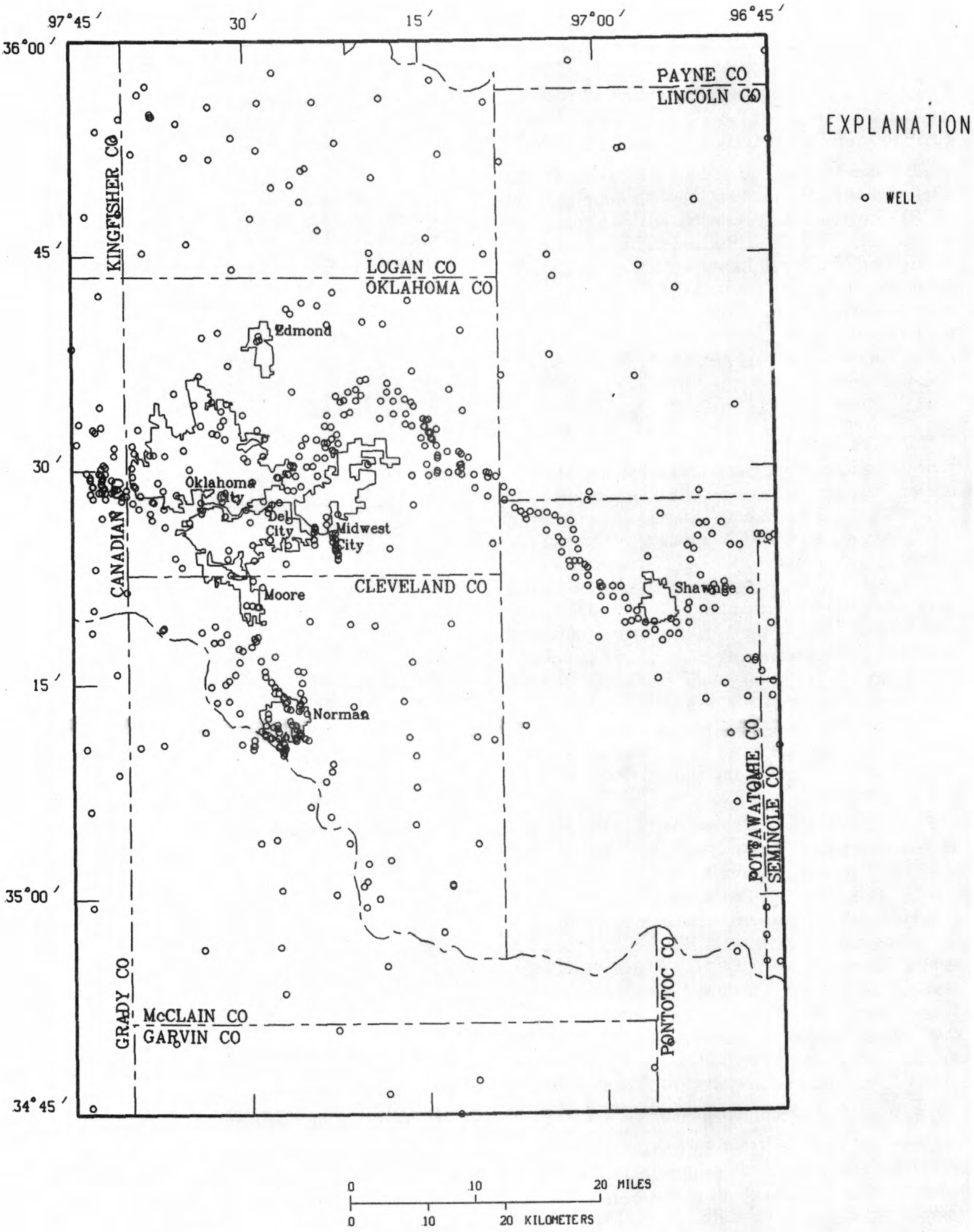

Figure 11.—Locations of wells sampled by the U.S. Geological Survey.

Nitrate samples are acidified with sulfuric acid and refrigerated. Analyses were performed on unfiltered samples and concentrations were reported as total concentrations. Any suspended solids present in the sample could contribute to the total concentration of some elements. The presence of suspended solids could result in larger concentrations and possibly more variability in the analyses in comparison to filtered samples. Sulfate concentration was reported as dissolved sulfate. Generally, pH was measured in the laboratory. In-gassing and de-gassing of carbon dioxide during shipment and storage can produce large changes in pH. Dissolved solids were measured by evaporation at 105 °C. This method may retain more water of hydration and thus give a larger value compared to evaporation at 180 °C. The Department of Health recently (1988) has begun analyzing for organic compounds, but these data were not available for this report.

The Environmental Laboratory of the Department of Health performs the chemical analyses for the Association of Central Oklahoma Governments and the Oklahoma Water Resources Board. Therefore, the laboratory methods used for the analyses were assumed to be the same among these agencies.

The chemical analyses from the Radiochemistry Laboratory are mostly of samples collected from distribution systems, so these data have the same limitations as the analyses from the Environmental Laboratory relative to requirements for an ideal water-quality assessment. Although a few of these analyses are from individual wells, these wells are not widely distributed throughout the Central Oklahoma aquifer.

(3) Oklahoma Water Resources Board: Wells sampled by the Oklahoma Water Resources Board were more evenly distributed areally than most of the other data bases except for the NURE data. All types of wells were sampled by the Board, including municipal wells, domestic wells, and irrigation wells. Because municipal and irrigation wells generally are deeper than domestic wells, wells of a range of depths were sampled. Municipal and irrigation wells generally are open to many hydrogeologic units. The water samples collected by the Board were analyzed by the Oklahoma State Department of Health. The Board has not analyzed any samples for organic compounds.

(4) U.S. Department of Defense: Data obtained from the U.S. Department of Defense included analyses of water from 192 wells within the boundary and in the vicinity of Tinker Air Force Base. Some of the samples were obtained from water-supply wells, which are open to many hydrogeologic units, and some samples were obtained from monitoring wells, which are open to specific hydrogeologic units. A wide range of inorganic and organic constituents were analyzed. Samples for total organic carbon, volatile and semivolatile organic compounds; total metals; and chloride, sulfate, dissolved solids, and alkalinity were refrigerated. Total organic carbon and metal samples were acidified to pH less than 2 (U.S. Army Corps of Engineers, 1987). The Department of Defense is continuing to sample wells within Tinker Air Force Base. The analyses discussed in this report, however, are limited to those data retrieved from STORET in October 1987.

(5) Department of Energy: The wells sampled as part of the Department of Energy's NURE Program are evenly distributed areally. The sampled wells generally were shallow, thus a large range of depths is not represented by the sampling. The samples generally were collected from domestic wells, which generally are open to a single hydrogeologic unit. The sampling procedures were the same for all wells. Field measurements were made for specific conductance, pH, and dissolved oxygen. Samples were filtered and the analytical results were reported as dissolved concentrations. Samples were not analyzed for dissolved solids or chloride. All samples collected in central Oklahoma were sent to the same laboratory. The chemical analyses that were performed on the water samples included a wide range of inorganic constituents, but no analyses were made for organic compounds.

The NURE data have many of the characteristics needed for an ideal water-quality assessment. The chief limitations of the NURE data are that no deep wells were sampled, so that a significant part of the water resource of the Central Oklahoma aquifer was not sampled, and that no analyses were made for organic compounds.

(6) U.S. Geological Survey: The U.S. Geological Survey data are primarily from wells located along the North Canadian River alluvium and terrace deposits, where the U.S. Geological Survey has conducted investigations in recent years. A smaller number of wells completed in consolidated geologic units were sampled.

Wells completed in a wide range of depths have been sampled including: domestic, stock, irrigation, public-supply, and industrial wells. Sampling and laboratory methods used by the U.S. Geological Survey have changed over time. More recent data have field parameters, generally including specific conductance, temperature, and pH. Samples analyzed for dissolved ions and metals were filtered in the field through a 0.45-micrometer filter. Samples were acidified to a pH less than 3 for constituents sensitive to oxidation, precipitation, or adsorption on the surfaces of the sample container (Brown and others, 1970). Analyses performed on samples that were filtered in the field were reported as dissolved concentrations. Analyses that were performed on unfiltered samples were reported as total or total recoverable concentrations. Dissolved solids were measured by evaporation at 180 °C. This method drives off more water of hydration and crystallization than evaporation at 105 °C, which results in a smaller dissolved solids concentration. A comprehensive suite of inorganic constituents was analyzed for some samples, but for other samples only field parameters (pH, temperature, and specific conductance) were measured. Although the sampling and analytical methods employed by the Survey have changed during the time that samples have been collected in central Oklahoma, all analyses were treated equally in this report.

Overall, the chemical analyses that are available for the study unit are not ideally suited for conducting water-quality assessments. Large amounts of data are available, but each agency sampled for a different purpose and analyzed different constituents using different sampling and analytical methods. Even within individual agencies, analytical methods have changed over time. This inconsistency in sampling and analytical methods makes it difficult to compare the data from the different agencies. Although some wells sampled by some agencies are evenly distributed areally (notably the NURE data), none of the data is evenly distributed vertically. The most obvious deficiency in the available data is the lack of organic analyses. Except for Department of Defense data from wells within and near Tinker Air Force Base, no analyses for organic compounds were available in the study unit.

ANALYSIS OF AVAILABLE GROUND-WATER-QUALITY DATA

Although the available ground-water-quality data for the Central Oklahoma aquifer are not ideally suited to a water-quality assessment, the data can be used to make a preliminary assessment of the occurrence of major ions and of trace elements for which water-quality standards have been established.

Much of the analysis of the available data examines the relation between major- and trace-element chemistry and two geohydrologic factors—geologic unit and depth. These two factors were chosen because they should be related to important controls on the evolution of water chemistry and because geologic unit and well depth (or sampling depth) were available for most of the chemical analyses. The mineralogy, organic carbon content, degree of weathering, proximity to outcrop, and hydraulic conductivity are among the characteristics of geologic units that affect water chemistry. Depth of ground water also is related to processes affecting water chemistry. Effects caused by human activities and interactions with the atmosphere are more likely to occur in water at shallow depths. Older water, deep in the aquifer, has had more time for geochemically slow reactions to occur and is less likely to be affected by human activities. The purpose of the data analysis is to discover relations between the geohydrologic factors and the occurrence of major ions and trace elements. It is outside the scope of this report to attempt to explain the relations in terms of specific chemical processes.

In this section of the report, the available data were used to determine regional variations in major-ion chemistry for the shallow and deep zones of the study unit, to calculate summary statistics for each constituent for which data were available, to map and tabulate the occurrence of constituents that exceeded water-quality standards, and to examine the relation of geologic unit and depth to the occurrence of constituents for which water-quality standards are established.

Regional Variations in the Major-Ion Chemistry

The major-ion chemistry of ground water in the study unit varies over a wide range of compositions. However, there are distinct spatial patterns in water compositions that are related to geologic units. Maps were constructed to show the general areal distribution of the major-ion composition of ground water. The major ions included on the maps are sodium, calcium plus magnesium, bicarbonate, sulfate, and chloride.

Major-ion chemistry was mapped in two zones of the study unit. A shallow zone was defined to include all wells in the alluvium and terrace deposits; the El Reno Group; the Hennessey Group; the Chase, Council Grove, and Admire Groups; and the Vanoss Formation. There are very few deep wells completed in these geologic units. The shallow zone also included wells less than 100 feet in depth in the Garber Sandstone and Wellington Formation. Most deep wells in the study unit are completed in the Garber Sandstone and Wellington Formation. A deep zone was defined to include only wells greater than 300 feet that were completed in the Garber Sandstone and Wellington Formation.

Methods of Map Construction

The maps of major-ion chemistry were based on all of the chemical data assembled from all of the agencies (except data from the Department of Defense at Tinker Air Force Base) that met two criteria: (1) Only analyses from wells that had a geologic unit identified were used, and (2) for wells in the Garber Sandstone and Wellington Formation, only wells with known depths were used. The shallow zone had a large number of analyses that were evenly distributed areally, largely because of the NURE data. In contrast, the data for the deep zone were clustered in areas of well fields of the major municipal ground-water users. Few data were available for the deep zone outside urban and suburban areas.

Analyses for dissolved and total concentrations of major ions were treated the same. The few wells with samples that were analyzed for both total concentrations and dissolved concentrations of major ions are consistent with the assumption that there is little difference between dissolved and total concentrations of the major ions. However, there are insufficient data to test this assumption rigorously.

Because many of the analyses included a measurement of hardness but no individual measurements of calcium or magnesium, calcium and magnesium were considered together in the construction of the maps. The term calcium plus magnesium is used to denote either a hardness measurement or a hardness value calculated from individual measurements of calcium and magnesium. Potassium was not mapped because potassium concentrations consistently were small relative to calcium, magnesium, and sodium.

The areal distribution of data for chloride was inadequate for the shallow zone, largely because the NURE data lacked chloride analyses. However, the NURE data did contain analyses for all major ions other than chloride. Therefore, for the NURE data, chloride was calculated as the difference of the major cation and anion equivalents and these calculated chloride concentrations were included in the set of data used to construct the map of major-ion chemistry in the shallow zone. If the calculated concentration of chloride was negative, the chloride value was eliminated. If the calculated chloride concentration was negative and greater than 10 percent of the total cations, all of the major ions for that analysis were eliminated.

In the pH range of water samples from the study unit (approximately 6.0 to 9.5), bicarbonate ion is the only major component of alkalinity. Thus, the term bicarbonate is used instead of alkalinity in the following discussion of cation and anion water compositions. Nitrate rarely accounted for more than 5 percent of the anion equivalents and was not included in the maps.

Two types of cations were mapped, sodium and calcium plus magnesium. Three anions were mapped, bicarbonate, sulfate, and chloride. The concentrations of each major ion initially were plotted individually and the data were contoured at 1 meq/L (milliequivalent per liter) intervals. A threshold value of 3 meq/L was used to distinguish areas of large concentrations of each ion. Areas that contained several wells with analyses greater than 3 meq/L were delineated for calcium plus magnesium, sodium, bicarbonate, chloride, and sulfate in each of the two zones. A delineated area did not necessarily have large concentrations of the specified ion in every well within the area. However, large concentrations of the specified ion did occur frequently within a designated area. The areas were transferred to a single map for each zone and the boundaries of the areas were smoothed and combined to provide a generalized description of the concentrations of these ions in each of the zones. Figures 12 and 13 are the results of this procedure.

Shallow Zone

A wide variety of water compositions are observed in the shallow zone and the patterns are closely related to the geologic units (fig. 12). Therefore, the discussion of water composition is organized by geologic unit, in order of increasing age of the units. The contacts between the consolidated geologic units are shown on figure 12. Chemical data for the alluvium and terrace deposits were included with data for the underlying geologic units in the construction of the map for the shallow zone. Some discussion of the alluvium and terrace deposits is included with the discussion of the underlying geologic units.

Alluvium and terrace deposits

The range of water composition in the alluvium and terrace deposits is large and locally variable. In general, the water compositions in the alluvium and

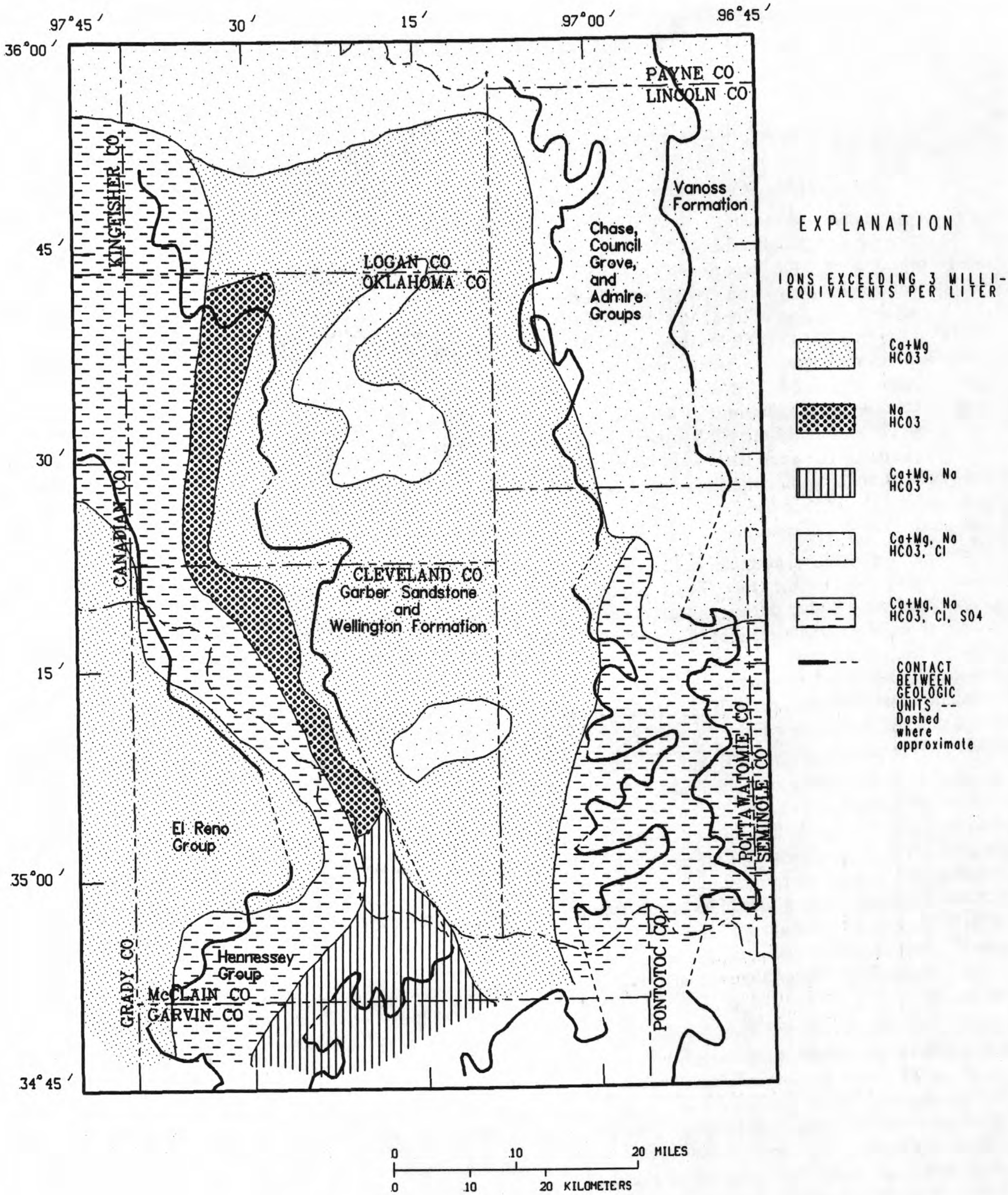

Figure 12. – Major-ion chemistry in the shallow zone of the study unit.

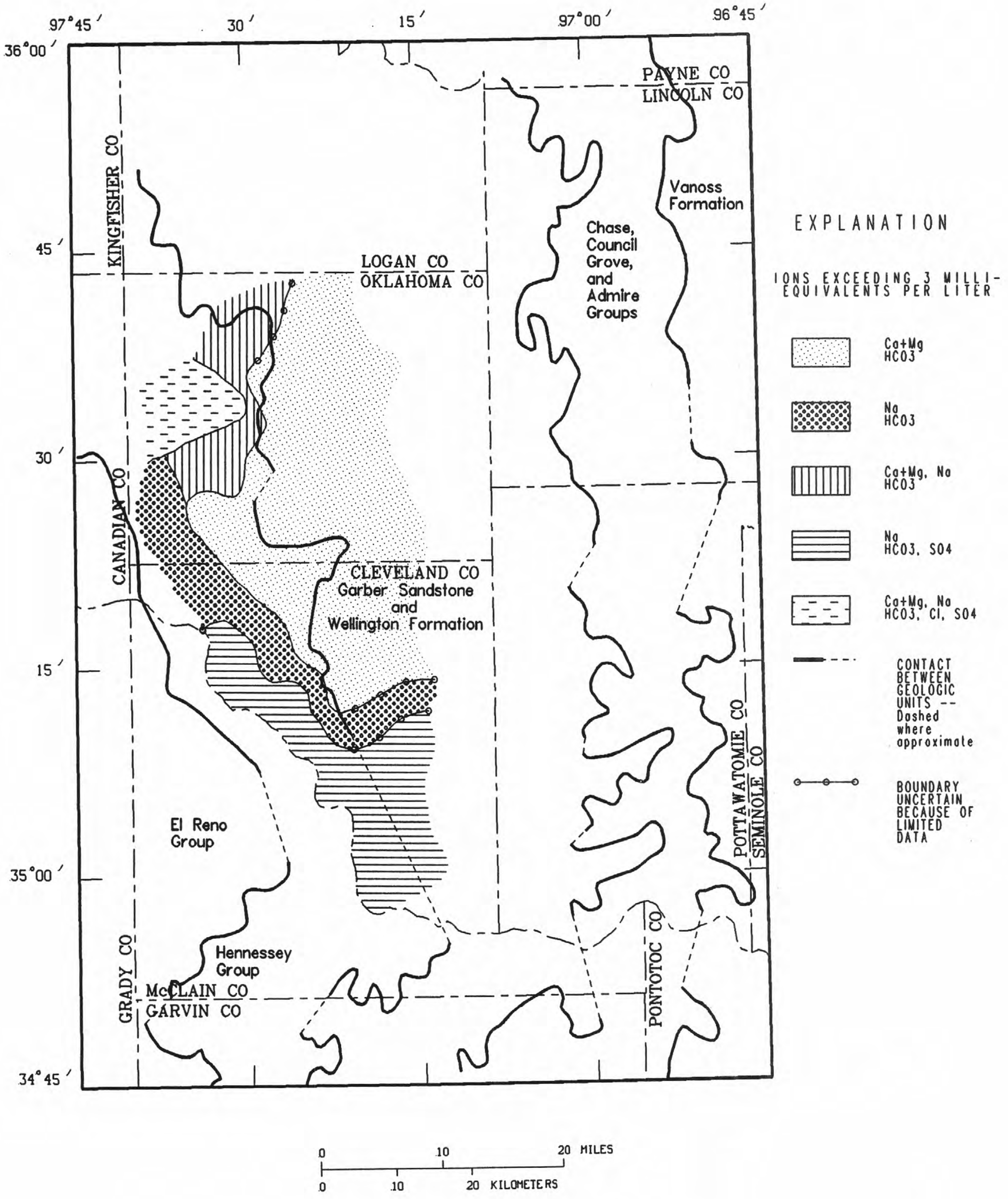

Figure 13.—Major-ion chemistry in the deep zone of the study unit.

terrace deposits are not distinguishable from the surrounding consolidated geologic unit. Two exceptions are: (1) The North Canadian alluvium and terrace deposits in central Oklahoma County have larger sodium and chloride concentrations than the Garber Sandstone and Wellington Formation south of the alluvium and terrace deposits, and (2) the Cimarron River alluvium and terrace deposits in the far northwest corner of the study unit do not have the large sulfate concentrations found in the adjacent Hennessey Group.

El Reno Group

The outcrop of the El Reno Group is in the southwest part of the study unit (fig. 12). Calcium plus magnesium and bicarbonate are the predominant ions in the water. Although the water composition is similar to the water composition of the Garber Sandstone and Wellington Formation, the water in the El Reno Group tends to have calcium plus magnesium, sodium, and chloride concentrations that are larger than water in the Garber Sandstone and Wellington Formation.

Hennessey Group

The Hennessey Group outcrops east of the El Reno Group and west of the Garber Sandstone. A range of water compositions is found in water in the western part of the outcrop of the Hennessey Group. Both sodium and calcium plus magnesium occur in large concentrations and bicarbonate, chloride, and sulfate also are found in large concentrations. This western area also includes parts of the alluvium and terrace deposits of the North Canadian and Canadian Rivers.

Sodium bicarbonate water occurs in an area that is closely aligned with the eastern part of the outcrop of the Hennessey Group. The northern part of this eastern area is the only place in the shallow zone where calcium plus magnesium concentrations are less than 3 meq/L. The southern part of this eastern area also has large concentrations of sodium, but calcium plus magnesium concentrations are large as well. Bicarbonate is the dominant anion in this southern area, but sulfate and chloride occur frequently at concentrations between 1 and 3 meq/L.

Garber Sandstone and Wellington Formation

The shallow zone includes wells completed in the Garber Sandstone and Wellington Formation that are less than 100 feet in depth. Calcium plus magnesium bicarbonate water is predominant in the shallow part of the Garber Sandstone and Wellington Formation. Three areas have water compositions that differ from this predominant composition:

(1) There is a transition to higher sodium and chloride concentrations in water in the northern part of the outcrop of the Garber Sandstone and Wellington Formation.

(2) Large concentrations of sodium, chloride, and to some extent sulfate, occur sporadically in water from an area in the central part of the Garber Sandstone and Wellington Formation outcrop, which stretches from the North Canadian River to the Deep Fork River. The southern part of this area includes large areas of the alluvium and terrace deposits associated with the North Canadian River.

(3) Large sodium and chloride concentrations occur in the southern part of the outcrop of the Garber Sandstone and Wellington Formation near the Little River.

Chase, Council Grove, and Admire Groups and Vanoss Formation

In the northern part of the outcrop of the Chase, Council Grove, and Admire Groups and Vanoss Formation, calcium plus magnesium concentrations generally are greater than sodium. Sodium commonly occurs in concentrations greater than 3 meq/L. Bicarbonate and chloride also occur in large concentrations.

In the southern part of the outcrop of the Chase, Council Grove, and Admire Groups and Vanoss Formation calcium plus magnesium, sodium, or both occur in large concentrations in ground water. Either calcium plus magnesium or sodium may be the dominant cation. Bicarbonate is the dominant anion in the western part of this southern area. In the eastern part of the southern area bicarbonate, chloride, and sulfate commonly occur in large concentrations. Thus, there is a transition to larger sulfate and, to some extent, sodium and chloride concentrations from north to south within the outcrop of the Chase, Council Grove, and Admire Groups and Vanoss Formation.

Deep Zone

Only wells completed in the Garber Sandstone and Wellington Formation were included in the deep zone because almost no deep wells are completed in the other geologic units. The deep zone exhibits a variety of water compositions as shown in figure 13. In the eastern part of the deep zone, which is not covered by the Hennessey Group, calcium plus magnesium and bicarbonate generally are the dominant cations and anion in the ground water. In the western and southern part of the deep zone, which is covered by the Hennessey Group, sodium concentrations increase and sodium becomes the dominant cation. To the southwest, the increase in sodium is associated with a decrease in calcium plus magnesium. To the northwest, the increase in sodium usually is not accompanied by a decrease in calcium plus magnesium and all cations occur in large concentrations.

In west-central Oklahoma County, large concentrations of sulfate, chloride, and bicarbonate are common. Along the southwestern edge of Cleveland County, sulfate is found in large concentrations and bicarbonate concentrations are larger than elsewhere in the study unit.

Throughout the study unit, sodium chloride brines are present at depth. Thus, a well of sufficient depth can encounter brine anywhere within the study unit. Large concentrations of chloride and sulfate do occur in individual wells throughout the study unit, but only those areas that had several wells or distribution systems with similar water compositions were delineated on the map.

General Water-Quality Considerations

In this section, summary statistics are presented for the available water-quality data. The methods of calculation and the limitations of the results are discussed. A summary of the number of wells and distribution systems that exceeded water-quality standards also is presented.

Minimum values, selected percentiles, and maximum values were obtained from the available data (except the Department of Defense data for Tinker Air Force Base). The most recent analysis for each constituent was used to represent each distribution system and well. If analyses were available from different sampling depths from a single well, then the most recent analysis for each constituent from each sampling depth of the well was included in the calculation of the statistics. By selecting the most recent analysis, some of the bias caused by unequal numbers of samples from individual wells and distribution systems was eliminated. However, other biases are present in the data that make it difficult to calculate summary statistics that are representative of the entire study unit. Some of the remaining sources of bias are: (1) Uneven areal distribution of sampled wells, (2) uneven vertical distribution of sampled wells, and (3) differences in sampling and analytical methods among the agencies that collected and analyzed water samples. No corrections were made to the summary statistics to account for these biases because of the difficulty of determining appropriate corrections.

The data for many constituents include values that are reported as less than a specified minimum-reporting level. These values are called censored values. When data from several laboratories and analytical methods are combined, it is common to have several different minimum-reporting levels. Percentiles below the largest minimum-reporting level cannot be calculated accurately using standard methods. A procedure developed by Helsel and Cohn (1988) for calculating percentiles in data with one or more minimum-reporting levels was used to calculate percentiles for any constituent that had censored values. The procedure used a statistical model to calculate any percentiles that were less than the largest minimum-reporting level. It was necessary to eliminate some censored values that had very large minimum-reporting levels relative to the rest of the data. These few values unduly affected the reliability of the calculation of all of the percentiles. Out of all the data for all the chemical constituents, fewer than 25 censored values were eliminated. In order to use the procedure, it also was necessary to eliminate any zero values. For those constituents with censored values, data that were reported as zero were set equal to the largest minimum-reporting level. If no censored data were present for a constituent, percentiles were calculated by standard methods. No percentiles were calculated if fewer than 20 analyses were available for a constituent.

Table 3 lists the number of analyses, the largest minimum-reporting level, the minimum value, selected percentiles, and the maximum value for all of the constituents measured in the study unit. The table also lists the method used to calculate the percentiles for each constituent. Because of biases in the areal and vertical distribution of samples, these statistics are only an approximate description of the entire water resource.

Many of the minimum values in table 3 are reported as less than the smallest minimum-reporting level for the constituent in the data set. Many percentiles calculated by the method of Helsel and Cohn (1988) are smaller than the smallest minimum-reporting level. The maximum values often greatly exceed the 95th percentile, and many of the maximum values are related to two samples from a single municipal well. A leaky casing allowed brines to enter the well, which resulted in very large concentrations for many of the constituents.

In terms of evaluating water quality, it is important to consider the number of wells and distribution systems that have exceeded water-quality standards. The water-quality standards listed in table 4 are taken from the primary and secondary drinking-water regulations of the U.S. Environmental Protection Agency

Table 3.—*Summary statistics for each chemical constituent using all sources of data (except the Department of Defense)*

[These statistics were calculated including only the most recent analysis for each constituent for each well. If analyses were available for different sampling depths from the same well, the most recent analysis for each constituent from each sampling depth of the well was included. Constituents and physical parameters: µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter. Method: 1, no censored data, ordinary percentile calculation; 2, censored data present, percentiles calculated using methods of Helsel and Cohn (1988); 3, no calculation, more than 95 percent of the data were censored; 4, no calculation, less than 20 analyses for the constituent. Largest MRL: largest minimum reporting level (percentiles less than this value were estimated using the methods of Helsel and Cohn (1988); percentiles greater than this value are the same as ordinary percentile calculation); -, no censored data for this constituent. Percentiles: -, indicates no statistic was calculated; Maximum value: -, indicates all data were censored for this constituent]

Constituents and properties	Method	Sample size	Largest MRL	Minimum value	Percentiles							Maximum value
					5	10	25	50	75	90	95	
Properties and major ions												
Specific conductance (µS/cm at 25 °C)	1	1,368	-	50	348	390	491	690	1,010	1,730	2,620	14,500
pH, field (standard units)	1	1,076	-	4.6	6.1	6.5	6.9	7.3	7.8	8.2	8.4	10
Temperature, water (°C)	1	899	-	4.5	9.5	12	15	17	19	20	21	33
Oxygen, dissolved (mg/L as O_2)	1	509	-	.5	2.4	3.2	4.8	6.9	8.3	9.7	11	15
Hardness, total (mg/L as $CaCO_3$)	2	958	10	0	14	32	116	210	300	490	720	18,000
Calcium, total (mg/L as Ca)	2	186	4	1	5.3	12	34	52	73	110	180	4,280
Calcium, dissolved (mg/L as Ca)	1	884	-	0	4.6	14	31	51	72	110	166	680
Magnesium, total (mg/L as Mg)	1	103	-	1	3	4.8	17	24	35	55	65	100
Magnesium, dissolved (mg/L as Mg)	1	883	-	0	2.3	7	16	26	39	56	75	320
Sodium, total (mg/L as Na)	2	220	10	8	5	10	15	30	75	150	180	18,900
Sodium, dissolved (mg/L as Na)	2	782	5	3.5	8.3	11	20	47	120	250	357	3,100
Sodium plus potassium, dissolved (mg/L as Na)	1	221	-	6.4	14	20	36	84	180	330	564	2,100
Potassium, dissolved (mg/L as K)	2	425	2	0	.5	.6	.9	1.5	2	3.2	4.4	17
Bicarbonate (mg/L as HCO_3)	1	365	-	0	133	187	250	320	393	503	610	1,440
Carbonate (mg/L as CO_3)	1	109	-	0	0	0	0	0	9	29	40	270
Alkalinity, total (mg/L as $CaCO_3$)	2	1,244	15	<15	90	126	196	254	320	404	451	1,150
Sulfate, dissolved (mg/L as SO_4)	2	1,453	20	3	1.7	3.1	8.1	24	65	180	370	5,400
Chloride, dissolved (mg/L as Cl)	2	986	20	2	2.4	4	9.7	20	62	173	310	45,400
Fluoride, total (mg/L as F)	2	227	.1	<.1	.08	.1	.2	.2	.4	.6	.9	4
Fluoride, dissolved (mg/L as F)	2	299	.1	0	.04	.06	.1	.2	.5	1.1	1.8	3
Bromide, dissolved (mg/L as Br)	1	26	-	.1	.1	.1	.2	.4	.6	1.4	3.6	4.5
Iodide, dissolved (mg/L as I)	4	5	-	0	-	-	-	-	-	-	-	.3
Silica, dissolved (mg/L as SiO_2)	1	234	-	0	4	5	6	9	14	21	25	54
Dissolved solids, residue at 180 °C (mg/L)	1	300	-	101	206	229	305	430	706	1,194	2,249	8,310
Dissolved solids, residue at 105 °C (mg/L)	1	236	-	57	124	180	249	327	440	779	1,101	71,700
Nutrients												
Nitrogen, nitrate, total (mg/L as N)	4	13	-	0	-	-	-	-	-	-	-	.1
Nitrogen, nitrate, dissolved (mg/L as N)	1	291	-	0	.02	.04	.1	.4	2.7	10	22	187
Nitrogen, nitrite, dissolved (mg/L as N)	4	2	-	0	-	-	-	-	-	-	-	.03
Nitrogen, nitrite plus nitrate, total (mg/L as N)	2	650	.5	<.1	.07	.1	.3	.8	2.8	6.8	11	94
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	1	33	-	.07	.1	.2	.6	1.9	6.3	34	66	73
Phosphorus, total (mg/L as P)	4	7	.01	<.01	-	-	-	-	-	-	-	.1
Phosphorus, dissolved (mg/L as P)	3	507	40	<40	-	-	-	-	-	-	-	324
Phosphorus, dissolved orthophosphate (mg/L as P)	2	126	.1	<.1	.04	.04	.05	.07	.08	.1	.1	.2

Table 3.—*Summary statistics for each chemical constituent using all sources of data (except the Department of Defense)*—Continued

Constituents and properties	Method	Sample size	Largest MRL	Minimum value	Percentiles							Maximum value
					5	10	25	50	75	90	95	
Trace elements												
Aluminum, dissolved (μg/L as Al)	2	507	10	<10	0.8	1.2	2.3	4.9	10	20	20	900
Arsenic, total (μg/L as As)	2	331	10	<10	.1	.2	.7	2.8	10	61	78	140
Arsenic, dissolved (μg/L as As)	2	511	1	<1	.2	.2	.4	.8	1	3	5	27
Barium, total (μg/L as Ba)	2	210	200	20	82	110	200	310	500	700	800	56,400
Barium, dissolved (μg/L as Ba)	2	507	2	<2	19	29	67	170	320	520	652	1,900
Beryllium, dissolved (μg/L as Be)	3	507	1	<1	-	-	-	-	-	-	-	1
Boron, dissolved (μg/L as B)	1	619	-	0	30	40	60	160	558	2,090	4,795	24,000
Cadmium, total (μg/L as Cd)	2	228	5	<2	.3	.4	.6	.8	1.2	1.6	1.9	5
Cadmium, dissolved (μg/L as Cd)	4	7	10	<1	-	-	-	-	-	-	-	18
Chromium, total (μg/L as Cr)	2	416	50	5	1	1.6	3.5	8.6	21	47	66	180
Chromium, dissolved (μg/L as Cr)	2	665	10	0	.04	.08	.2	.8	2.5	7.4	10	130
Chromium, hexavalent (μg/L as Cr)	4	11	50	<50	-	-	-	-	-	-	-	130
Cobalt, dissolved (μg/L as Co)	2	507	2	<2	.2	.3	.5	.9	1.4	2	3	10
Copper, total recoverable (μg/L as Cu)	2	216	10	<4	1.9	3	6.4	14	30	68	147	2,520
Copper, dissolved (μg/L as Cu)	2	514	14	<2	.1	.2	.6	1.9	6.2	19	46	650
Iron, total (μg/L as Fe)	2	289	100	0	1	2	6.5	24	89	350	940	22,700
Iron, dissolved (μg/L as Fe)	2	659	100	0	0	0	0	.1	5.3	500	1,300	24,000
Lead, total (μg/L as Pb)	3	218	45	<20	-	-	-	-	-	-	-	50
Lead, dissolved (μg/L as Pb)	4	6	100	3	-	-	-	-	-	-	-	4
Lithium, dissolved (μg/L as Li)	2	524	10	<2	4	5.2	8.1	13	20	32	43	130
Manganese, total (μg/L as Mn)	2	224	20	<5	.05	.1	.5	2.4	12	35	155	1,610
Manganese, dissolved (μg/L as Mn)	2	637	20	0	.08	.2	.7	3.1	13	80	131	1,300
Mercury, total recoverable (μg/L as Hg)	3	118	.6	<.5	-	-	-	-	-	-	-	.7
Mercury, dissolved (μg/L as Hg)	4	2	-	0	-	-	-	-	-	-	-	.1
Molybdenum, dissolved (μg/L as Mo)	2	507	4	<4	.4	.7	1.3	2.6	5	11	16	94
Nickel, dissolved (μg/L as Ni)	2	507	4	<4	.2	.3	.7	1.4	2.9	5	7	81
Niobium, dissolved (μg/L as Nb)	2	507	4	<4	.5	.8	1.5	2.9	6	10	20	50
Scandium dissolved (μg/L as Sc)	3	507	1	<1	-	-	-	-	-	-	-	2
Selenium, total (μg/L as Se)	2	423	10	<5	.1	.2	.6	1.9	6.5	21	38	380
Selenium, dissolved (μg/L as Se)	2	664	10	0	.01	.02	.06	.2	.6	1.5	2.8	150
Silver, total (μg/L as Ag)	3	118	70	<3	-	-	-	-	-	-	-	-
Silver, dissolved (μg/L as Ag)	3	507	2	<2	-	-	-	-	-	-	-	3
Strontium, dissolved (μg/L as Sr)	1	195	-	11	48	100	170	380	830	1,500	2,120	10,000
Tin, dissolved (μg/L as Sn)	1	177	-	0	3.9	4	6	7	9	10	10	30
Titanium, dissolved (μg/L as Ti)	2	507	2	<2	.08	.1	.2	.5	1	1.8	2	10
Vanadium, dissolved (μg/L as V)	2	507	4	<4	.3	.5	1.2	3.3	9	24	38	400
Yttrium, total (μg/L as Y)	2	507	1	<1	.3	.4	.6	.8	1	2	2	9
Zinc, total (μg/L as Zn)	2	215	5	<4	1.5	2.7	8	20	74	184	380	6,000
Zinc, dissolved (μg/L as Zn)	2	514	4	<4	3.4	5	17	59	140	380	605	3,400
Zirconium, dissolved (μg/L as Zr)	2	507	2	<2	.2	.2	.4	.6	1.2	2	3	10

Table 3.—*Summary statistics for each chemical constituent using all sources of data (except the Department of Defense)*—Continued

Constituents and properties	Method	Sample size	Largest MRL	Minimum value	Percentiles 5	10	25	50	75	90	95	Maximum value
Radionuclides												
Alpha radioactivity, total (pCi/L)	1	213	-	-1.9	-0.8	0.03	1.8	6	21	59	120	830
Residual-alpha radioactivity (pCi/L)	2	103	9.5	<1	.0	.0	.0	.0	.5	4.9	34.6	80
Beta radioactivity, total (pCi/L)	4	8	-	7	-	-	-	-	-	-	-	38
Beta, gross, total (pCi/L as Sr/Y-90)	1	208	1	-.8	.1	.2	1	2	3.2	7	11	100
Ra-226, total (pCi/L)	1	69	-	-.3	-.1	-.08	0	.1	.3	.6	.8	1.1
Thorium, dissolved (µg/L as Th)	2	507	10	<5	1.2	1.8	3.3	6.4	13	23	30	98
Uranium, natural, total (pCi/L as U)	1	50	-	1.2	1.5	6.5	13	21	37	82	115	210
Uranium, natural, dissolved (µg/L as U)	2	509	.2	0	.1	.2	.6	2.3	7.9	19	38	180
Organic carbon												
Carbon, organic dissolved (mg/L as C)	4	15	-	.6	-	-	-	-	-	-	-	34

(U.S. Environmental Protection Agency, 1986a and 1986b). The primary regulations set maximum contaminant levels (MCL's) to protect public health. The secondary regulations set secondary maximum contaminant levels (SMCL's) for aesthetic reasons related to public acceptance of drinking water. The regulations for MCL's and SMCL's apply only to public water supplies and are not enforceable for domestic and other types of wells. Even though the regulations do not apply to all of the wells considered in this report, the MCL's and SMCL's define the standards used for comparison purposes throughout this report.

Table 4 lists the number of wells and distribution systems that exceeded the water-quality standard for each chemical constituent. The number of wells or distribution systems that were sampled are listed also. Individual wells are listed separately from distribution systems and total concentrations are listed separately from dissolved concentrations. Table 4 may show fewer wells than are indicated in table 3 because some wells were sampled by more than one agency.

The maximum value for each constituent for each well and distribution system was used in the tabulation of statistics for table 4. The minimum values of pH were also tabulated. The maximum value was compared to the water-quality standard to determine whether or not it exceeded the standard. Each well and each distribution system was weighted equally. The largest values (rather than the most recent) were tabulated (table 4) in order to include all occurrences of two types of water-quality problems:

(1) Some wells in the Central Oklahoma aquifer appear to have intermittent water-quality problems, which are possibly related to pumping history, and

(2) water-quality problems in distribution systems often depend on the mixture of water from several wells. Thus, problems may occur intermittently as the mixture of water from different wells varies.

By selecting the largest value for each constituent, intermittent problems of these types will be included in the tabulated data. Thus, table 4 is a description of wells and distribution systems that, at any time, exceeded a water-quality standard. It is not a description of the number of wells or distribution systems that currently exceed water-quality standards.

The data in table 4 show that nitrate, arsenic, chromium, selenium, and residual-alpha radioactivity (gross alpha particle activity excluding radon and uranium) concentrations exceeded the MCL's in some ground-water samples from the study unit. Concentrations of sulfate, chloride, manganese, and dissolved-solids and pH values exceeded the SMCL's in some ground-water samples. Iron concentrations exceeded the SMCL's in some ground-water samples. Dissolved and total iron concentrations are discussed more fully below.

Only mercury, silver, and radium-226 concentrations were not reported to be larger than their respective MCL in any ground-water samples. Fluoride, cadmium, copper, lead, and zinc concentrations in ground water exceeded their standards in samples from no more than two wells and two distribution systems. Barium concentrations in ground water exceeded the MCL in less than 2 percent of the wells sampled and in just over 4 percent of the distribution systems.

Spatial Distribution and Statistical Summaries of Selected Constituents

Thus far, the occurrence of chemical constituents that exceeded water-quality standards has been discussed for the study unit as a whole. This section presents a more detailed examination of the relation of geologic unit and depth to the occurrence of constituents that exceed water-quality standards. Large variations exist in major-ion chemistry related to geologic unit and similar variations are expected for other chemical constituents. Maps were constructed to show the location of samples that exceeded water-quality standards. Contingency tables were calculated to test for differences among geohydrologic categories in the proportion of analyses that exceeded water-quality standards. Although no regulations currently apply to uranium concentrations, an MCL is under consideration and large concentrations of uranium are a potential problem in the study unit. Thus, a discussion of the occurrence of large uranium concentrations is included in this section.

Construction of Maps

For the following discussion, a map was produced for each constituent listed in table 4 and for uranium. The map for each constituent shows each sampling location (open or closed symbol) and each location where a sample exceeded the water-quality standard (closed symbol). Total-concentration data are distinguished from dissolved-concentration data and samples from distribution systems are plotted with a different symbol than samples from individual wells. Some distribution systems may have only one well; but single-well systems were treated the same as multi-well systems. The maps make no distinction as to the depth of the wells.

Table 4.—*Listing of water-quality standards, the number of wells and distribution systems that were sampled, and the number of wells and distribution systems that exceeded the water-quality standard for each constituent*

[The columns showing the number of wells and distribution systems that exceeded a standard include any well or distribution system with any analysis that exceeded the standard. The numbers do not indicate the number of wells currently exceeding a standard nor do they indicate how consistently a problem has occurred at a given well or distribution system. Constituents and physical parameters: µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter. Type of standard: MCL, maximum contaminant level; SMCL, secondary maximum contaminant level]

Chemical constituent	Description of analysis	Water-quality standard	Type of standard	Number of wells: Sampled	Number of wells: Exceeded standard	Number of distribution systems: Sampled	Number of distribution systems: Exceeded standard
pH	Field (Standard units)	6.5	SMCL	961	[1]96	0	0
pH	Field (Standard units)	8.5	SMCL	961	37	0	0
Sulfate	Dissolved (mg/L as SO_4)	250	SMCL	1,180	117	122	5
Chloride	Dissolved (mg/L as Cl)	250	SMCL	711	50	124	3
Fluoride	Total (mg/L as F)	4	MCL	104	0	124	1
	Dissolved (mg/L as F)			170	0	0	0
Dissolved solids	Residue at 180 °C (mg/L)	500	SMCL	300	121	0	0
	Residue at 105 °C (mg/L)			106	30	116	32
Nitrate	Total (mg/L as N)	10	MCL	2	0	0	0
	Dissolved (mg/L as N)			302	32	0	0
Nitrite plus nitrate	Total (mg/L as N)	10	MCL[2]	134	13	401	39
	Dissolved (mg/L as N)			33	5	0	0
Arsenic	Total (µg/L as As)	50	MCL	183	27	118	7
	Dissolved (µg/L as As)			511	0	0	0
Barium	Total (µg/L as Ba)	1,000	MCL	96	1	118	5
	Dissolved (µg/L as Ba)			507	7	0	0
Cadmium	Total (µg/L as Cd)	10	MCL	97	0	122	0
	Dissolved (µg/L as Cd)			7	1	0	0
Chromium	Total (µg/L as Cr)	50	MCL	264	41	122	9
	Dissolved (µg/L as Cr)			529	7	0	0
Copper	Total recoverable(µg/L as Cu)	1,000	SMCL	97	2	120	2
	Dissolved (µg/L as Cu)			514	0	0	0
Iron	Total (µg/L as Fe)	300	SMCL	168	21	122	24
	Dissolved (µg/L as Fe)			546	12	0	0
Lead	Total (µg/L as Pb)	50	MCL	97	2	122	1
	Dissolved (µg/L as Pb)			6	0	0	0
Manganese	Total (µg/L as Mn)	50	SMCL	107	9	118	13
	Dissolved (µg/L as Mn)			529	32	0	0

Table 4.—*Listing of water-quality standards, the number of wells and distribution systems that were sampled, and the number of wells and distribution systems that exceeded the water-quality standard for each constituent*—Continued

Chemical constituent	Description of analysis	Water-quality standard	Type of standard	Number of wells		Number of distribution systems	
				Sampled	Exceeded standard	Sampled	Exceeded standard
Mercury	Total recoverable (µg/L as Hg)	2	MCL	0	0	118	0
	Dissolved (µg/L as Hg)			2	0	0	0
Selenium	Total (µg/L as Se)	10	MCL	274	84	119	16
	Dissolved (µg/L as Se)			527	11	0	0
Silver	Total (µg/L as Ag)	50	MCL	0	0	118	0
	Dissolved (µg/L as Ag)			507	0	0	0
Zinc	Total (µg/L as Zn)	5,000	SMCL	97	0	120	1
	Dissolved (µg/L as Zn)			514	0	0	0
Residual-alpha radioactivity	Total (pCi/L)	15	MCL[3]	18	4	81	8
Radium-226	Total (pCi/L)	5	MCL[4]	15	0	61	0

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[1] Ninety-six is the number of samples that had pH values less than 6.5.

[2] The MCL applies to nitrate; the nitrite plus nitrate analysis is used as an estimate of nitrate.

[3] The MCL for gross alpha particle activity is 15 pCi/L, excluding radon and uranium alpha radioactivity. Residual-alpha radioactivity is directly comparable to the MCL for gross-alpha particle activity. (See text for a discussion of alpha radioactivity.)

[4] The radium MCL is 5 pCi/L for radium-226 plus radium-228 radioactivity.

Treatment of Data for the Contingency-Table Analysis

For the contingency-table analysis, the chemical data were grouped into geohydrologic categories that were defined by geologic unit and, for data from the Garber Sandstone and Wellington Formation, by depth. Analyses of samples from the alluvium and terrace deposits were combined into one geohydrologic category (referred to as the alluvium-terrace category) because the alluvium and terrace deposits frequently occur together and are geologically similar. Analyses of samples from the El Reno Group and Hennessey Group were treated as separate geohydrologic categories, referred to as the El Reno and Hennessey categories, respectively. Analyses of samples from the Garber Sandstone and Wellington Formation were combined because these formations are lithologically similar. The analyses of samples from the Garber Sandstone and Wellington Formation were divided into three geohydrologic categories based on well depth or sampling depth (if sampling depth was available)—shallow Garber-Wellington category, depths less than 100 feet; medium-depth Garber-Wellington category, depths 100 to 300 feet; and deep Garber-Wellington category, depths greater than 300 feet. Analyses of samples from the Chase, Council Grove, and Admire Groups were included in a single geohydrologic category, referred to as the Chase-Admire category, because these geologic units are lithologically similar. All analyses of samples from the Vanoss Formation were included in the geohydrologic category referred to as the Vanoss category. The geohydrologic categories are listed in relation to chronostratigraphic units in table 1.

The contingency-table analysis only included data from wells and distribution systems for which it was possible to determine the geohydrologic category. For each constituent, the chemical analysis with the maximum concentration was used to represent the well or distribution system for the contingency-table analysis. Some wells in the Garber Sandstone and Wellington Formation were sampled at several depths as they were drilled. Thus, it was possible for one well to be represented in each of the three Garber-Wellington categories. In that case, the analyses from the well were divided among the three categories and the maximum value for each constituent in each category was included in the contingency-table analysis.

In general, fewer chemical analyses were used in the contingency-table analysis than shown in table 4 because data were excluded for all wells for which the geohydrologic category could not be determined. The data from distribution systems were used if all wells in the system were within the same geohydrologic category. Data from a distribution system were treated the same as data from a single well.

Description of the Contingency-Table Analysis

A contingency-table analysis was used to test if the proportion of chemical analyses that exceeded water-quality standards was different among the geohydrologic categories. The contingency table presents a concise tabulation of the available information in addition to testing a hypothesis. (For a discussion of contingency tables, see Iman and Conover, 1983, p. 291-322.)

The data for a given constituent were categorized as either exceeding or not exceeding the water-quality standard for that constituent. The contingency-table analysis was used to test whether the proportion of analyses that exceeded a water-quality standard is significantly different among the geohydrologic categories. For a given constituent, the null hypothesis for the test is that the proportion of analyses that exceeded the water-quality standard is the same among the geohydrologic categories.

The test statistic for the hypothesis test is the overall chi-square statistic, which is calculated from the observed data. The larger the overall chi-square statistic, the more likely that the null hypothesis should be rejected. In the following discussion, the attained significance level (also called p-value) for the overall chi-square statistic is used to determine whether to accept or reject the null hypothesis. The attained significance level is the probability of obtaining an overall chi-square statistic greater than or equal to the observed overall chi-square statistic if the null hypothesis is true. Thus, a small attained significance level suggests that the null hypothesis can be rejected. In the discussion, if the attained significance level is less than 0.05, then the null hypothesis is rejected. If the null hypothesis is rejected, then the alternative hypothesis is accepted. For this contingency-table analysis, the alternative hypothesis is that the proportion of analyses that exceeded the water-quality standard is significantly different among the geohydrologic categories.

In addition to the attained significance level for the overall chi-square statistic, the number of analyses in each cell, the expected value for each cell, the cell chi-square statistic, and the percentage of analyses that exceeded the standard are presented for each geohydrologic category. The expected value is calculated assuming the proportion of analyses that exceeded the water-quality standard for each geohydrologic category is the same as the overall proportion of analyses that exceeded the water-quality standard. The cell chi-square statistic is a measure of how much the observed value deviates from the expected value. A large cell chi-square statistic indicates a large deviation from the expected value. The cell chi-square statistics are used in the discussion to determine which geohydrologic categories are most likely to be different from other geohydrologic categories. The overall chi-square statistic is the sum of the cell chi-square statistics.

The chi-square approximation in the contingency-table analysis is not applicable if there are many small expected values for the cells. If most of the expected values are greater than 1, the approximation may still be appropriate, especially if the degrees of freedom are large. If some of the expected values are less than 0.5, the chi-square contingency-table analysis probably should not be used (Iman and Conover, 1983). In the contingency-table analysis of this report, if the expected value for a geohydrologic category was less than 0.5, that geohydrologic category was excluded from the analysis and the calculations were repeated. For all tables presented in the text, the calculations made when a geohydrologic category was excluded led to the same conclusions as the original calculations. Therefore, the original tables are included in the text to present the most complete tabulation of the data. If several expected values were less than 1.0, the contingency-table analysis was not used. The smallest expected value is noted for each table.

Data were not available for all geohydrologic categories for every constituent. Thus, some of the contingency tables compare different sets of geohydrologic categories. If no data were available for a geohydrologic category, the number of sites is given as zero and no other statistics are listed for that geohydrologic category.

Comparison of dissolved and total concentrations of specific constituents is a recurring problem in the analysis of the available data. It is not known whether the dissolved-concentration data are significantly different from the total-concentration data. Many of the water-quality constituents of concern have a large set of analyses for dissolved and total concentrations but the water samples for these analyses are collected and analyzed differently. It is assumed that with good well construction a well would produce little suspended sediment and the difference between the dissolved and total concentrations would be small. However, there are too few wells that have been sampled for both dissolved and total concentrations to make a rigorous comparison; therefore, there is little opportunity to test the assumption that there is no difference between dissolved and total concentrations. Most of the discussion in this report has treated dissolved and total analyses separately. In the contingency-table analysis, calculations were made for dissolved and total concentrations of each constituent separately as well as combined. The tables presented in the text generally were calculated from the combined analyses for each constituent (both total- and dissolved-concentration data). The combined tables are presented, but the results are qualified in the text by the results of the separate contingency tables.

Because of the spatial biases in the data, the contingency-table analysis may indicate significant differences that are due to local anomalies. A visual inspection of the locations of the analyses that exceeded the standard was made to determine if the statistical differences were due to local anomalies or to variations among the geohydrologic categories.

Results

The discussion of the maps showing the locations of wells with samples that exceeded the water-quality standards and the results of the contingency-table analysis are presented in this section, in order by constituent. The word "common" is used to describe situations where approximately 10 percent or more of the data exceeded a water-quality standard.

pH

Measurements of pH were made in the field as the samples were collected or in the laboratory at the time of analysis. The field measurements are considered more reliable because in-gassing and out-gassing of carbon dioxide during shipment and storage can produce large changes in pH. Thus, only the field values are considered below.

The SMCL for pH specifies that pH values should be in the range of 6.5 to 8.5. Figure 14 shows locations where field pH was measured. A total of 133 of 961 wells had pH values outside the 6.5 to 8.5 range. Samples from 96 wells had pH values less than 6.5 and samples from 37 wells had pH values greater than 8.5 (table 4). Most of the values greater than 8.5 are in the western third of the study unit. Values less than 6.5 are distributed throughout the study unit.

Contingency tables were calculated for: (1) the pH values less than 6.5 (table 5) and (2) the pH values greater than 8.5 (table 6). The contingency-table statistics indicated that the proportion of pH values that were less than 6.5 was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level of 0.036 is less than 0.05). The deep Garber-Wellington category had no pH values less than 6.5, which resulted in the largest cell chi-square statistic (7.6). The cell chi-square statistics for the other geohydrologic categories were smaller (less than 2.0). The overall percentage of pH values that were less than 6.5 was 10.0 percent. The available data indicate that ground-water pH values less than the 6.5 commonly occur in most parts of the study unit except at depths greater than 300 feet in the Garber Sandstone and Wellington Formation.

The contingency-table statistics indicated that the proportion of pH values that were greater than 8.5 was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001) (table 6). The deep Garber-Wellington and the Vanoss categories had the largest percentage of pH values greater than 8.5 and the largest cell chi-square statistics, 39.4 and 8.2. The cell chi-square statistics indicated that these geohydrologic categories had the greatest deviation between the observed value and the expected

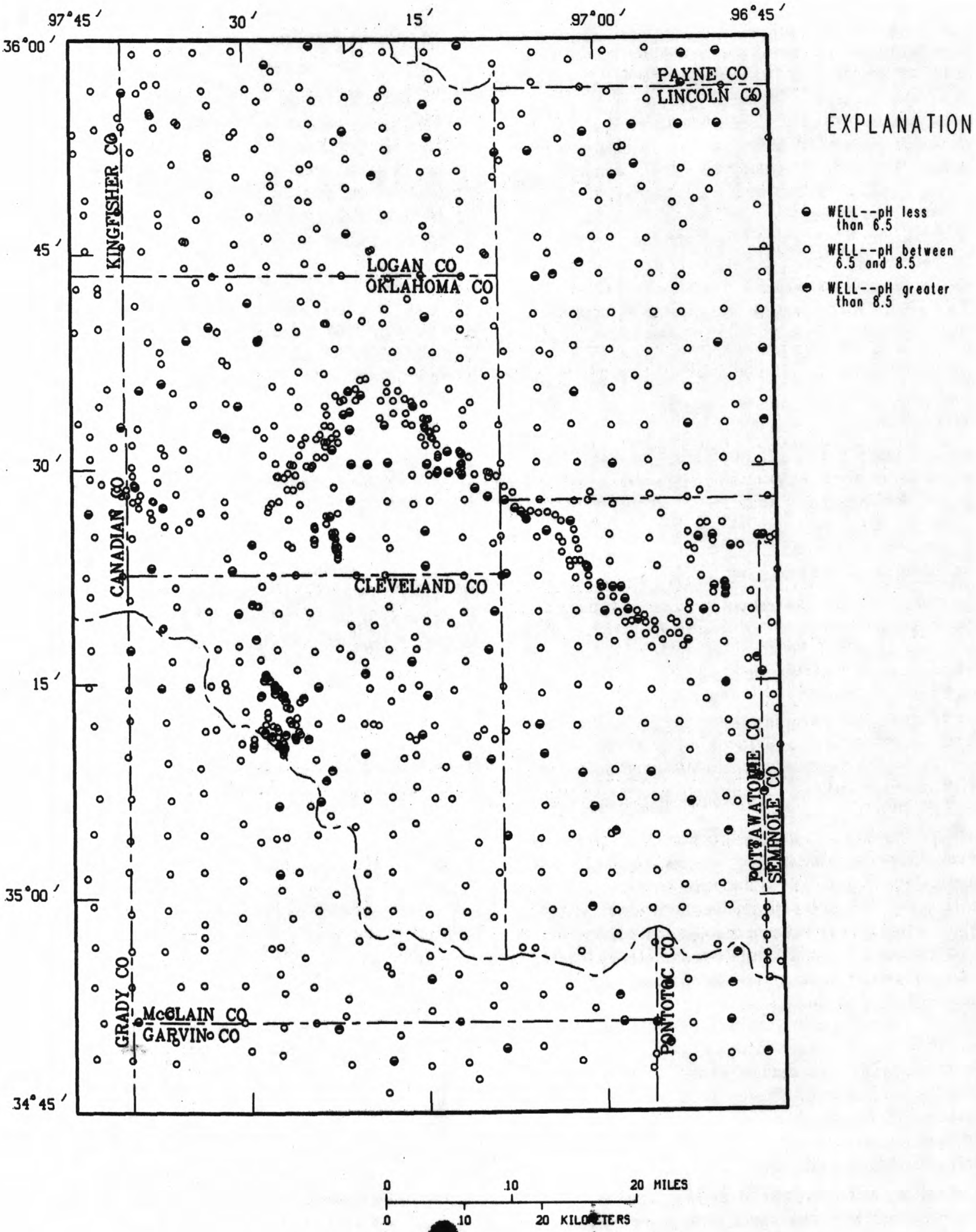

Figure 14.—Locations of wells where field pH was measured.

Table 5. – *Contingency table of field pH values less than 6.5 by geohydrologic category*

[Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal]

		Geohydrologic category								
					Garber-Wellington					
pH value	Statistic	Alluvium-terrace	El Reno	Henn-essey	Shallow	Medium-depth	Deep	Chase-Admire	Vanoss	Row totals
> = 6.5	Number of analyses	286	46	57	153	98	76	84	63	863
	Expected value	293.4	43.2	54.0	154.8	100.8	68.4	85.5	63.0	
	Cell chi square	0.2	0.2	0.2	0.0	0.1	0.8	0.0	0.0	
< 6.5	Number of analyses	40	2	3	19	14	0	11	7	96
	Expected value	32.6	4.8	6.0	17.2	11.2	7.6	9.5	7.0	
	Percent < 6.5	12.3	4.2	5.0	11.0	12.5	0.0	11.6	10.0	10.0
	Cell chi square	1.7	1.6	1.5	0.2	0.7	7.6	0.2	0.0	
	Total number of analyses	326	48	60	172	112	76	95	70	959

Overall statistics: chi square 15.0, attained significance level 0.036, smallest expected value 4.8, degrees of freedom 7.

Table 6. – *Contingency table of field pH values greater than 8.5 by geohydrologic category*

[Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. < =, less than or equal; >, greater than]

		Geohydrologic category								
					Garber-Wellington					
pH value	Statistic	Alluvium-terrace	El Reno	Henn-essey	Shallow	Medium-depth	Deep	Chase-Admire	Vanoss	Row totals
< = 8.5	Number of analyses	320	48	57	170	111	63	93	63	925
	Expected value	314.4	46.3	57.9	165.9	108.0	73.3	91.6	67.5	
	Cell chi square	0.1	0.1	0.0	0.1	0.1	1.4	0.0	0.3	
>8.5	Number of analyses	6	0	3	2	1	13	2	7	34
	Expected value	11.6	1.7	2.1	6.1	4.0	2.7	3.4	2.5	
	Percent > 8.5	1.8	0.0	5.0	1.2	0.9	17.1	2.1	10.0	3.5
	Cell chi square	2.7	1.7	0.4	2.8	2.2	39.4	0.6	8.2	
	Total number of analyses	326	48	60	172	112	76	95	70	959

Overall statistics: chi square 60.0, attained significance level less than 0.001, smallest expected value 1.7, degrees of freedom 7.

value. The percentage of analyses in the deep Garber-Wellington and Vanoss categories that had pH values greater than 8.5 was 17.1 and 10.0, respectively, compared to 5 percent or less for all other geohydrologic categories. The available data indicate that ground water with pH greater than 8.5 is common at depths greater than 300 feet in the Garber Sandstone and the Wellington Formation and in the Vanoss Formation.

Sulfate

The SMCL for sulfate is 250 mg/L. The SMCL was exceeded in 117 of 1,180 wells and 5 of 122 distribution systems (table 4). Figure 15 shows locations where sulfate was analyzed and where sulfate concentrations exceeded the SMCL.

All agencies reported sulfate as a dissolved constituent; therefore, there is only one contingency table (table 7) for sulfate. The contingency-table statistics indicated that the proportion of analyses that exceeded the SMCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). The Hennessey and El Reno categories had the largest cell chi-square statistics (14.6 and 13.7), which was caused by more analyses that exceeded the SMCL than the expected values. Further investigation revealed that most of the large sulfate concentrations in the El Reno Group occurred in a small area in the west-central part of the study unit, near the North Canadian River. These large sulfate concentrations appear to be a local anomaly and probably are not representative of the El Reno Group.

Overall, the percentage of analyses that exceeded the SMCL was 9.6. The Hennessey category had the largest percentage of analyses that exceeded the SMCL, 24.2 percent. The available analyses indicate that ground-water concentrations of sulfate greater than the 250-mg/L SMCL commonly occur in most parts of the study unit and occur most commonly in ground water from the Hennessey Group.

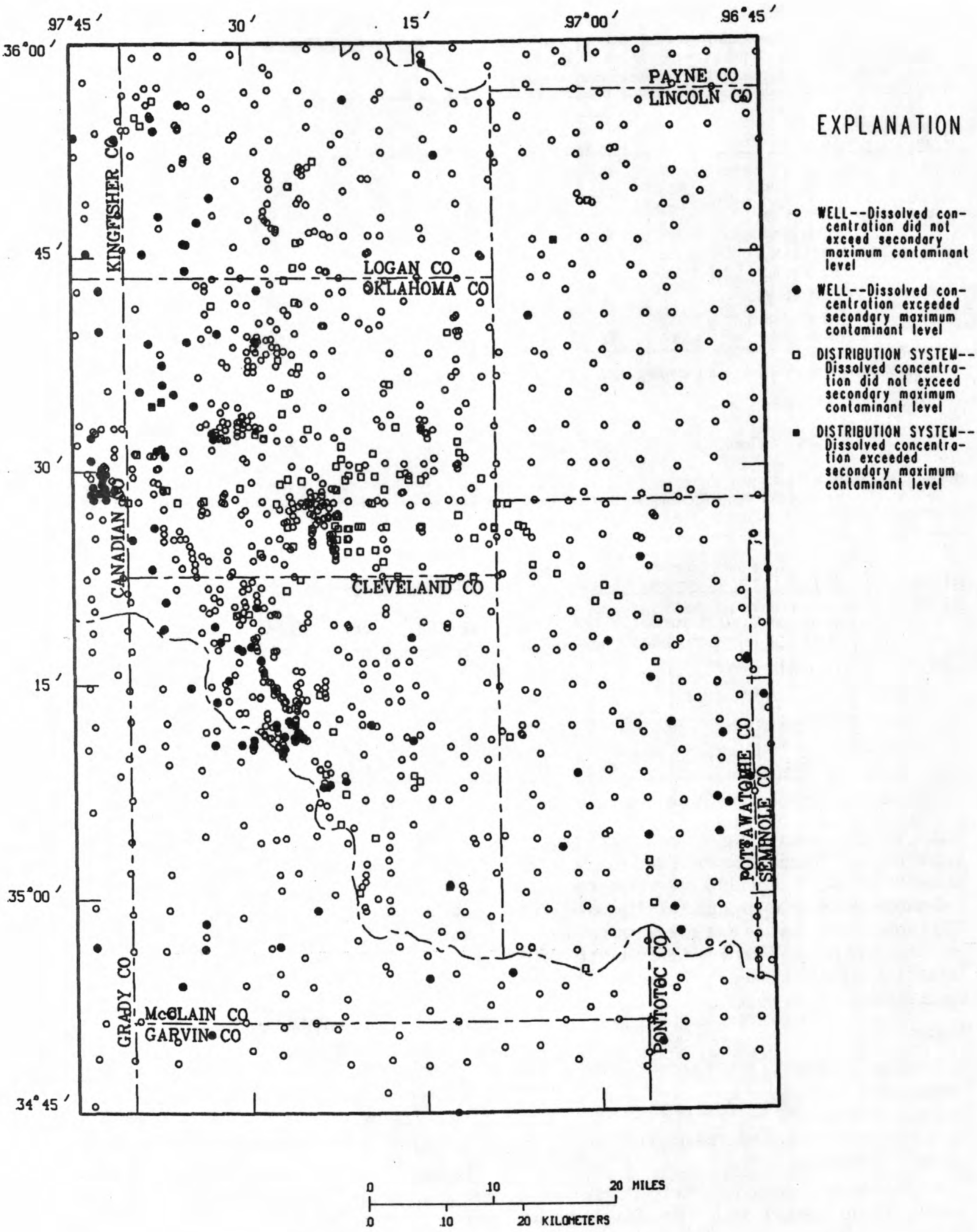

Figure 15.—Locations of wells and distribution systems where sulfate was measured.

Table 7.—*Contingency table of sulfate concentrations by geohydrologic category*

[Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. mg/L, milligrams per liter; <, less than; > =, greater than or equal]

Sulfate concentration	Statistic	Geohydrologic category								Row totals
		Alluvium-terrace	El Reno	Henn-essey	Garber-Wellington			Chase-Admire	Vanoss	
					Shallow	Medium-depth	Deep			
< 250 mg/L	Number of analyses	212	47	50	162	168	297	98	64	1,098
	Expected value	217.8	56.0	59.6	153.6	160.9	289.2	96.7	64.2	
	Cell chi square	0.2	1.5	1.6	0.5	0.3	0.2	0.0	0.0	
> = 250 mg/L	Number of analyses	29	15	16	8	10	23	9	7	117
	Expected value	23.2	6.0	6.4	16.4	17.1	30.8	10.3	6.8	
	Percent > = 250 mg/L	12.0	24.2	24.2	4.7	5.6	7.2	8.4	9.9	9.6
	Cell chi square	1.4	[a]13.7	14.6	4.3	3.0	2.0	0.2	0.0	
	Total number of analyses	241	62	66	170	178	320	107	71	1,215

Overall statistics: chi square 43.3, attained significance level less than 0.001, smallest expected value 6.0, degrees of freedom 7.

[a]Most large sulfate concentrations in the El Reno Group occur in a small area near the North Canadian River. The large apparent cell chi square probably is not representative of the El Reno Group in the study unit.

Chloride

The SMCL for chloride is 250 mg/L. The SMCL was exceeded in 50 of 711 wells and 3 of 124 distribution systems (table 4). Figure 16 shows locations where chloride was analyzed and where chloride concentrations exceeded the SMCL. There are few definite areal trends for occurrence of chloride in excess of 250 mg/L. The chloride concentrations that exceeded the SMCL in central Cleveland County are from test holes that were drilled until they encountered saltwater.

The contingency-table statistics for chloride (table 8) indicated that the proportion of analyses that exceeded the SMCL is the same among the geohydrologic categories (null hypothesis accepted, attained significance level of 0.782 is greater than 0.05). The overall percentage of analyses that exceeded the SMCL was 6.9. The available analyses indicate that ground-water concentrations of chloride greater than the 250-mg/L SMCL occur throughout the study unit.

Fluoride

The MCL for fluoride is 4 mg/L. The MCL was exceeded in none of 104 wells and only one of 124 distribution systems where total fluoride was measured and in none of 170 wells where dissolved fluoride was measured (table 4). Figure 17 shows the locations where fluoride was analyzed and where fluoride exceeded the MCL. Too few analyses exceeded the MCL to calculate meaningful contingency-table statistics. The available analyses indicate that ground-water concentrations of fluoride greater than the 4-mg/L MCL are rare in the study unit.

Table 8.—*Contingency table of chloride concentrations by geohydrologic category*

[Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal; mg/L, milligrams per liter]

Chloride concentration	Statistic	Geohydrologic category								Row totals
		Alluvium-terrace	El Reno	Henn-essey	Garber-Wellington			Chase-Admire	Vanoss	
					Shallow	Medium-depth	Deep			
< 250 mg/L	Number of analyses	146	26	21	27	125	302	28	23	698
	Expected value	146.1	24.2	20.5	27.0	123.8	303.4	29.8	23.3	
	Cell chi square	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	
> = 250 mg/L	Number of analyses	11	0	1	2	8	24	4	2	52
	Expected value	10.9	1.8	1.5	2.0	9.2	22.6	2.2	1.7	
	Percent > = 250 mg/L	7.0	0.0	4.5	6.9	6.0	7.4	12.5	8.0	6.9
	Cell chi square	0.0	1.8	0.2	0.0	0.2	0.1	1.4	0.0	
	Total number of analyses	157	26	22	29	133	326	32	25	750

Overall statistics: chi square 3.9, attained significance level 0.782, smallest expected value 1.5, degrees of freedom 7.

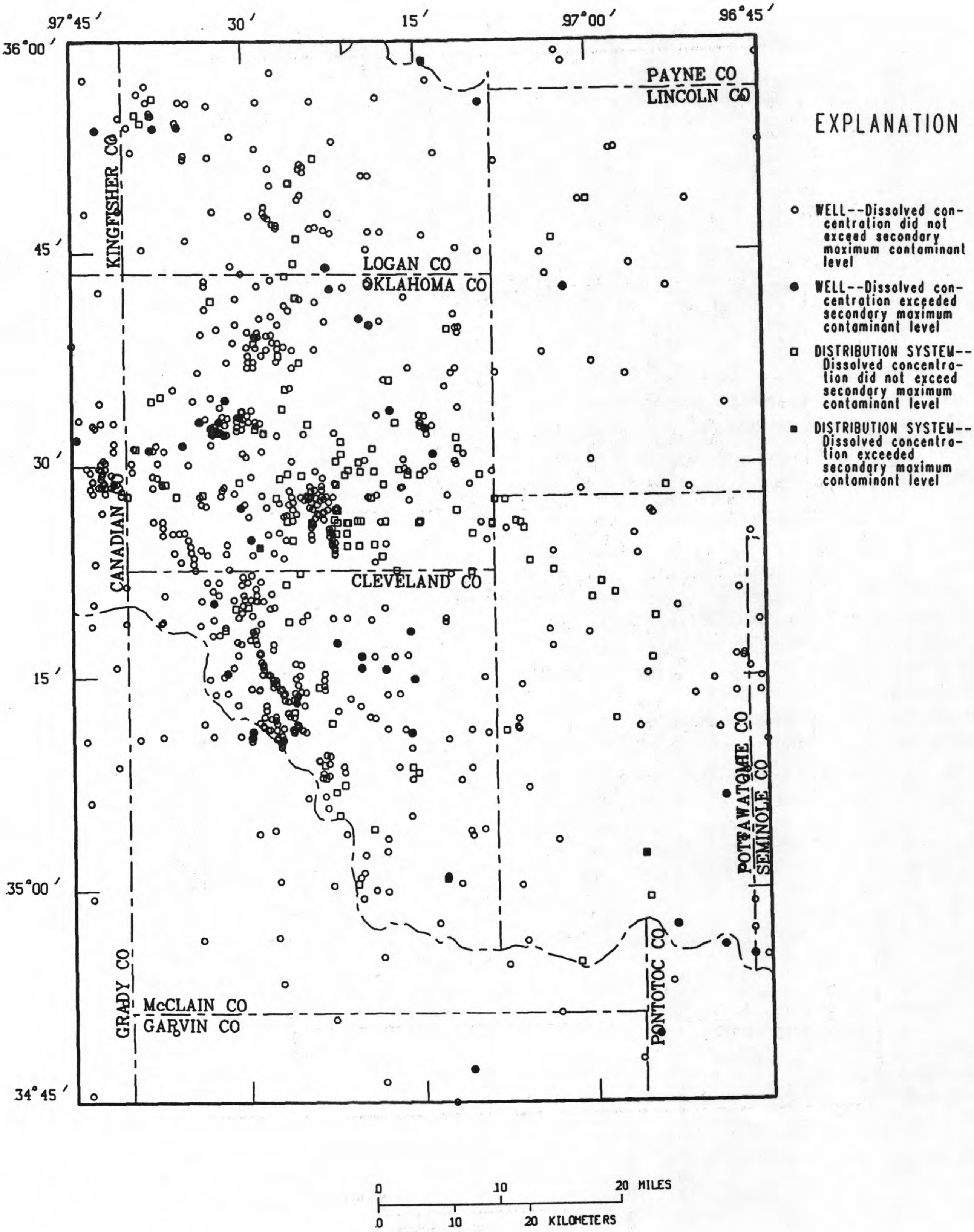

Figure 16.—Locations of wells and distribution systems where chloride was measured.

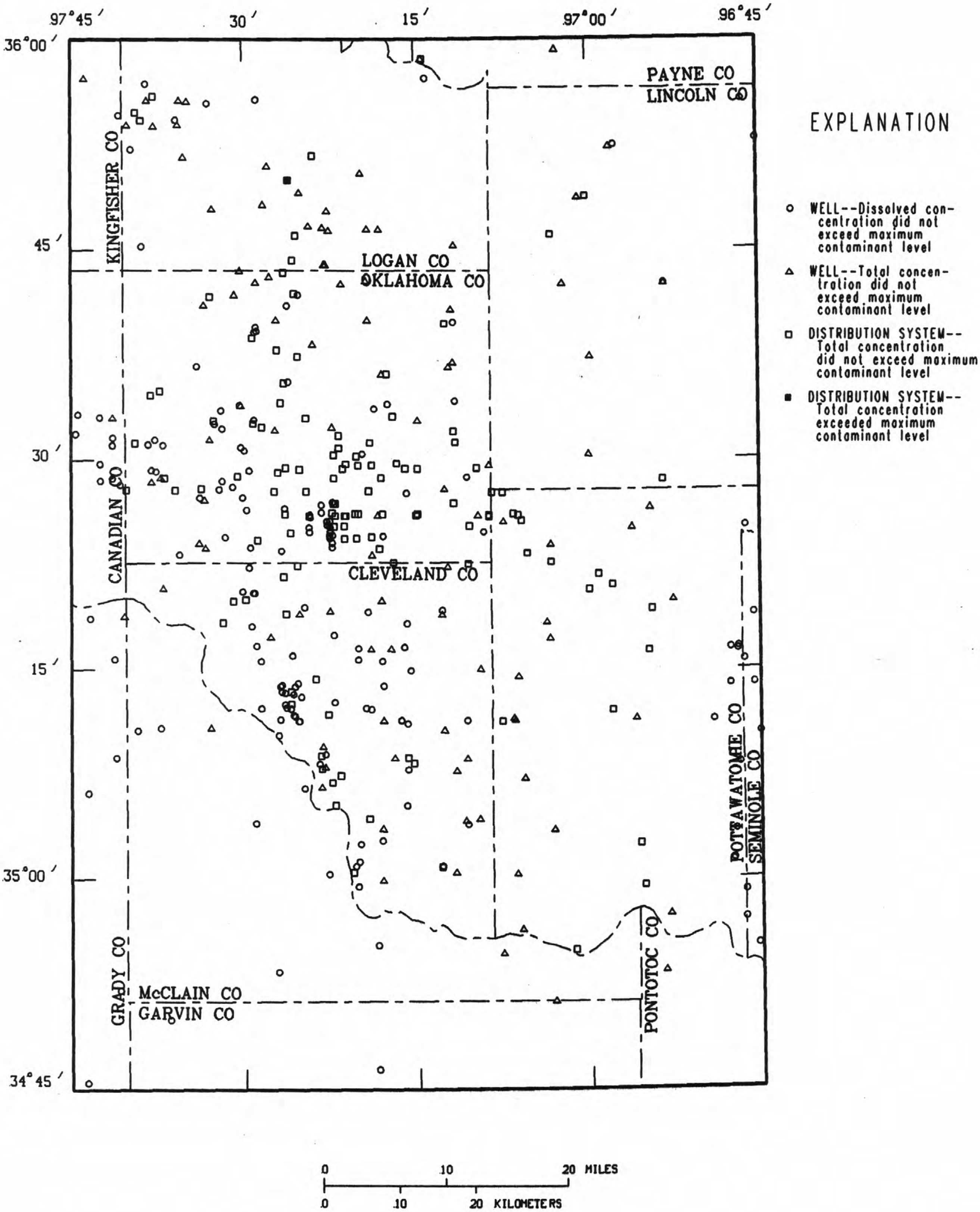

Figure 17.—Locations of wells and distribution systems where fluoride was measured.

Dissolved solids

The SMCL for dissolved solids is 500 mg/L. Two different analytical methods were used to analyze dissolved solids. One method was the residue on evaporation at 180 °C and the other was the residue on evaporation at 105 °C. The SMCL was exceeded in 121 of 300 wells where residue on evaporation at 180 °C was analyzed and in 30 of 106 wells and 32 of 116 distribution systems where residue on evaporation at 105 °C was analyzed (table 4). Figure 18 shows the locations where dissolved solids were analyzed and where dissolved solids exceeded the SMCL.

Individual contingency tables (not presented) and a combined table (table 9) were calculated for dissolved solids. The contingency-table statistics for residue at 105 °C indicated that the proportion of analyses that exceeded the SMCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level of 0.005). The largest chi-square statistic was for the medium-depth Garber-Wellington category, which had fewer analyses that exceeded the SMCL than the expected value.

The contingency-table statistics for residue at 180 °C indicated that the proportion of analyses that exceeded the SMCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level of 0.0049). The largest cell chi-square statistic was for the alluvium-terrace category, which had more analyses that exceeded the SMCL than the expected value.

For the combined table, the contingency-table statistics indicated that the proportion of analyses that exceeded the SMCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). The alluvium-terrace category had more analyses that exceeded the SMCL than the expected value and the medium-depth Garber-Wellington category had fewer. These two geohydrologic categories had the largest cell chi-square statistics.

The three sets of contingency-table statistics indicated differences among the geohydrologic categories, but there was no consistent indication of which geohydrologic categories was the most likely cause of the difference. For the combined data, dissolved-solids concentrations exceeded the SMCL in 37.9 percent of the analyses. The percentage of analyses that exceeded the MCL ranged from 21.4 to 51.9 in the individual geohydrologic categories. The available analyses indicate that ground-water concentrations of dissolved solids greater than the 500-mg/L SMCL are common throughout the study unit.

Nitrate

Several different analytical methods were used by the various agencies to analyze nitrogen species. Dissolved nitrate, total nitrate, dissolved nitrite plus nitrate, and total nitrite plus nitrate were analyzed in ground-water samples from the study unit. This discussion considers: (1) dissolved and total nitrate analyses, (2) dissolved and total nitrite plus nitrate analyses, and (3) all of the analyses combined.

The MCL for nitrate is 10 mg/L (as nitrogen). The MCL was exceeded in neither of two wells where total nitrate was analyzed and in 32 of 302 wells where dissolved nitrate was analyzed (table 4). Figure 19 shows locations where nitrate (dissolved or total) was analyzed and where nitrate exceeded the MCL.

The contingency-table analysis for nitrate (table 10) included only the dissolved-nitrate analyses because there were only two total-nitrate analyses. The contingency-table statistics indicated that the proportion of dissolved-nitrate analyses that exceeded the MCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). Overall, 10.1 percent of the analyses exceeded the MCL. The largest cell chi-square statistic (9.5) was for the deep Garber-Wellington category, which had no nitrate analyses that exceeded the MCL.

Table 9.—*Contingency table of dissolved-solids concentrations by geohydrologic category*

[Combined data of residue on evaporation at 105 °C and residue on evaporation at 180 °C. Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal; mg/L, milligrams per liter]

		Geohydrologic category								
					Garber-Wellington					
Dissolved-solids concentration	Statistic	Alluvium-terrace	El Reno	Henn-essey	Shallow	Medium-depth	Deep	Chase-Admire	Vanoss	Row totals
< 500 mg/L	Number of analyses	52	3	8	17	81	79	17	12	269
	Expected value	67.1	3.7	9.3	13.7	64.0	77.0	19.3	14.9	
	Cell chi square	3.4	0.1	0.2	0.8	4.5	0.1	0.3	0.6	
> = 500 mg/L	Number of analyses	56	3	7	5	22	45	14	12	164
	Expected value	40.9	2.3	5.7	8.3	39.0	47.0	11.7	9.1	
	Percent > = 500 mg/L	51.9	50.0	46.7	22.7	21.4	36.3	45.2	50.0	37.9
	Cell chi square	5.6	0.2	0.3	1.3	7.4	0.1	0.4	0.9	
	Total number of analyses	108	6	15	22	103	124	31	24	433

Overall statistics: chi square 26.2, attained significance level less than 0.001, smallest expected value 2.3, degrees of freedom 7.

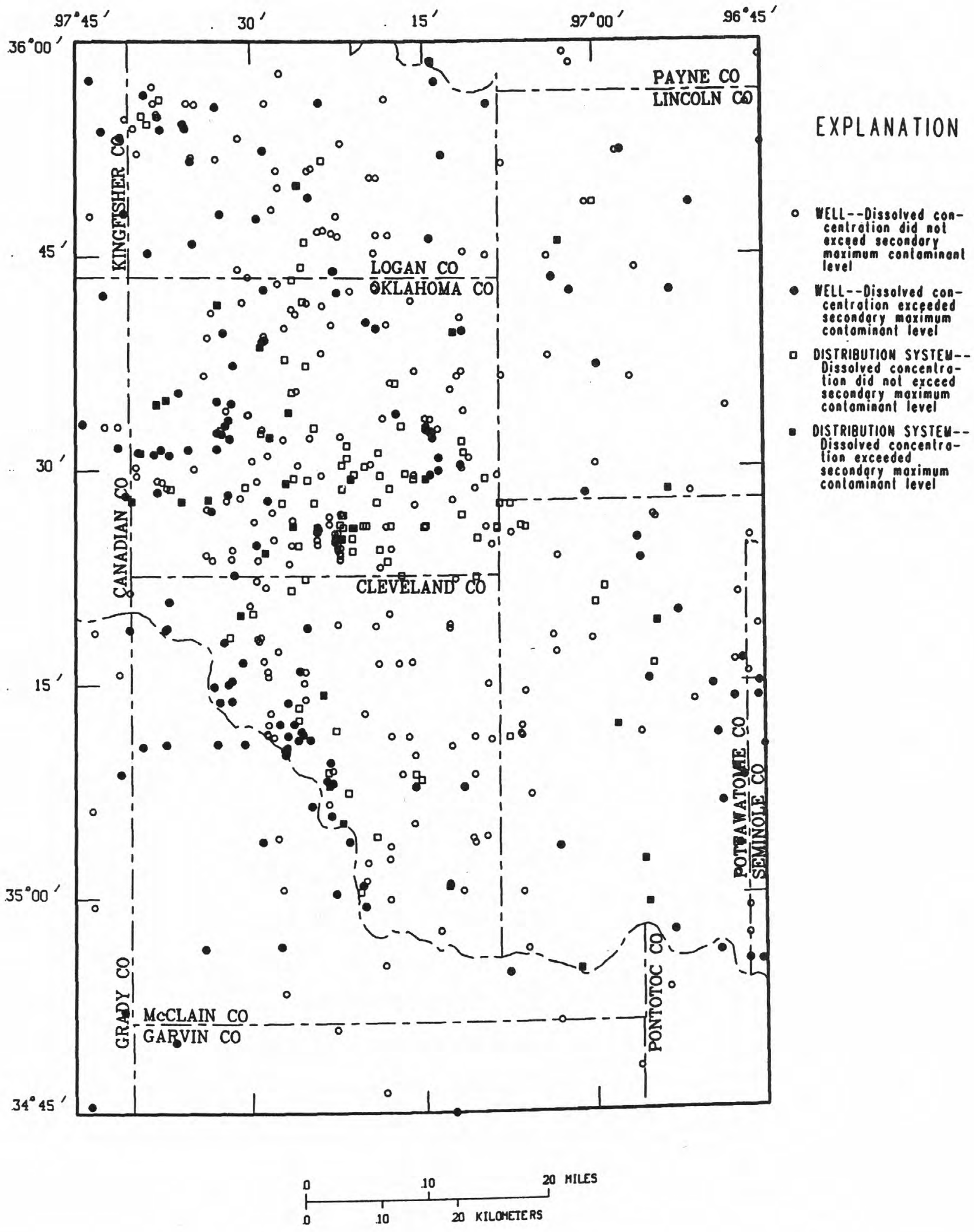

Figure 18.—Locations of wells and distribution systems where dissolved solids were measured.

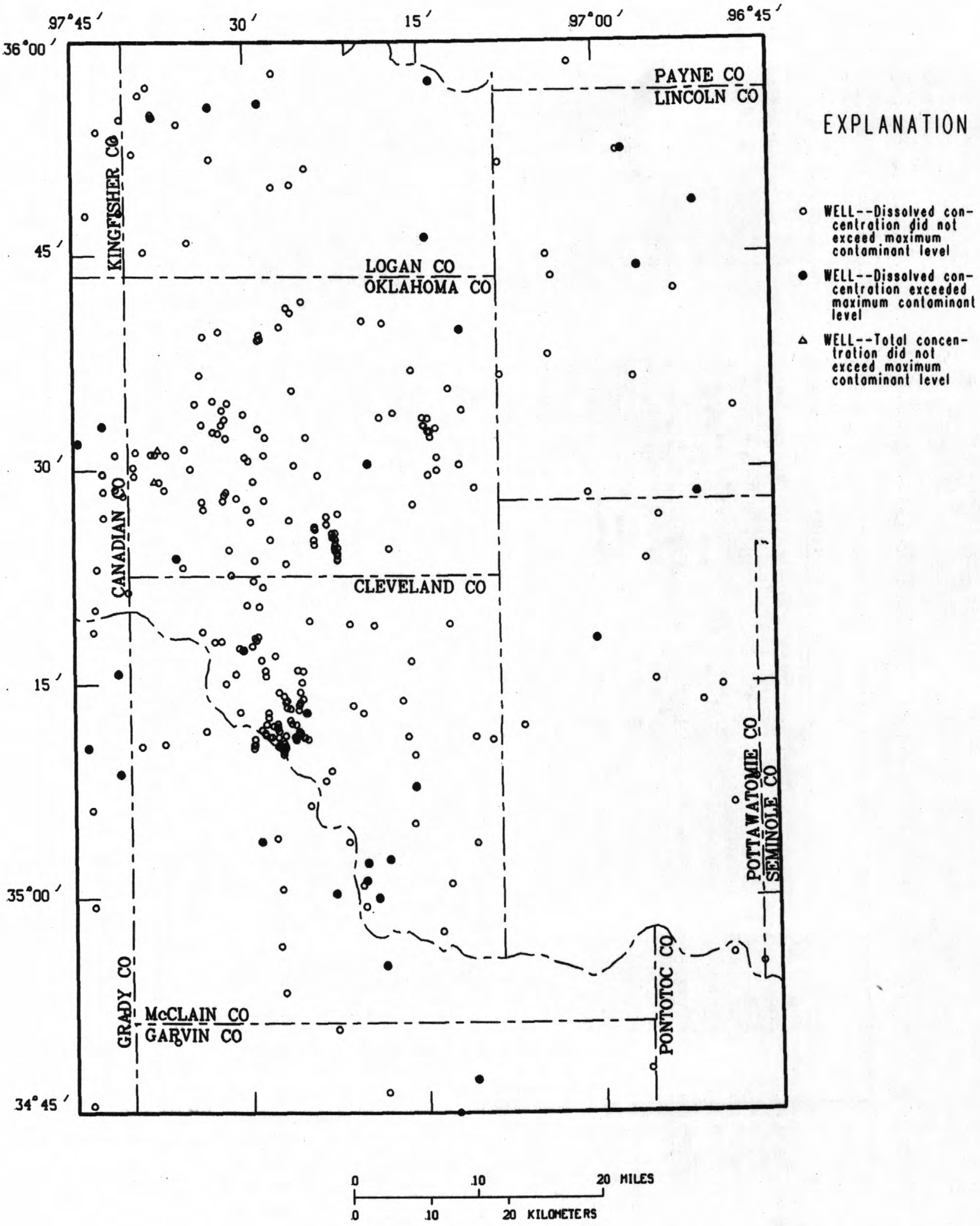

Figure 19.—Locations of wells where nitrate was measured.

Nitrite concentrations in ground water generally are much smaller than nitrate concentrations, therefore the analysis of nitrite plus nitrate often is used as an indicator of compliance with the MCL for nitrate. The MCL was exceeded in 13 of 134 wells and 39 of 401 distribution systems where total nitrite plus nitrate was analyzed and in 5 of 33 wells where dissolved nitrite plus nitrate was analyzed (table 4). Figure 20 shows the locations where nitrite plus nitrate (including all analyses for dissolved and total) was analyzed and where the concentrations exceeded the nitrate MCL.

Dissolved nitrite plus nitrate analyses were available for only 30 wells for the contingency-table analysis. Total nitrite plus nitrate analyses were available for 196 wells and distribution systems, but the analyses predominantly were in the medium-depth and deep Garber-Wellington categories and in the alluvium-terrace category. The contingency-table statistics for the combined nitrite plus nitrate table (table 11) indicated that the proportion of nitrite plus nitrate analyses that exceeded the MCL is the same among the geohydrologic categories (null hypothesis accepted, attained significance level of 0.186). The overall percentage of analyses that exceeded the MCL (for the combined nitrite plus nitrate data) was 6.2 percent. Only one of 75 analyses exceeded the MCL in the deep Garber-Wellington category.

When all of the dissolved nitrate, dissolved nitrite plus nitrate, and total nitrite plus nitrate data were combined into a single contingency table (table 12), the contingency-table statistics indicated that the proportion of analyses that exceeded the MCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). Only one of 166 analyses in the deep Garber-Wellington category exceeded the MCL. The deep Garber-Wellington category had the largest deviation from the expected value (cell chi-square statistic of 12.4). The El Reno, shallow Garber-Wellington, and Chase-Admire categories had more analyses that exceeded the MCL than the expected values and had cell chi-square statistics that ranged from 8.2 to 3.9. The overall percentage of analyses that exceeded the MCL was 8.6 percent.

The nitrite plus nitrate statistics (table 11) did not indicate a significant difference but the nitrate statistics (table 10) and the combined statistics (table 12) did indicate a significant difference among geohydrologic categories in the proportion of analyses that exceeded the MCL. The lack of a significant difference among geohydrologic categories for the nitrite plus nitrate data was probably caused by the small sample sizes in geohydrologic categories other than the medium-depth and deep Garber-Wellington categories. All data sets for nitrate parameters indicate that nitrate concentrations above the MCL are common in most geologic units. The number of analyses that exceeded the MCL was between 6.2 and 10.1 percent for the parameters that were considered. Only one analysis in the deep Garber-Wellington category exceeded the MCL. The available analyses indicate that ground-water concentrations of nitrate greater than the 10-mg/L MCL commonly occur in most parts of the study unit except at depths greater than 300 feet in the Garber Sandstone and Wellington Formation.

Arsenic

The MCL for arsenic is 50 μg/L. The MCL was exceeded in 27 of 183 wells and 7 of 118 distribution systems that were analyzed for total arsenic and in none of 511 wells that were analyzed for dissolved

Table 10.—*Contingency table of dissolved nitrate concentrations by geohydrologic category*

[Data are dissolved nitrate analyses only. Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal; mg/L, milligrams per liter]

		Geohydrologic category								
					Garber-Wellington					
Nitrate concentration	Statistic	Alluvium-terrace	El Reno	Henn-essey	Shallow	Medium-depth	Deep	Chase-Admire	Vanoss	Row totals
< 10 mg/L	Number of analyses	90	5	16	11	34	94	11	5	266
	Expected value	91.7	7.2	16.2	14.4	33.2	84.5	13.5	5.4	
	Cell chi square	0.0	0.7	0.0	0.8	0.0	1.1	0.5	0.0	
> = 10 mg/L	Number of analyses	12	3	2	5	3	0	4	1	30
	Expected value	10.3	0.8	1.8	1.6	3.7	9.5	1.5	0.6	
	Percent > = 10 mg/L	11.8	37.5	11.1	31.2	8.1	0.0	26.7	16.7	10.1
	Cell chi square	0.3	5.9	0.0	7.0	0.1	9.5	4.0	0.3	
	Total number of analyses	102	8	18	16	37	94	15	6	296

Overall statistics: chi square 30.2, attained significance level less than 0.001, smallest expected value 0.6, degrees of freedom 7.

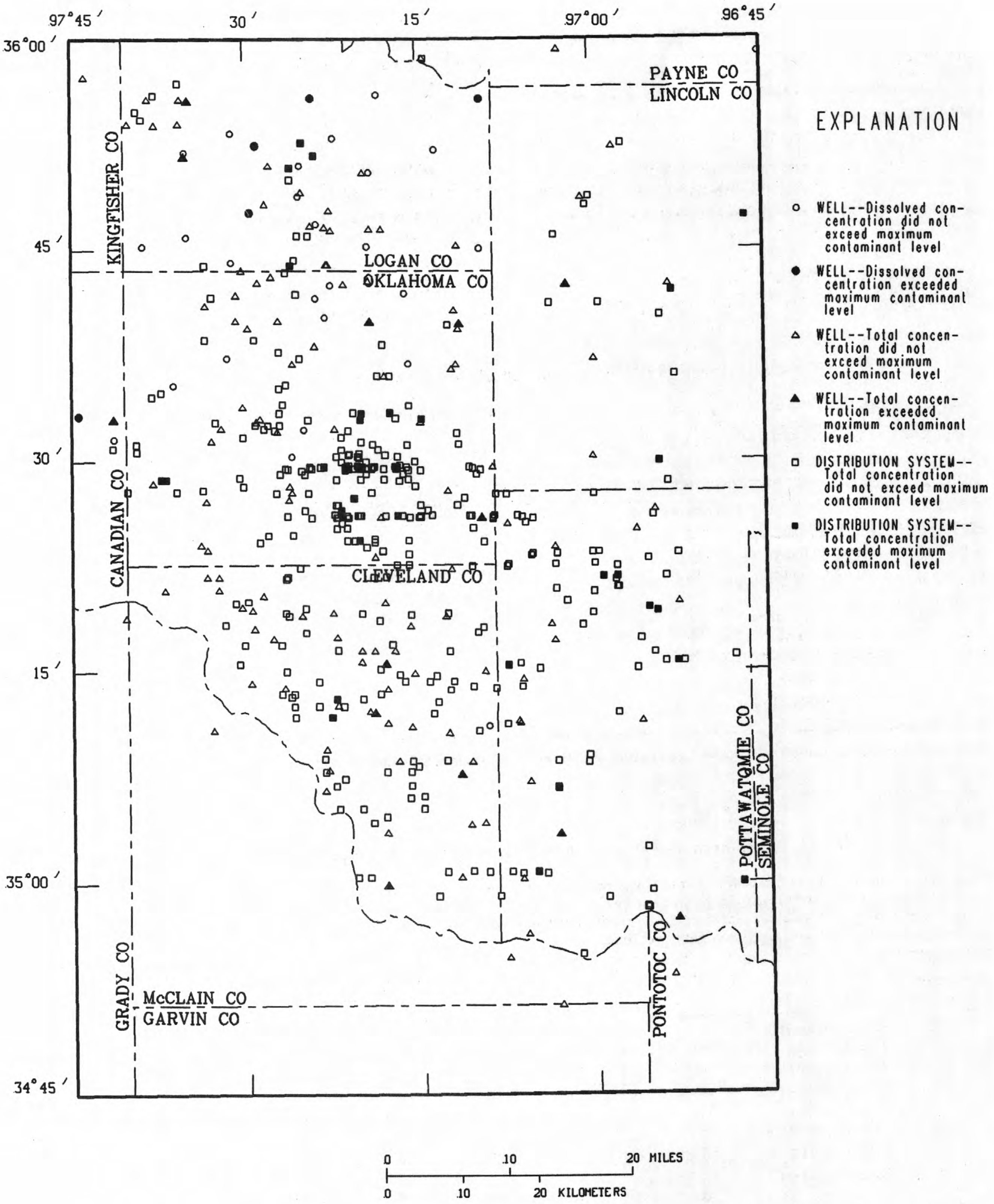

Figure 20.—Locations of wells and distribution systems where nitrite plus nitrate was measured.

arsenic (table 4). Figure 21 shows the locations where arsenic was analyzed and where arsenic exceeded the MCL. All locations where the MCL was exceeded are in the western third of the study unit.

The contingency-table statistics for total arsenic (not presented) indicated that the proportion of analyses that exceeded the MCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level of 0.005). The deep Garber-Wellington category had the largest percentage of analyses that exceeded the MCL. With a single exception, all of the analyses that exceeded the MCL in the total-arsenic data were in the medium-depth and deep Garber-Wellington categories.

For the dissolved-arsenic data, no analyses exceeded the MCL. However, no analyses for dissolved arsenic were in the deep Garber-Wellington category, whereas more than 50 percent of the analyses for total arsenic were in that geohydrologic category.

For the combined arsenic data, the contingency-table statistics (table 13) indicated that the proportion of analyses that exceeded the MCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). Overall, only 4.3 percent of the analyses exceeded the MCL. However, 21.3 percent of the analyses exceeded the MCL in the deep Garber-Wellington category. The medium-depth

Table 11. – *Contingency table of nitrite plus nitrate concentrations by geohydrologic category*

[Data include dissolved and total nitrite plus nitrate analyses. Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal; mg/L, milligrams per liter]

Nitrite plus nitrate concentration	Statistic	Geohydrolcgic category								Row totals
					Garber-Wellington					
		Alluvium-terrace	El Reno	Henn-essey	Shallow	Medium-depth	Deep	Chase-Admire	Vanoss	
< 10 mg/L	Number of analyses	31	0	0	11	80	74	16	0	212
	Expected value	31.9			12.2	80.7	70.4	16.9		
	Cell chi square	0.0			0.1	0.0	0.2	0.0		
> = 10 mg/L	Number of analyses	3	0	0	2	6	1	2	0	14
	Expected value	2.1			0.8	5.3	4.6	1.1		
	Percent > = 10 mg/L	8.8			15.4	7.0	1.3	11.1		6.2
	Cell chi square	0.4			1.8	0.1	2.9	0.7		
	Total number of analyses	34	0	0	13	86	75	18	0	226

Overall statistics: chi square 6.2, attained significance level 0.186, smallest expected value 0.8, degrees of freedom 4.

Table 12. – *Contingency table of combined nitrate parameters by geohydrologic category*

[Data include dissolved nitrate, dissolved nitrite plus nitrate, and total nitrite plus nitrate analyses. Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal; mg/L, milligrams per liter]

Nitrate-parameter concentration	Statistic	Geohydrologic category								Row totals
					Garber-Wellington					
		Alluvium-terrace	El Reno	Henn-essey	Shallow	Medium-depth	Deep	Chase-Admire	Vanoss	
< 10 mg/L	Number of analyses	121	5	16	22	108	166	26	5	469
	Expected value	124.3	7.3	16.5	26.5	107.0	152.7	29.3	5.5	
	Cell chi square	0.1	0.7	0.0	0.8	0.0	1.2	0.4	0.0	
> = 10 mg/L	Number of analyses	15	3	2	7	9	1	6	1	44
	Expected value	11.7	0.7	1.5	2.5	10.0	14.3	2.7	0.5	
	Percent > = 10 mg/L	11.0	37.5	11.1	24.1	7.7	0.6	18.7	16.7	8.6
	Cell chi square	1.0	7.8	0.1	8.2	0.1	12.4	3.9	0.5	
	Total number of analyses	136	8	18	29	117	167	32	6	513

Overall statistics: chi square 37.0, attained significance level less than 0.001, smallest expected value 0.5[a], degrees of freedom 7.

[a] The contingency table excluding the Vanoss and El Reno categories also indicated that the null hypothesis should be rejected.

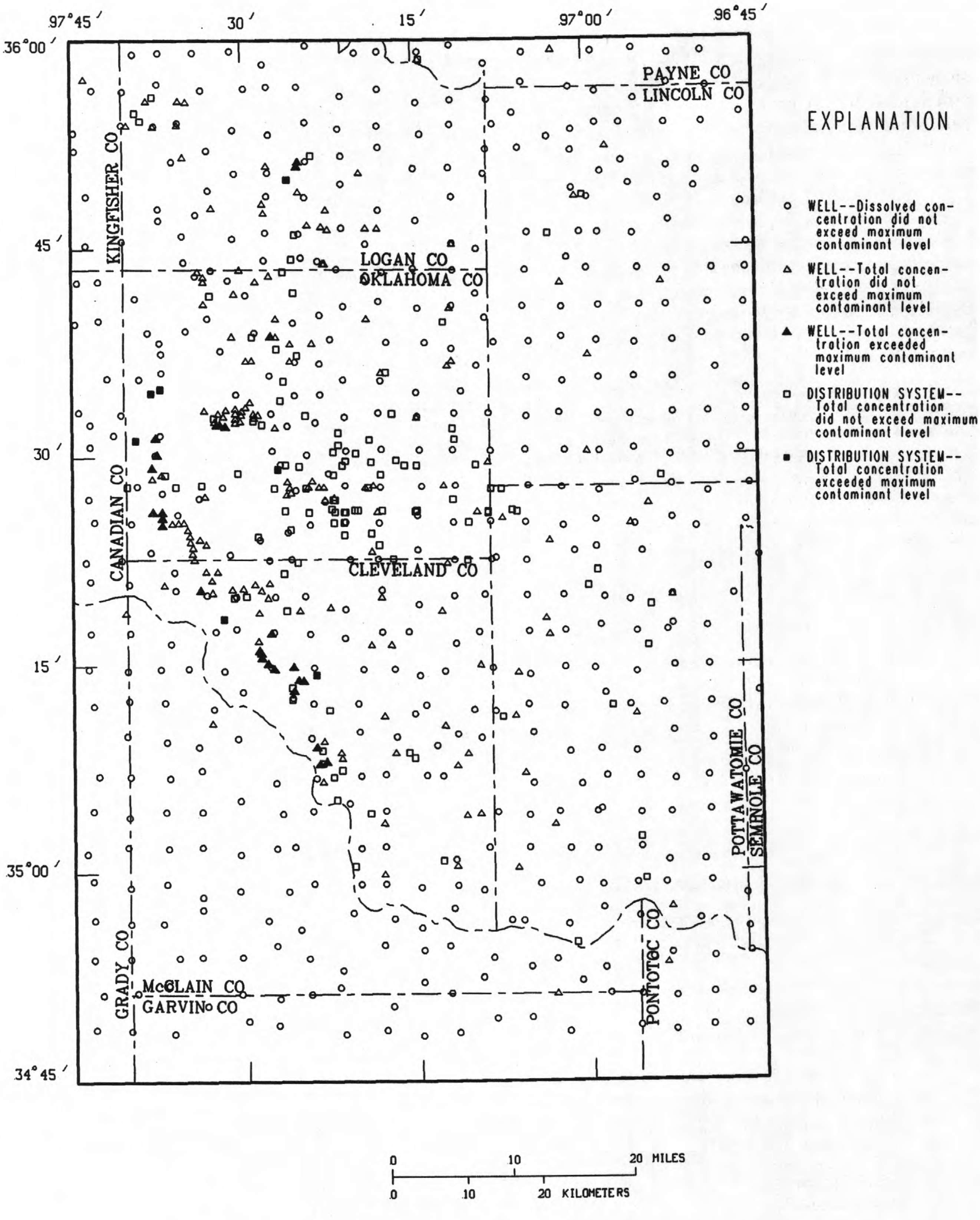

Figure 21.—Locations of wells and distribution systems where arsenic was measured.

Garber-Wellington category was the only other geohydrologic category that had more than one analysis that exceeded the MCL. The available analyses indicate that ground-water concentrations of arsenic greater than the 50-μg/L MCL are common at depths greater than 300 feet in the Garber Sandstone and Wellington Formation, but are rare in the rest of the study unit.

Barium

The MCL for barium is 1,000 μg/L. The MCL was exceeded in one of 96 wells and five of 118 distribution systems where total barium was analyzed and in seven of 507 wells where dissolved barium was analyzed (table 4). Figure 22 shows locations where barium was analyzed and where barium exceeded the MCL.

In the data assembled for the contingency tables, analyses from only 11 of 643 wells and distribution systems, less than 2 percent, exceeded the MCL. Too few analyses exceeded the MCL to calculate meaningful contingency-table statistics. The available analyses indicate that ground-water concentrations of barium greater than the 1,000-μg/L SMCL are not common in the study unit.

Cadmium

The MCL for cadmium is 10 μg/L. The MCL was exceeded in none of 97 wells and none of 122 distribution systems where total cadmium was analyzed and in one of seven wells where dissolved cadmium was analyzed (table 4). Figure 23 shows the locations where cadmium was analyzed and the location of the well where the MCL was exceeded.

Too few analyses exceeded the MCL to calculate meaningful contingency-table statistics. The available analyses indicate that ground-water concentrations of cadmium greater than the 10-μg/L MCL are rare in the study unit.

Chromium

The MCL for chromium is 50 μg/L. The MCL was exceeded in 41 of 264 wells and nine of 122 distribution systems where total chromium was analyzed and in seven of 529 wells where dissolved chromium was analyzed (table 4). Figure 24 shows the locations where chromium was analyzed and where concentrations exceeded the MCL. Most of the locations where the MCL was exceeded are in the western third of the study unit.

Too few analyses exceeded the MCL in the dissolved-chromium data to calculate meaningful contingency-table statistics. The small number of analyses that exceeded the MCL for the dissolved data could be caused by the lack of dissolved-chromium analyses in the deep Garber-Wellington category (only 15 analyses).

The contingency-table statistics for the total-chromium data indicated that the proportion of analyses that exceeded the MCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). The medium-depth Garber-Wellington category had fewer analyses that exceeded the MCL than the expected value and the deep Garber-Wellington category had more analyses that exceeded the MCL than the expected value. These two categories had the largest cell chi-square statistics (5.7 and 5.4, respectively).

The contingency-table statistics for the combined chromium data (table 14) indicated that the proportion of analyses that exceeded the MCL was

Table 13.—*Contingency table of arsenic concentrations by geohydrologic category*

[Data include dissolved and total arsenic analyses. Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium- depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal; μg/L, micrograms per liter]

		Geohydrologic category								
					Garber-Wellington					
Arsenic concentration	Statistic	Alluvium-terrace	El Reno	Henn-essey	Shallow	Medium-depth	Deep	Chase-Admire	Vanoss	Row totals
< 50 μg/L	Number of analyses	116	46	49	148	102	100	95	48	704
	Expected value	111.9	44.0	46.9	141.6	101.4	121.5	90.9	45.9	
	Cell chi square	0.1	0.1	0.1	0.3	0.0	3.8	0.2	0.1	
> = 50 μg/L	Number of analyses	1	0	0	0	4	27	0	0	32
	Expected value	5.1	2.0	2.1	6.4	4.6	5.5	4.1	2.1	
	Percent > = 50 μg/L	0.9	0.0	0.0	0.0	3.8	21.3	0.0	0.0	4.3
	Cell chi square	3.3	2.0	2.1	6.4	0.1	83.5	4.1	2.1	
	Total number of analyses	117	46	49	148	106	127	95	48	736

Overall statistics: chi square 108.4, attained significance level less than 0.001, smallest expected value 2.0, degrees of freedom 7.

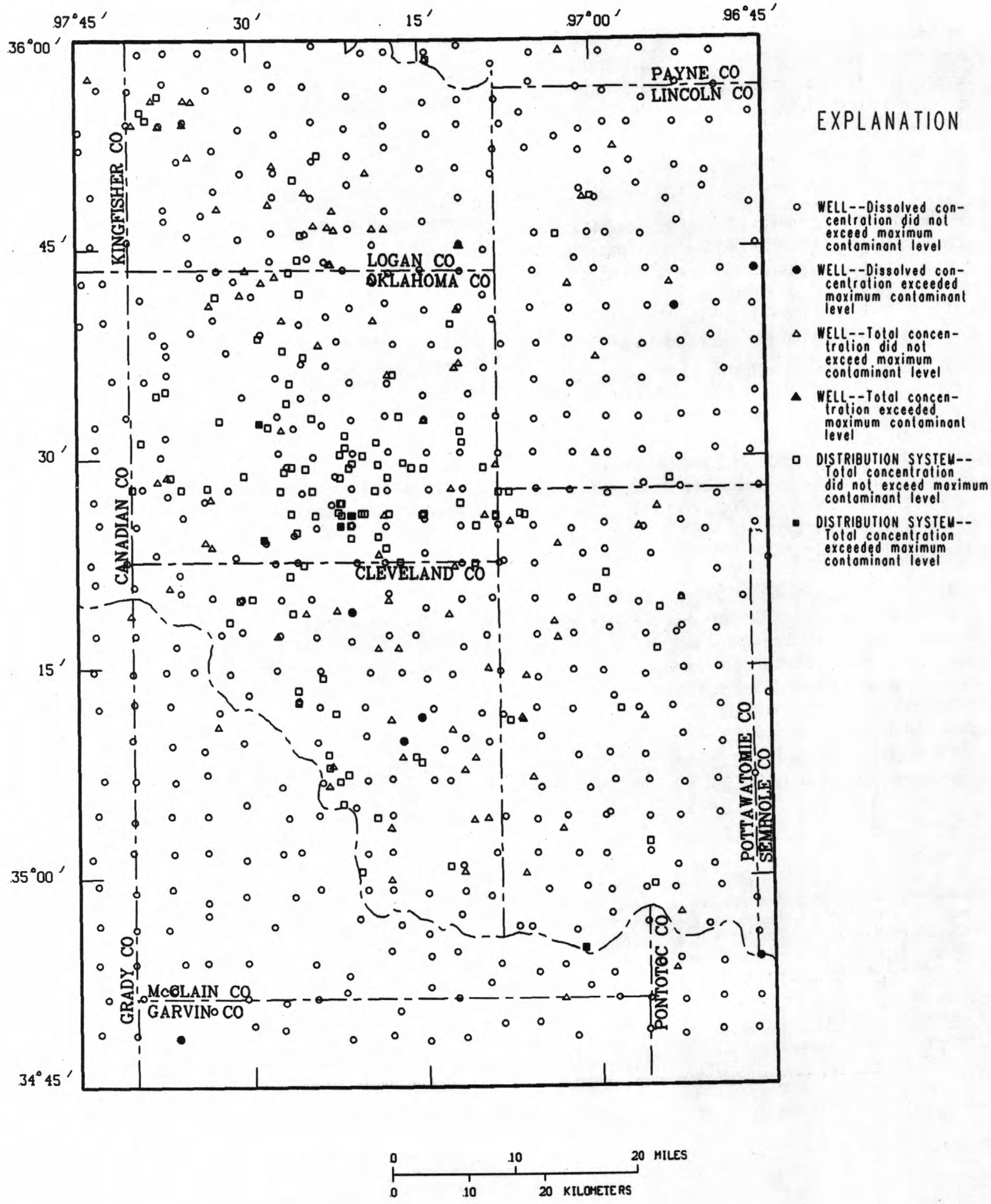

Figure 22.—Locations of wells and distribution systems where barium was measured.

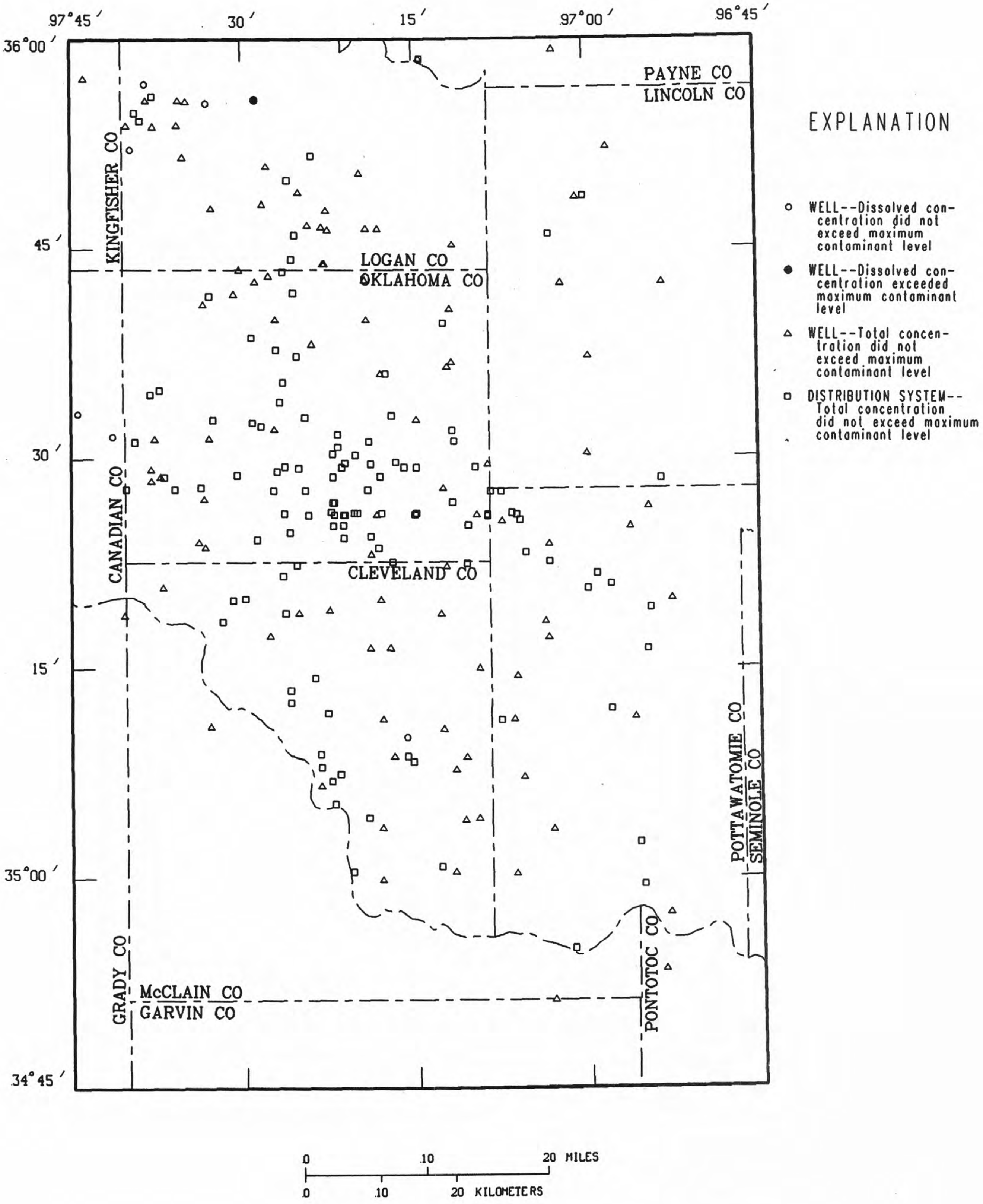

Figure 23.—Locations of wells and distribution systems where cadmium was measured.

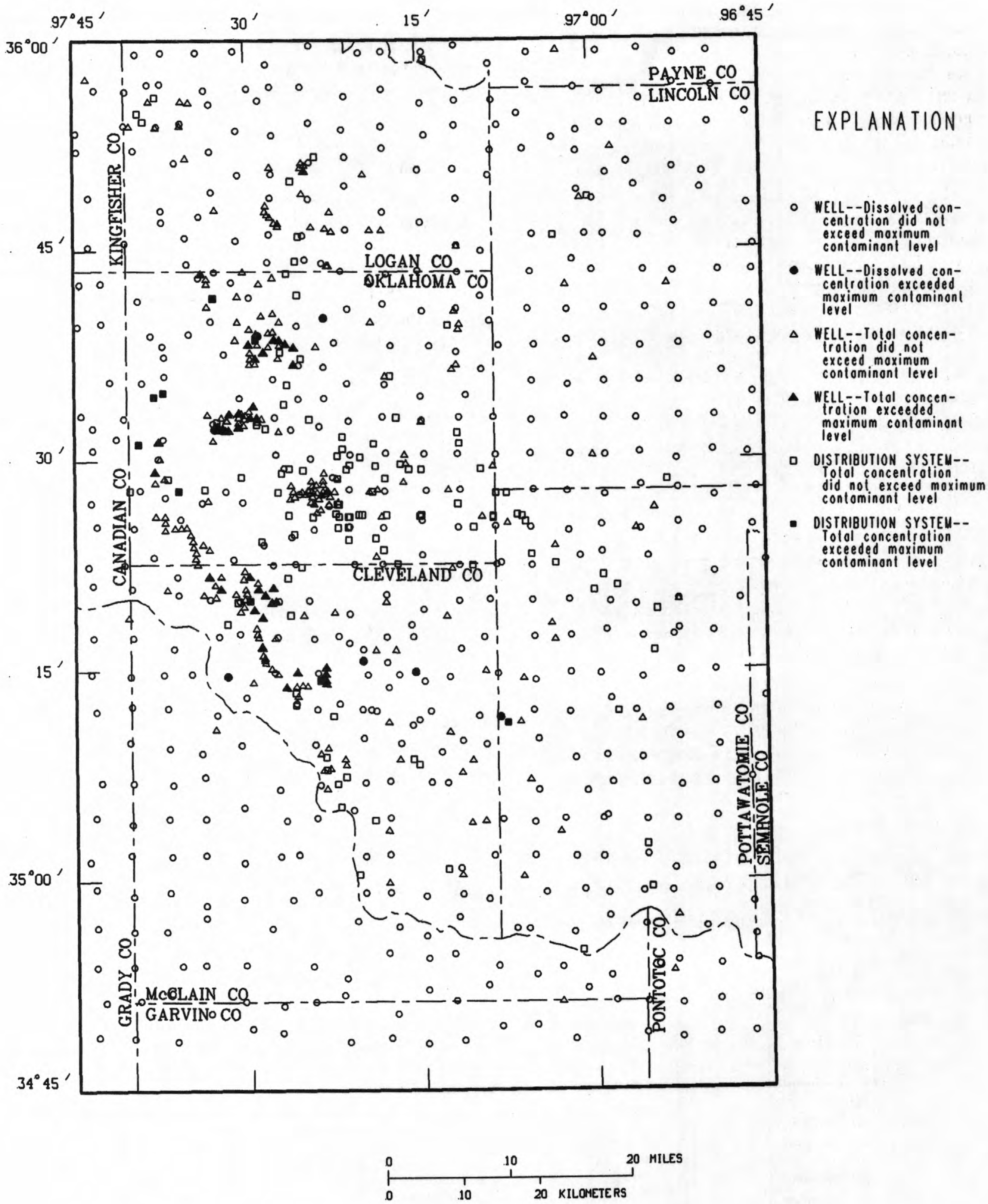

Figure 24.—Locations of wells and distribution systems where chromium was measured.

significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). The percentage of analyses that exceeded the MCL was much larger in the deep Garber-Wellington category than in any other geohydrologic category. The cell chi-square statistics indicated that the deep Garber-Wellington category had the largest deviation from the expected value.

In all, 48 out of 58 analyses that exceeded the MCL were in the deep Garber-Wellington category. For the combined data, the overall percentage of analyses that exceeded the MCL was 6.8 percent. However, the percentage of analyses in the deep Garber-Wellington category that exceeded the MCL was 23.1 percent and in the Hennessey category, the geohydrologic category with the second largest percentage, only 4.2 percent. The available analyses indicate that ground-water concentrations of chromium greater than the 50-μg/L MCL are common at depths greater than 300 feet in the Garber Sandstone and Wellington Formation and rare in the rest of the study unit.

Copper

The SMCL for copper is 1,000 μg/L. The SMCL was exceeded in two of 97 wells and two of 120 distribution systems where total copper was analyzed and in none of 514 wells where dissolved copper was analyzed (table 4). The locations where copper was analyzed and where the SMCL was exceeded are plotted in figure 25. Too few analyses exceeded the SMCL to calculate meaningful contingency-table statistics. The available analyses indicate that ground-water concentrations of copper greater than the 1,000-μg/L SMCL are rare in the study unit.

Iron

The SMCL for iron is 300 μg/L. The SMCL was exceeded in 21 of 168 wells and 24 of 122 distribution systems where total iron was analyzed and in 12 of 546 wells where dissolved iron was analyzed (table 4). The locations where iron was analyzed and where the SMCL was exceeded are shown in figure 26.

The separate contingency tables for the dissolved and total concentrations of iron (not presented) produced conflicting results. The contingency-table statistics indicated that the proportion of total-iron analyses that exceeded the SMCL was the same among the geohydrologic categories (null hypothesis accepted, attained significance level of 0.380). The contingency-table statistics for dissolved-iron analyses indicated that the proportion of analyses that exceeded the SMCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). The deep Garber-Wellington category had more analyses that exceeded the SMCL than the expected value. However, the large concentrations of dissolved iron in the Garber Sandstone and Wellington Formation occurred almost exclusively in a set of test holes drilled for the City of Norman in the vicinity of Lake Thunderbird. Thus, the dissolved-iron data do not show a regional trend for iron, only a local anomaly caused by local variations in the water chemistry or, more likely, differences in sampling, sample preservation, or analytical procedure. Excluding these data decreases the number of analyses that exceeded the SMCL from 22 to just one out of 540 analyses for

Table 14.—*Contingency table of chromium concentrations by geohydrologic category*

[Data include dissolved and total chromium analyses. Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal; μg/L, micrograms per liter]

		Geohydrologic category								
					Garber-Wellington					
Chromium concentration	Statistic	Alluvium-terrace	El Reno	Henn-essey	Shallow	Medium-depth	Deep	Chase-Admire	Vanoss	Row totals
< 50 μg/L	Number of analyses	117	46	46	150	127	160	95	48	789
	Expected value	111.8	42.9	44.7	140.7	122.0	193.8	88.5	44.7	
	Cell chi square	0.2	0.2	0.0	0.6	0.2	5.9	0.5	0.2	
> = 50 μg/L	Number of analyses	3	0	2	1	4	48	0	0	58
	Expected value	8.2	3.1	3.3	10.3	9.0	14.2	6.5	3.3	
	Percent > = 50 μg/L	2.5	0.0	4.2	0.7	3.1	23.1	0.0	0.0	6.8
	Cell chi square	3.3	3.1	0.5	8.4	2.8	80.0	6.5	3.3	
	Total number of analyses	120	46	48	151	131	208	95	48	847

Overall statistics: chi square 115.8, attained significance level less than 0.001, smallest expected value 3.1, degrees of freedom 7.

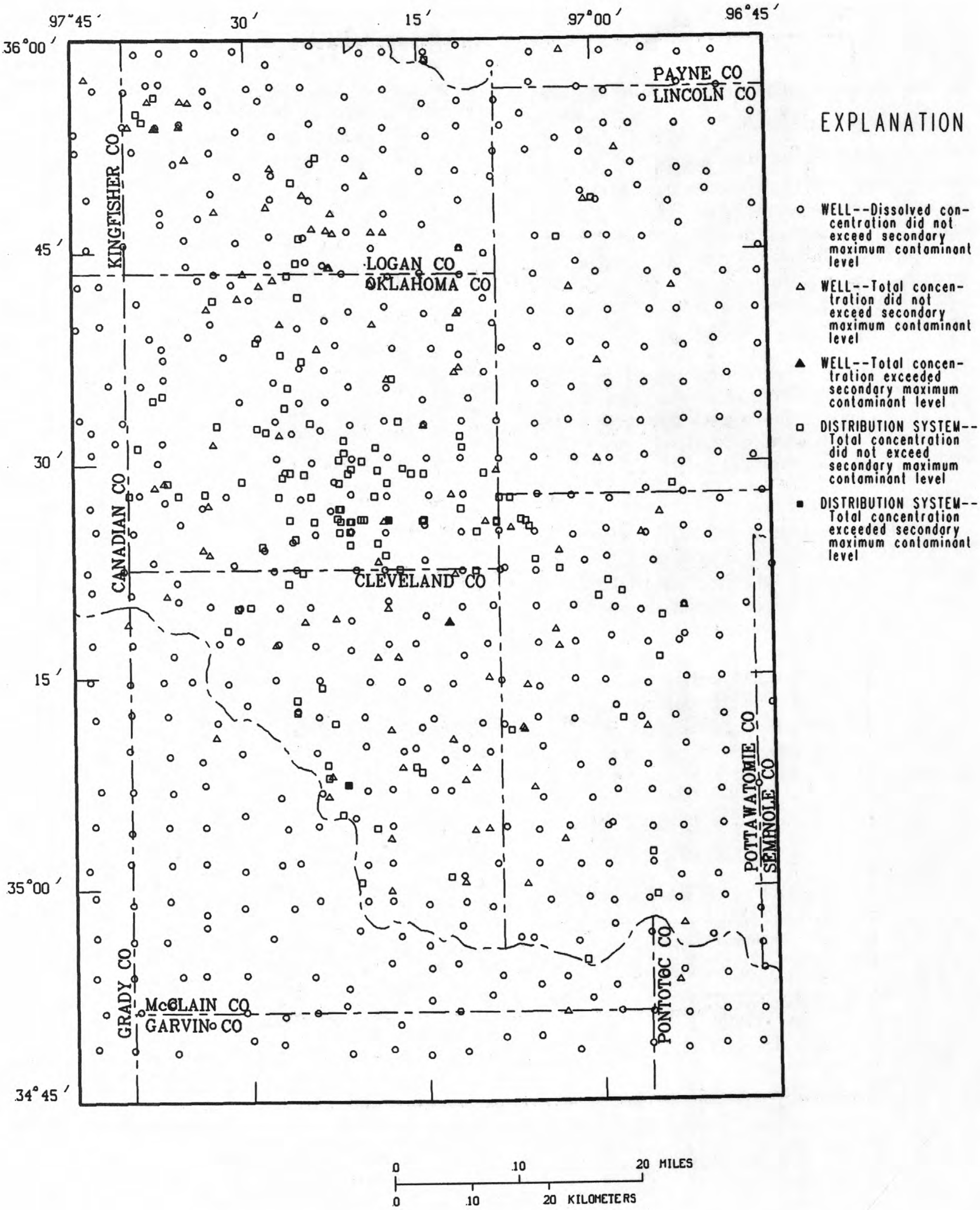

Figure 25.—Locations of wells and distribution systems where copper was measured.

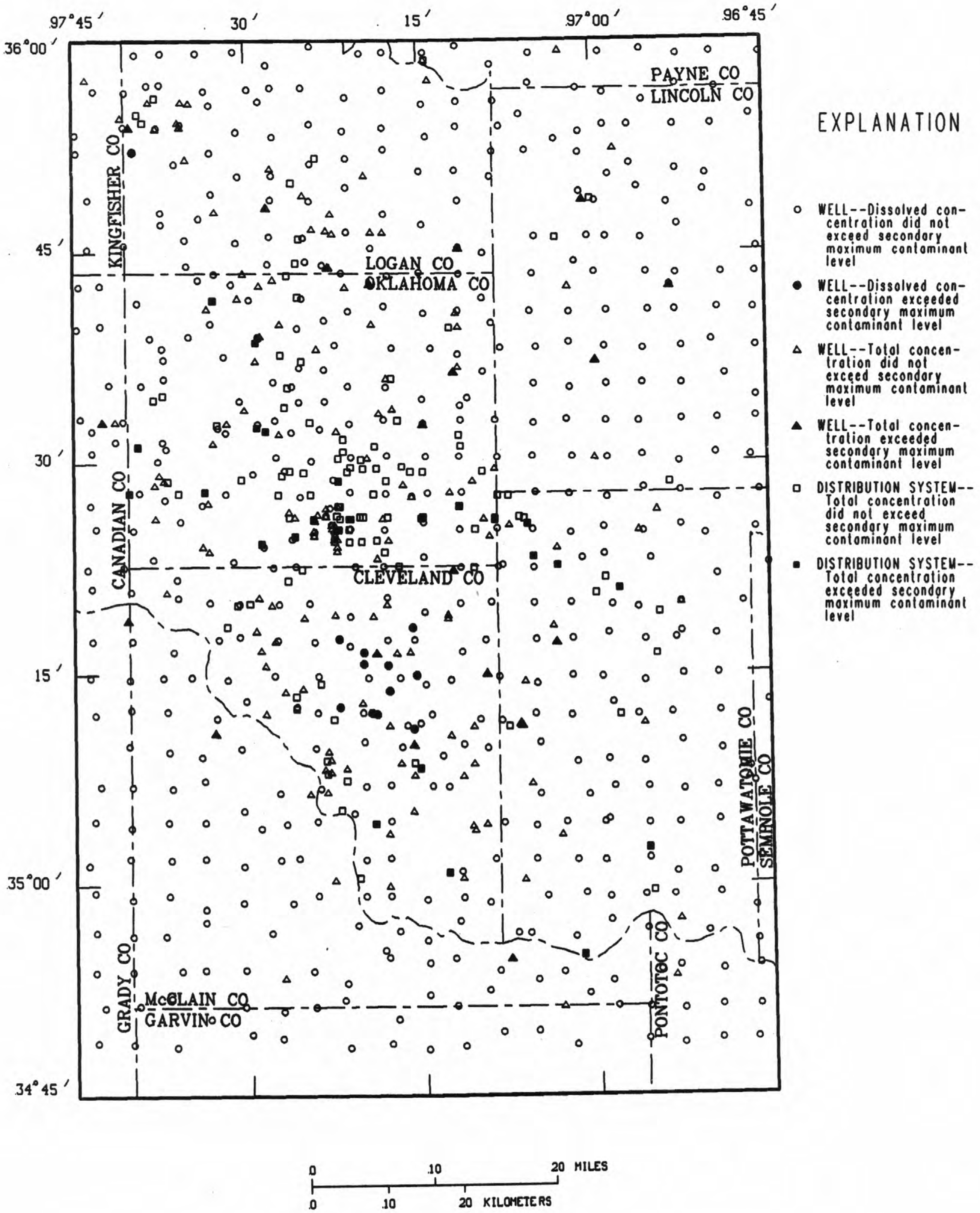

Figure 26.—Locations of wells and distribution systems where iron was measured.

dissolved iron. With just one analysis that exceeded the MCL, it was not possible to calculate meaningful contingency-table statistics.

The contingency table for the combined dissolved and total iron data, excluding the data from the Norman test holes, is given in table 15. The contingency-table statistics indicated that the proportion of analyses that exceeded the SMCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). This result contrasts with a lack of significance indicated by the statistics for both the dissolved-iron (excluding the Norman test holes) and the total-iron data. Thus, there is no consistent conclusion among the contingency tables for iron. The overall percentage of analyses that exceeded the SMCL is 4.1 percent for the combined data, compared to 14.3 percent for the total-iron data and 0.2 percent for the dissolved-iron data (excluding the test holes). The available analyses indicate that concentrations of total-iron greater than the 300-μg/L SMCL are common in water from wells in the study unit; but concentrations of dissolved-iron greater than the SMCL are rare.

Lead

The MCL for lead is 50 μg/L. The MCL was exceeded in two of 97 wells and one of 122 distribution systems where total lead was analyzed and in none of 6 wells where dissolved lead was analyzed (table 4). The locations where lead was analyzed and the locations where the MCL was exceeded are shown in figure 27. Too few analyses exceeded the MCL to calculate meaningful contingency-table statistics. The available analyses indicate that ground-water concentrations of lead greater than the 50-μg/L MCL are rare in the study unit.

Manganese

The SMCL for manganese is 50 μg/L. The SMCL was exceeded in nine of 107 wells and 13 of 118 distribution systems where total manganese was analyzed and in 32 of 529 wells where dissolved manganese was analyzed (table 4). Figure 28 shows the locations where manganese was analyzed and where the SMCL was exceeded.

The contingency-table statistics for total manganese indicated that the proportion of samples that exceeded the SMCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level of 0.045). The number of analyses that exceeded the SMCL was less than the expected value in the deep Garber-Wellington category and greater than the expected value in the alluvium-terrace category. These two geohydrologic categories had the largest deviations from the expected values, based on the chi-square statistics.

The contingency-table statistics for dissolved manganese indicated that the proportion of analyses that exceeded the SMCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). The number of analyses that exceeded the SMCL was greater than the expected value in the deep and medium-depth Garber-Wellington categories and less than the expected value for the El Reno, Hennessey, and Chase-Admire categories. Most of the large concentrations of dissolved manganese for the medium-depth and deep Garber-Wellington categories were analyses of samples from the same test holes for the City of Norman that had large concentrations of iron. When the test-hole data were excluded, there was a significant difference among the geohydrologic categories (null hypothesis rejected, attained

Table 15.—*Contingency table of iron concentrations by geohydrologic category*

[Data include dissolved and total iron analyses. Data from the Norman test holes were excluded. Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal; μg/L, micrograms per liter]

		Geohydrologic category								
					Garber-Wellington					
Iron concentration	Statistic	Alluvium-terrace	El Reno	Henn-essey	Shallow	Medium-depth	Deep	Chase-Admire	Vanoss	Row totals
< 300 μg/L	Number of analyses	123	46	50	155	109	80	93	48	704
	Expected value	126.6	44.1	48.0	149.6	116.1	82.5	91.1	46.0	
	Cell chi square	0.1	0.1	0.1	0.2	0.4	0.1	0.0	0.1	
> = 300 μg/L	Number of analyses	9	0	0	1	12	6	2	0	30
	Expected value	5.4	1.9	2.0	6.4	4.9	3.5	3.9	2.0	
	Percent > = 300 μg/L	6.8	0.0	0.0	0.6	9.9	7.0	2.1	0.0	4.1
	Cell chi square	2.4	1.9	2.0	4.5	10.1	1.8	0.9	2.0	
	Total number of analyses	132	46	50	156	121	86	95	48	734

Overall statistics: chi square 26.6, attained significance level less than 0.001, smallest expected value 1.9, degrees of freedom 7.

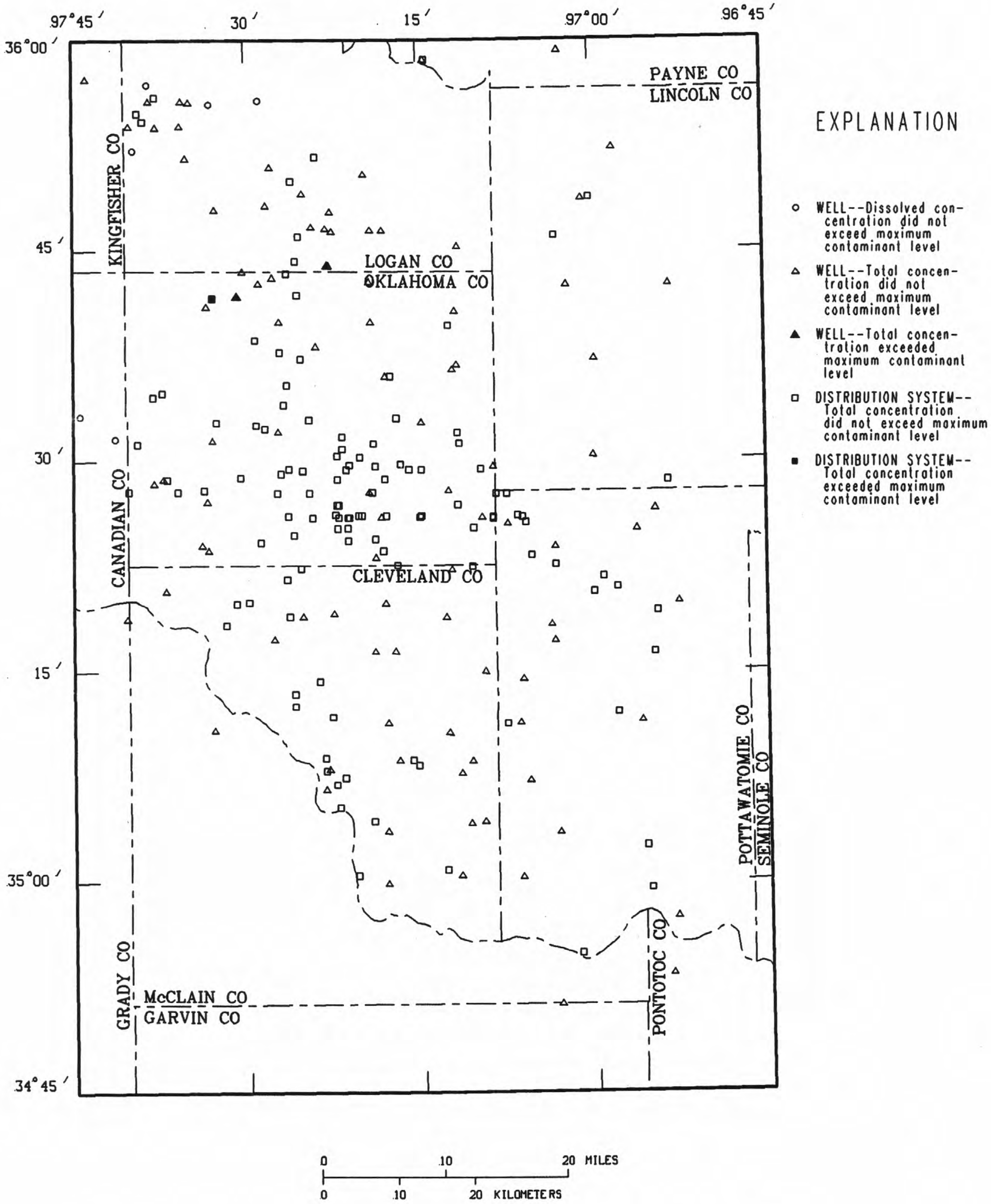

Figure 27.—Locations of wells and distribution systems where lead was measured.

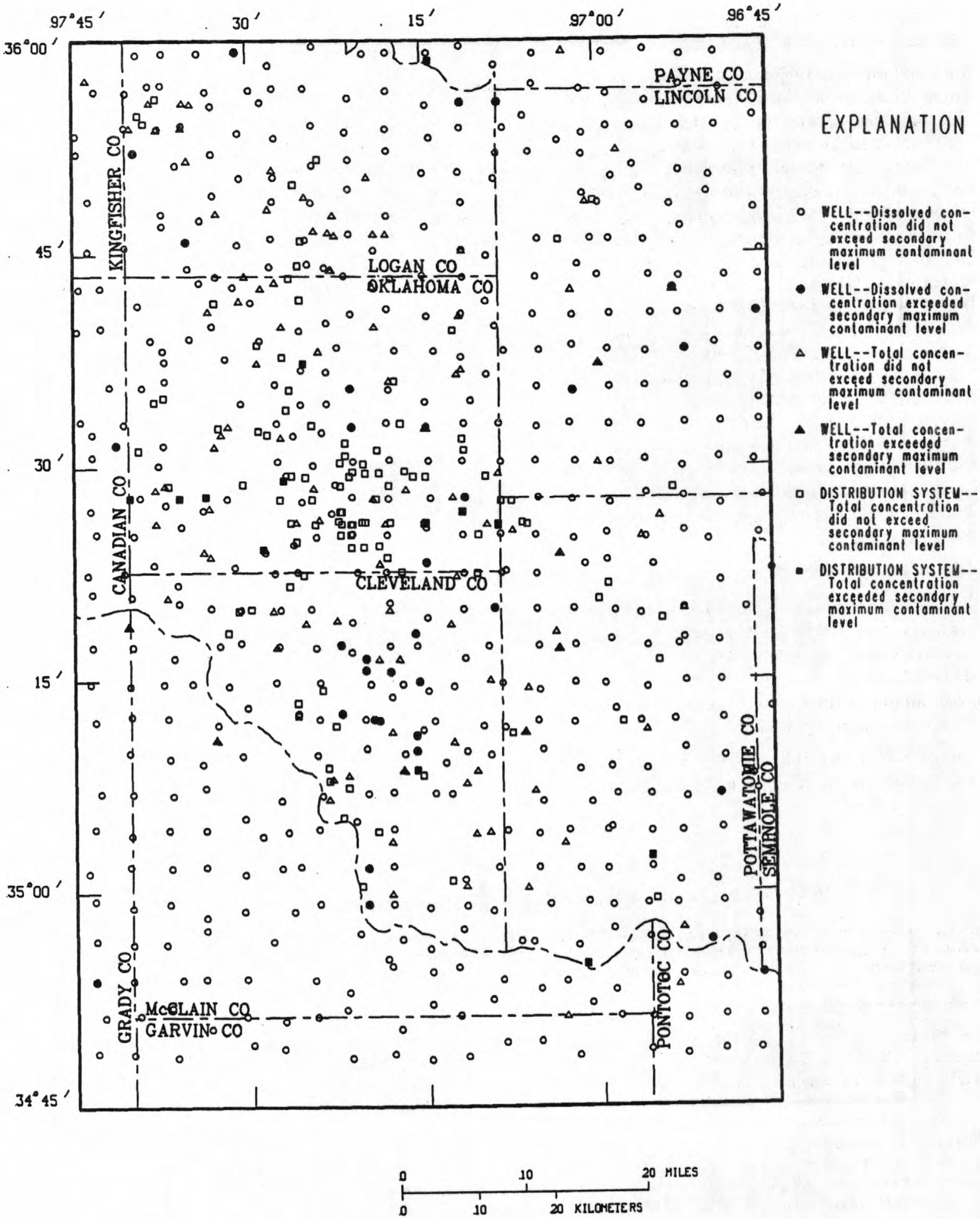

Figure 28.—Locations of wells and distribution systems where manganese was measured.

significance level of 0.015). The cell chi-square statistics indicated that the greatest deviation from the expected value was for the alluvium-terrace category.

The combined contingency table was calculated excluding the data from the test holes (table 16). The contingency-table statistics indicated that the proportion of analyses that exceeded the SMCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level of 0.003). The alluvium-terrace category had the largest percentage of analyses that exceeded the SMCL and the largest deviation from the expected value, based on the chi-square statistic. The overall percentage of analyses that exceeded the SMCL was 5.3, 10.3, and 4.0 percent, for the combined, total, and dissolved data (excluding the test-hole data), respectively. The percentages of analyses from the alluvium-terrace category that exceeded the SMCL were 12.4, 22.2, and 9.5 percent for the combined, total, and dissolved data, respectively. The available analyses indicate that ground-water concentrations greater than the 50-μg/L SMCL occur in the study unit and that ground water in the alluvium and terrace deposits commonly exceeds the manganese SMCL.

Mercury

The MCL for mercury is 2 μg/L. The MCL for mercury was exceeded in no samples from two wells where dissolved mercury was analyzed and in no samples from 118 distribution systems where total mercury was analyzed (table 4). Figure 29 shows the locations where mercury was analyzed.

The contingency-table statistics were not computed because no analyses exceeded the MCL. The available analyses indicate that ground-water concentrations of mercury greater than the 2-μg/L MCL are rare in the study unit.

Selenium

The MCL for selenium is 10 μg/L. The MCL was exceeded in 84 of 274 wells and 16 of 119 distribution systems where total selenium was analyzed and in 11 of 527 wells where dissolved selenium was analyzed (table 4). The locations where selenium was analyzed and where the SMCL was exceeded are shown in figure 30. Most of the occurrences of large selenium concentrations are in the western half of the study unit.

The contingency-table statistics (not presented) for total selenium indicated that the proportion of analyses that exceeded the MCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). The deep Garber-Wellington category had the largest cell chi-square statistic and the largest percentage of analyses that exceeded the MCL. Too few analyses exceeded the MCL to calculate meaningful contingency-table statistics for the dissolved-selenium analyses, but seven of 13 analyses that exceeded the MCL were in the deep Garber-Wellington category.

The contingency-table statistics for the combined data (table 17) indicated that the proportion of analyses that exceeded the MCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). The combined data show that 89 out of 107 selenium concentrations that exceeded the MCL were in the

Table 16.—*Contingency table of manganese concentrations by geohydrologic category*

[Data include dissolved and total manganese analyses. Data from the Norman test holes were excluded. Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal; μg/L, micrograms per liter]

		Geohydrologic category								
					Garber-Wellington					
Manganese concentration	Statistic	Alluvium-terrace	El Reno	Henn-essey	Shallow	Medium-depth	Deep	Chase-Admire	Vanoss	Row totals
< 50 μg/L	Number of analyses	106	46	47	143	103	58	92	44	639
	Expected value	114.5	43.5	44.5	141.1	104.1	55.9	89.9	45.4	
	Cell chi square	0.6	0.1	0.1	0.0	0.0	0.1	0.0	0.0	
> = 50 μg/L	Number of analyses	15	0	0	6	7	1	3	4	36
	Expected value	6.5	2.5	2.5	7.9	5.9	3.1	5.1	2.6	
	Percent > = 50 μg/L	12.4	0.0	0.0	4.0	6.4	1.7	3.2	8.3	5.3
	Cell chi square	11.3	2.5	2.5	0.5	0.2	1.5	0.8	0.8	
	Total number of analyses	121	46	47	149	110	59	95	48	675

Overall statistics: chi square 21.2, attained significance level 0.003, smallest expected value 2.5, degrees of freedom 7.

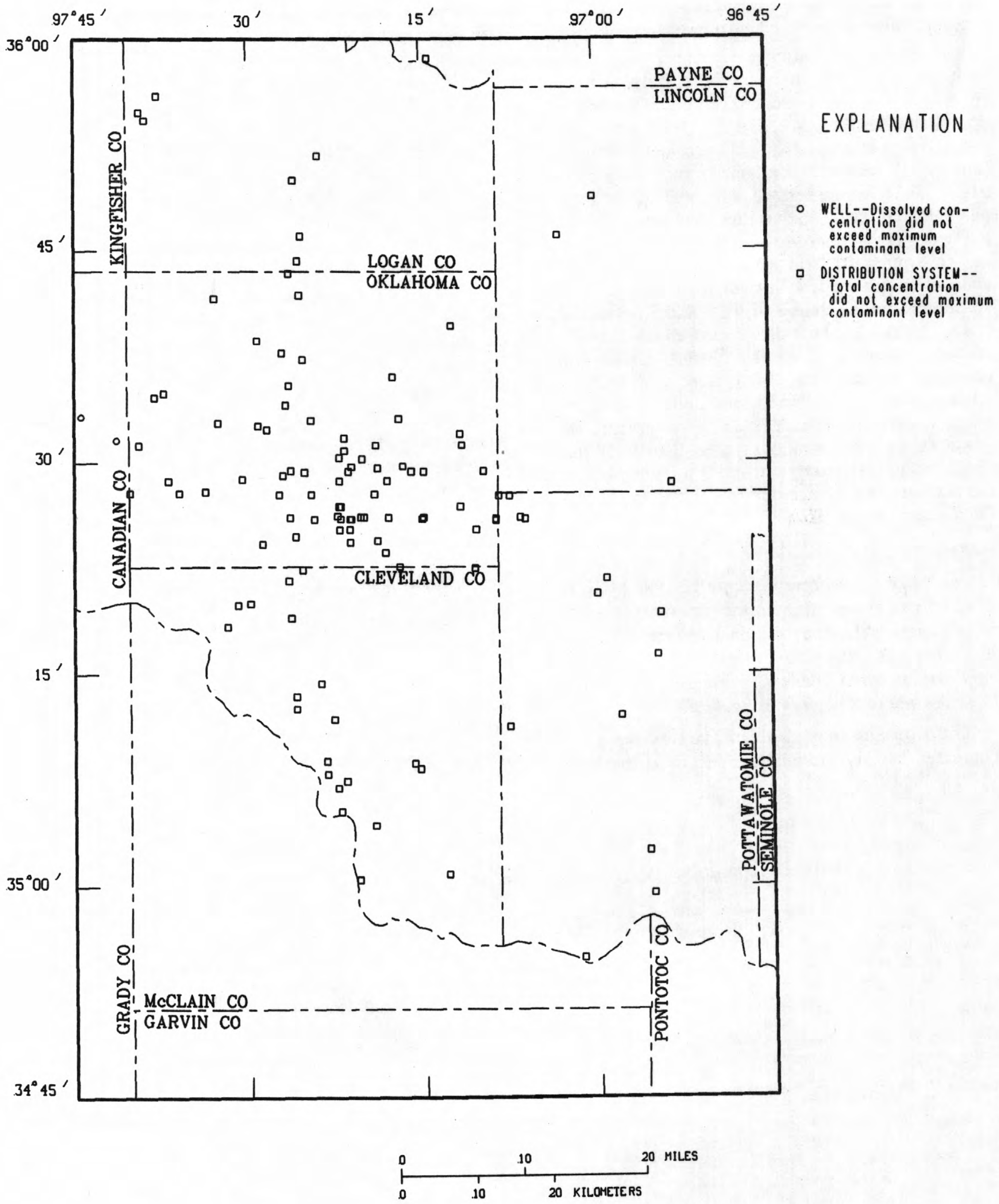

Figure 29.—Locations of wells and distribution systems where mercury was measured.

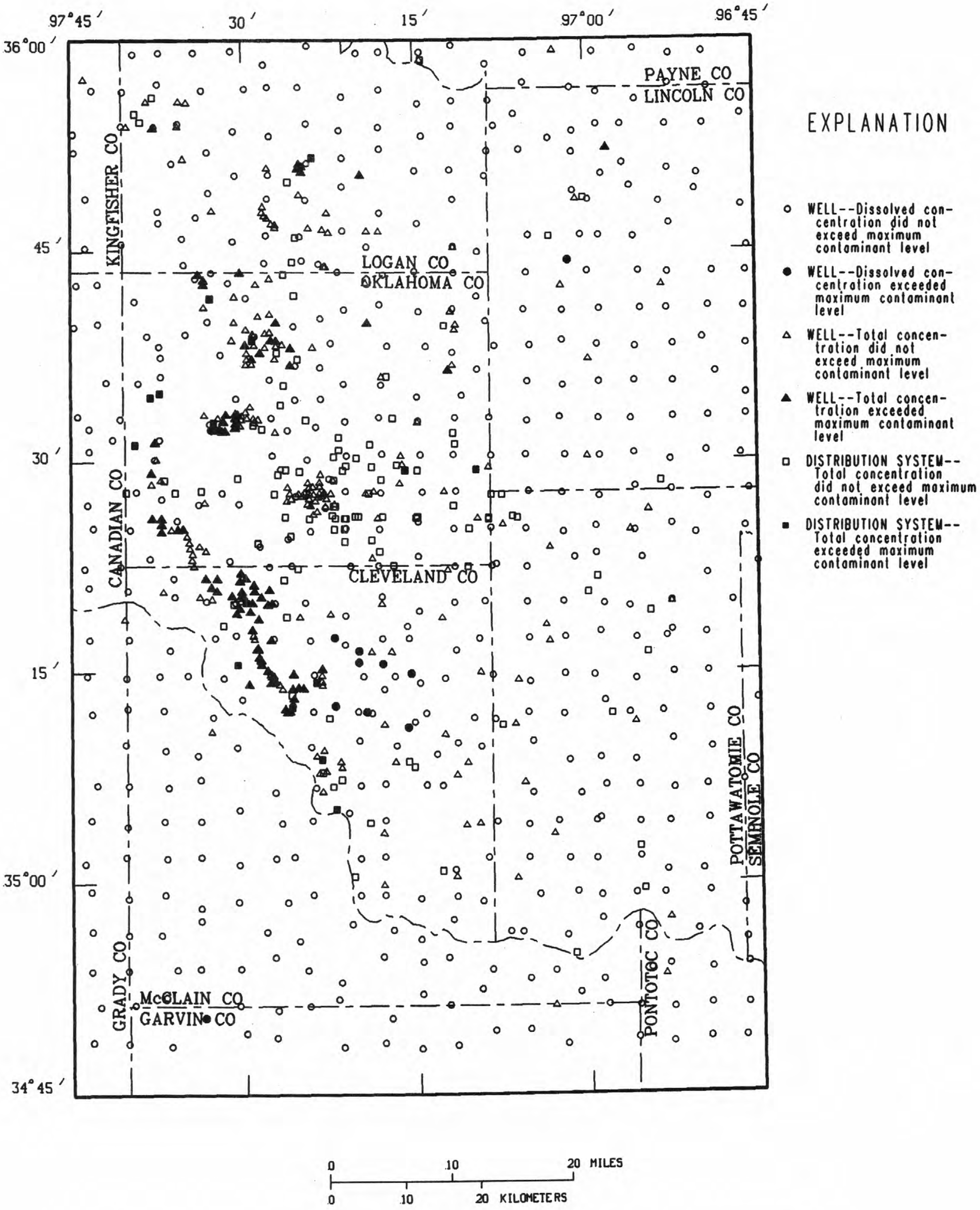

Figure 30.—Locations of wells and distribution systems where selenium was measured.

deep Garber-Wellington category. The deep Garber-Wellington had, by far, the largest cell chi-square statistic. Nearly 41 percent of the deep Garber-Wellington category had selenium concentrations that exceeded the MCL compared to 9.2 percent in the medium-depth Garber-Wellington category and less than 3 percent in all other geohydrologic categories. The available analyses indicate that ground-water concentrations of selenium greater than the 10-μg/L MCL are common at depths greater than 100 feet in the Garber Sandstone and Wellington Formation and rare in other parts of the study unit.

Silver

The MCL for silver is 50 μg/L. No samples from 507 wells and 118 distribution systems exceeded the MCL for silver (table 4). The locations where silver was analyzed are shown in figure 31. The contingency-table statistics were not computed because no analyses exceeded the MCL. The available analyses indicate that ground-water concentrations of silver greater than the 50-μg/L MCL are rare in the study unit.

Zinc

The SMCL for zinc is 5,000 μg/L. The SMCL was exceeded in none of 97 wells and one of 120 distribution systems where total zinc was analyzed and in none of 514 wells where dissolved zinc was analyzed (table 4). The locations where zinc was analyzed and the location where the SMCL was exceeded are shown in figure 32.

Too few analyses exceeded the SMCL to calculate meaningful contingency-table statistics. The available analyses indicate that ground-water concentrations of zinc greater than the 5,000-μg/L SMCL are rare in the study unit.

Gross alpha particle activity

The MCL for "gross alpha particle activity (including radium-226 but excluding radon and uranium)" is 15 pCi/L (U.S. Environmental Protection Agency, 1986a). The analytical method commonly used for measuring gross-alpha radioactivity excludes any contribution from radon but includes the contribution from uranium. In this report, the term gross-alpha radioactivity is used for the measured gross-alpha radioactivity including the contribution of uranium. The term residual-alpha radioactivity is used for the quantity gross-alpha radioactivity minus the uranium-alpha radioactivity. The residual-alpha radioactivity is the quantity that is compared to the MCL for gross-alpha particle activity.

If the gross-alpha radioactivity for a sample is less than 15 pCi/L, then residual-alpha radioactivity must be less than the MCL. If gross-alpha radioactivity is greater than 15 pCi/L, this does not necessarily imply that residual-alpha radioactivity is greater than the MCL. For samples taken by the Oklahoma State Department of Health, if gross-alpha radioactivity plus the standard deviation of the measurement is greater than 15 pCi/L, then uranium-alpha radioactivity is measured and the residual-alpha radioactivity is calculated. The MCL is exceeded if the residual-alpha radioactivity exceeds 15 pCi/L.

Most samples for gross-alpha radioactivity were collected by the Association of Central Oklahoma Governments or the Oklahoma State Department of Health. The data from the Association of Central Oklahoma Governments is not discussed because no measurements of uranium were made and it was not possible to calculate residual-alpha radioactivity.

Table 17.—*Contingency table of selenium concentrations by geohydrologic category*

[Data include dissolved and total selenium analyses. Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal; μg/L, micrograms per liter]

Selenium concentration	Statistic	Geohydrologic category								Row totals
		Alluvium-terrace	El Reno	Henn-essey	Garber-Wellington			Chase-Admire	Vanoss	
					Shallow	Medium-depth	Deep			
< 10 μg/L	Number of analyses	114	46	49	151	118	129	93	48	748
	Expected value	102.4	40.2	43.7	132.1	113.7	190.7	83.1	42.0	
	Cell chi square	1.3	0.8	0.6	2.7	0.2	20.0	1.2	0.9	
> = 10 μg/L	Number of analyses	3	0	1	0	12	89	2	0	107
	Expected value	14.6	5.8	6.3	18.9	16.3	27.3	11.9	6.0	
	Percent > = 10 μg/L	2.6	0.0	2.0	0.0	9.2	40.8	2.1	0.0	12.5
	Cell chi square	9.3	5.8	4.4	18.9	1.1	139.6	8.2	6.0	
	Total number of analyses	117	46	50	151	130	218	95	48	855

Overall statistics: chi square 220.9, attained significance level less than 0.001, smallest expected value 5.8, degrees of freedom 7.

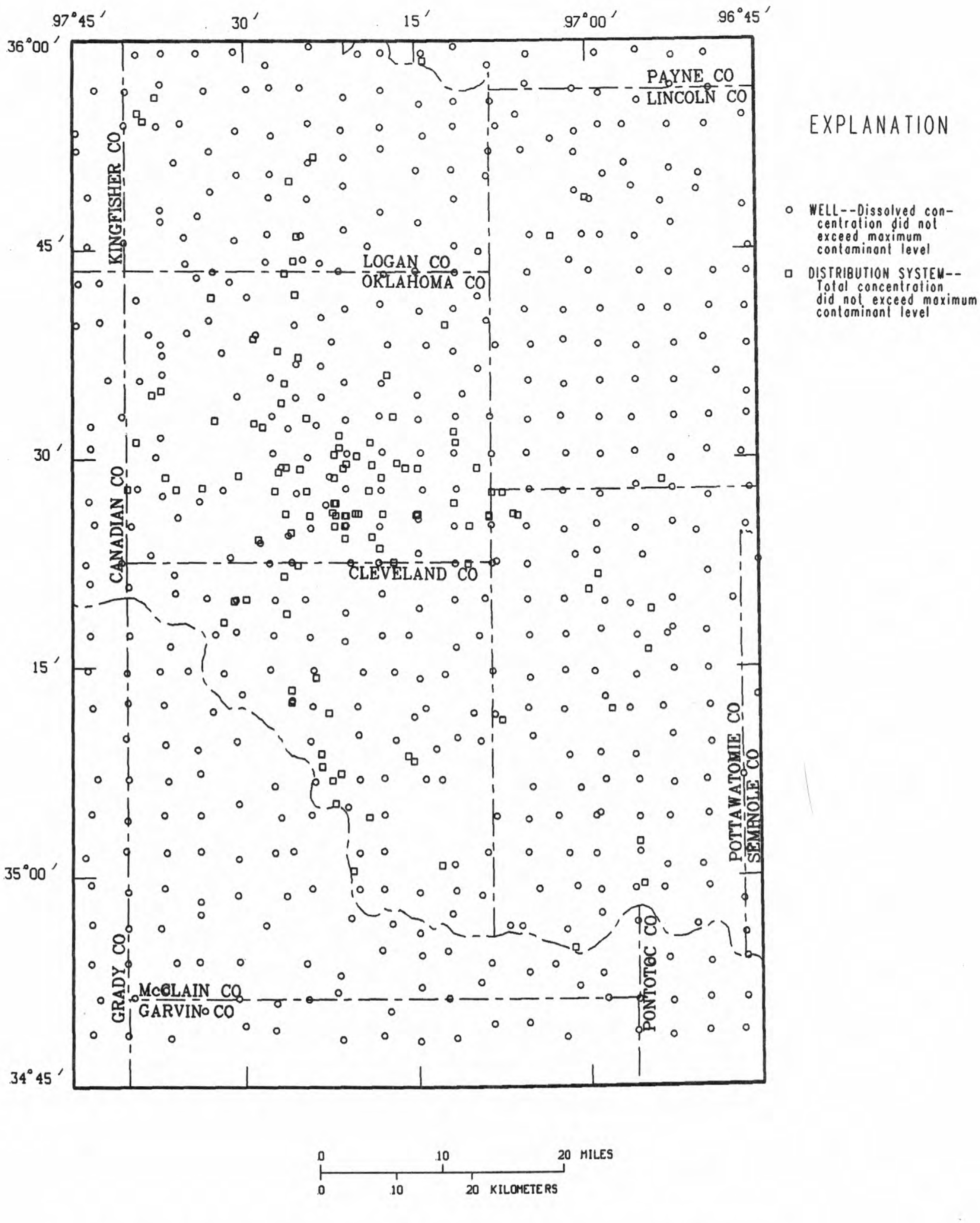

Figure 31.—Locations of wells and distribution systems where silver was measured.

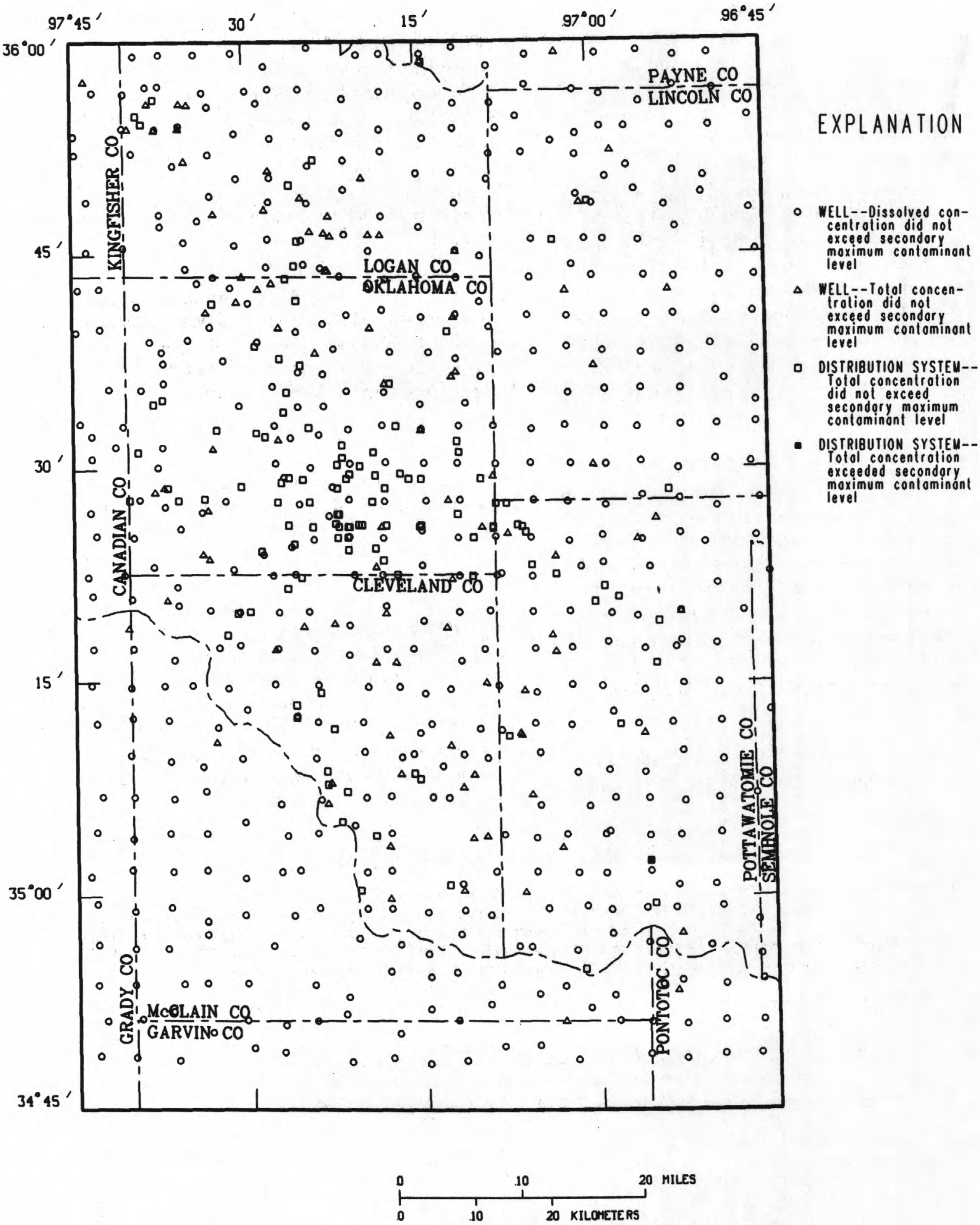

Figure 32.–Locations of wells and distribution systems where zinc was measured.

The data from the Oklahoma State Department of Health included the uranium-alpha-radioactivity measurements necessary to compute residual-alpha radioactivity and all of the following discussion is about these data. Figure 33 shows the locations of wells and distribution systems where residual-alpha-radioactivity data were available and where residual-alpha radioactivity exceeded the MCL.

In the contingency-table analysis, the MCL was exceeded in 10 of 82 wells and distribution systems where residual-alpha-radioactivity data were available (table 18). Six of the 10 analyses that exceeded the MCL were in the Chase-Admire category. The contingency-table statistics for residual-alpha radioactivity indicated that the proportion of analyses that exceeded the MCL was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). However, no data were available in the El Reno, shallow Garber-Wellington, Hennessey, or Vanoss categories.

Residual-alpha radioactivity exceeded the MCL in medium-depth and deep wells in the Garber Sandstone and Wellington Formation, and in the Chase, Council Grove, and Admire Groups. The available data indicate that ground-water concentrations of residual-alpha radioactivity greater than the MCL occur most commonly in the Chase, Council Grove, and Admire Groups, but the data are limited.

Radium

The MCL for radium-226 plus radium-228 is 5 pCi/L. For samples taken by the Oklahoma State Department of Health, if gross-alpha radioactivity is less than 5 pCi/L, then radium-226 plus radium-228 is assumed to be less than the 5-pCi/L MCL. However, if gross-alpha radioactivity is greater than 5 pCi/L, the sample is analyzed for radium-226. If radium-226 is less than 3.0 pCi/L, then radium-226 plus radium-228 is assumed to be less than the 5-pCi/L MCL. In all cases in which radium-226 was measured in the study unit, the concentration was less than 3 pCi/L. Figure 34 shows the locations where radium-226 was measured.

No contingency-table statistics were calculated because no samples exceeded the MCL. The available analyses indicate that large ground-water concentrations of radium-226 are rare in the study unit and it is inferred that concentrations of radium-226 plus radium-228 greater than the radium MCL also are rare.

Uranium

At present (1988) a drinking-water standard for uranium has not been established by the U.S. Environmental Protection Agency. However, according to the Safe Drinking Water Act Amendments of 1986 (U.S. Environmental Protection Agency, 1986c), a MCL for uranium will be established within the next few years. American Public Health Association and others (1985) states that a MCL of 10 pCi/L is under consideration for uranium. Zapecza and Szabo (1988) used a level of 10 pCi/L to delineate areas of the United States with relatively large uranium concentrations in ground water. A value of 10 pCi/L corresponds to 15 μg/L of

Table 18. — *Contingency table of residual-alpha radioactivity by geohydrologic category*

[Residual-alpha radioactivity is the difference between gross-alpha radioactivity and uranium-alpha radioactivity. Residual-alpha radioactivity can be compared directly to the 15-picocurie-per-liter maximum contaminant level for gross alpha particle activity. Only data from the Oklahoma State Department of Health were included. Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. <, less than; > =, greater than or equal; pCi/L, picocuries per liter]

Residual-alpha radioactivity	Statistic	Geohydrologic category								Row totals
		Alluvium-terrace	El Reno	Henn-essey	Garber-Wellington			Chase-Admire	Vanoss	
					Shallow	Medium-depth	Deep			
< 15 pCi/L	Number of analyses	11	0	0	0	16	38	7	0	72
	Expected value	9.7				14.9	36.0	11.4		
	Cell chi square	0.2				0.1	0.1	1.7		
> = 15 pCi/L	Number of analyses	0	0	0	0	1	3	6	0	10
	Expected value	1.3				2.1	5.0	1.6		
	Percent > = 15 pCi/L	0.0				5.9	7.3	46.2		12.2
	Cell chi square	1.3				0.6	0.8	12.1		
	Total number of analyses	11	0	0	0	17	41	13	0	82

Overall statistics: chi square 17.0, attained significance level 0.001, smallest expected value 1.3, degrees of freedom 3.

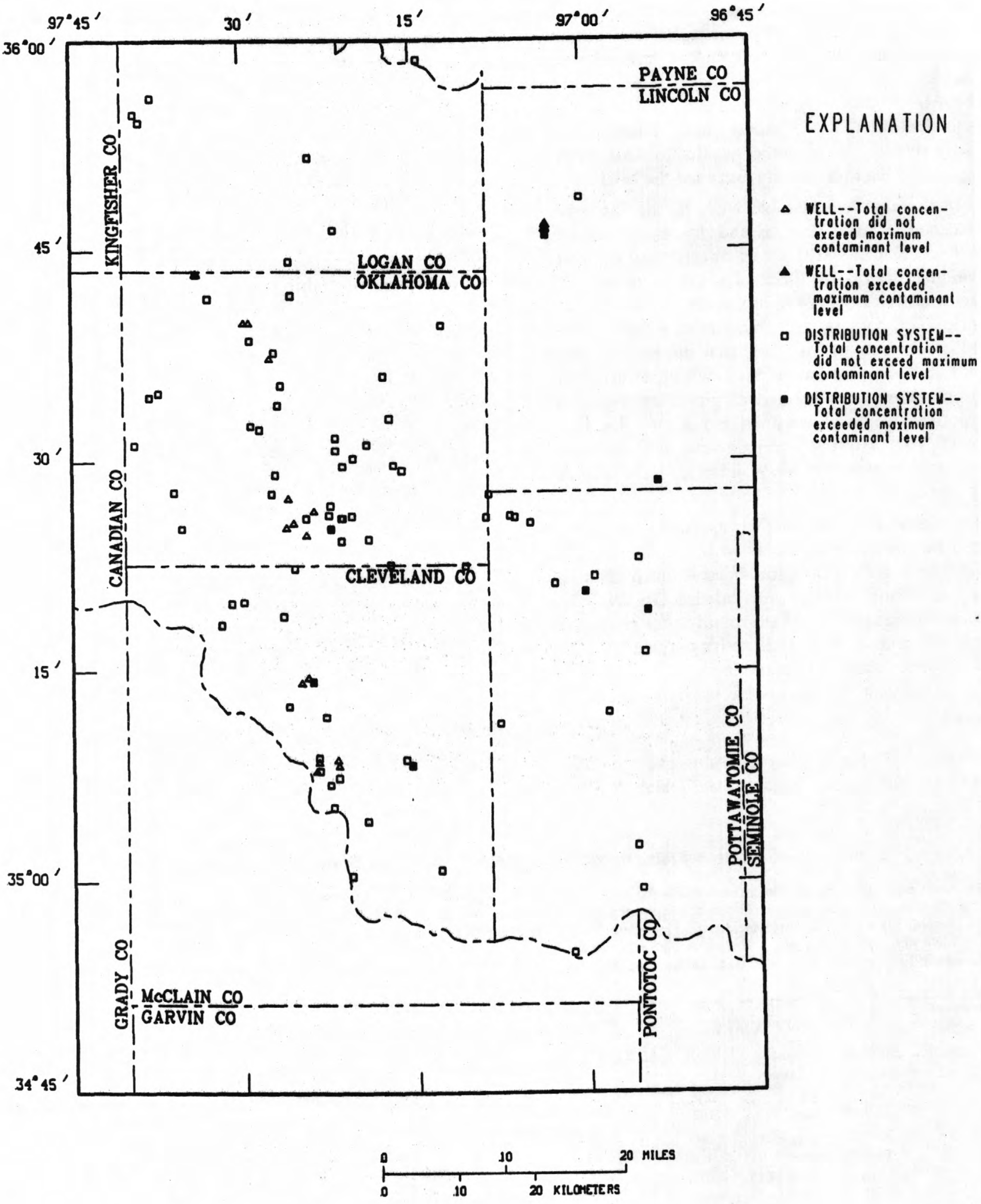

Figure 33.—Locations of wells and distribution systems where residual-alpha-radioactivity data were available.

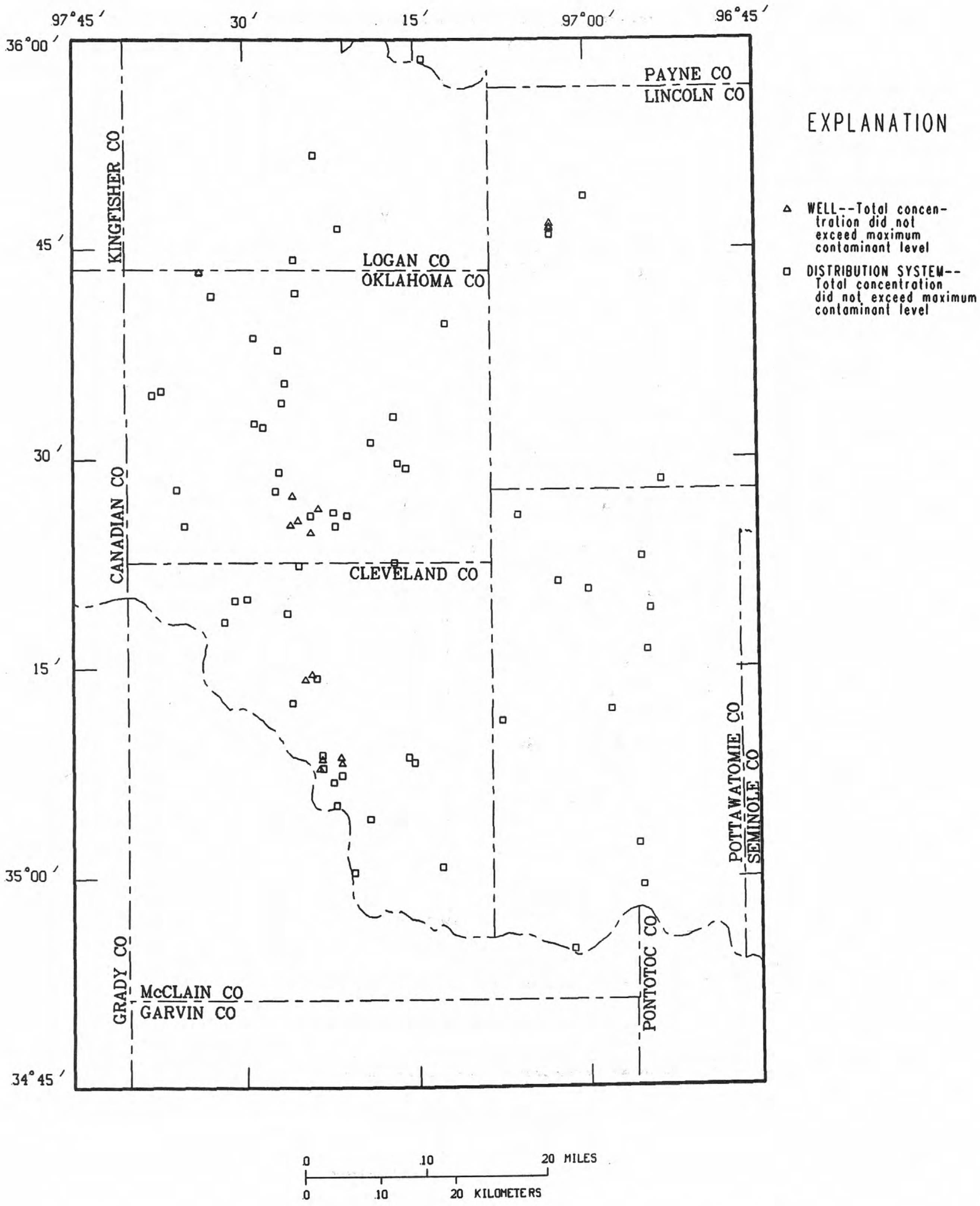

Figure 34.—Locations of wells and distribution systems where radium-226 was measured.

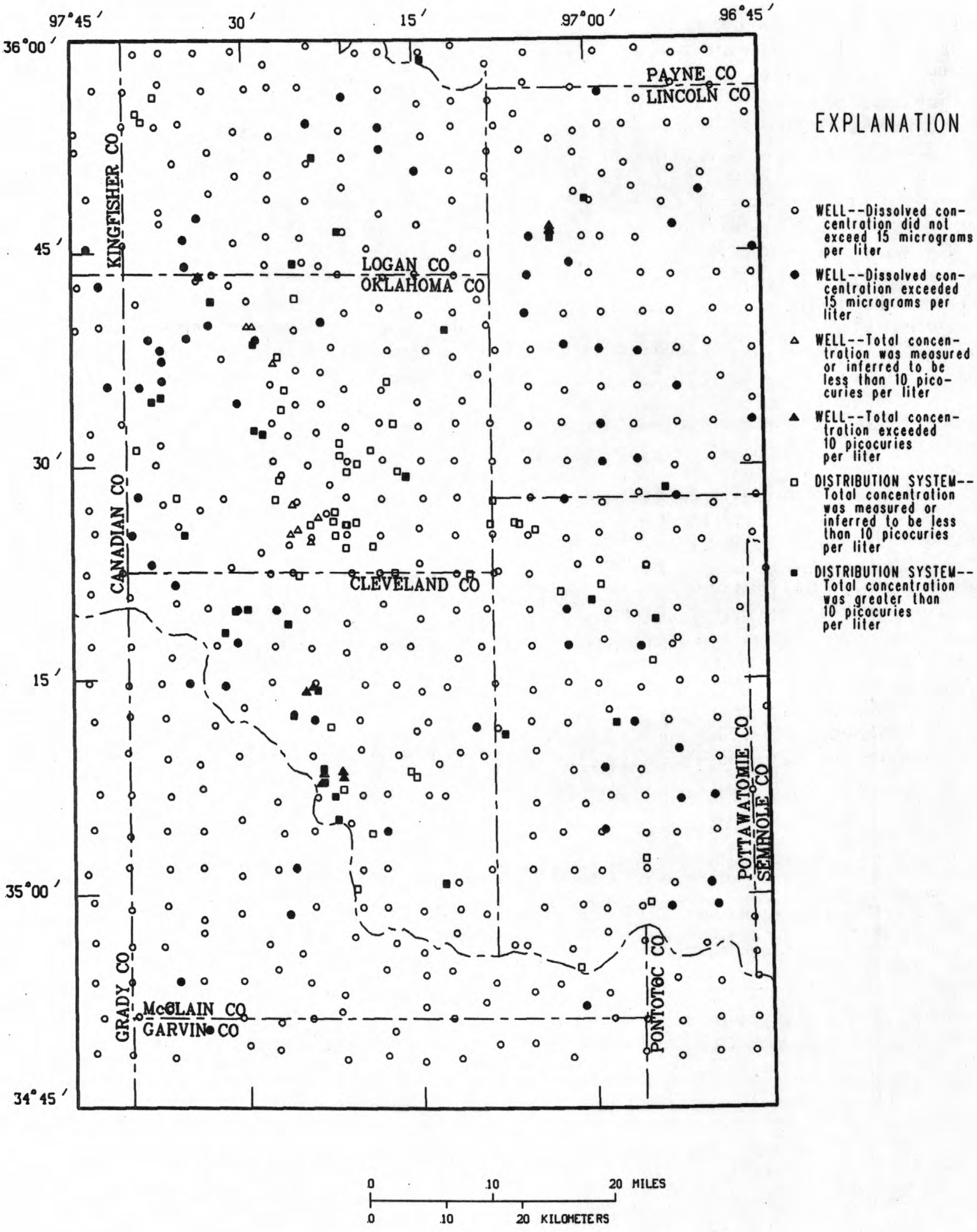

Figure 35. – Locations of wells and distribution systems where uranium was measured or uranium concentration could be inferred.

uranium if the isotopes of uranium are in secular equilibrium. For this report, levels of 10 pCi/L and 15 μg/L are used for purposes of comparison in the contingency-table analysis.

Dissolved uranium (in μg/L) was analyzed in the NURE samples. Uranium concentrations exceeded 15 μg/L in 68 of 509 wells where dissolved uranium was analyzed. The locations where dissolved uranium was analyzed and where dissolved uranium exceeded 15 μg/L are shown on figure 35.

Uranium-alpha radioactivity exceeded 10 pCi/L in 10 of 10 wells and 33 of 40 distribution systems where uranium-alpha radioactivity was analyzed. If the data for uranium-alpha radioactivity were used without qualification to estimate the percentage of analyses that exceeded 10 pCi/L, it would appear that most wells have large uranium concentrations. This is because samples were analyzed for uranium-alpha radioactivity only if the gross-alpha radioactivity was greater than 15 pCi/L. For this report, it was inferred that samples with gross-alpha radioactivity less than 15 pCi/L were implicitly analyzed for uranium-alpha radioactivity and that the concentration was less than 10 pCi/L in these samples. The locations of the wells and distribution systems (sampled by the Oklahoma State Department of Health) with measured uranium-alpha radioactivity less than 10 pCi/L are shown in figure 35 along with the sites where uranium-alpha radioactivity was inferred to be less than 10 pCi/L on the basis of the gross-alpha radioactivity measurement. The locations of wells and distribution systems where uranium-alpha radioactivity exceeded 10 pCi/L also are shown. All of the samples analyzed for gross-alpha radioactivity by the Oklahoma State Department of Health Radiochemistry Laboratory were included in the contingency-table analysis for uranium.

The contingency table for uranium-alpha radioactivity (not presented) contained data for the alluvium-terrace, medium-depth Garber-Wellington, deep Garber-Wellington, and Chase-Admire categories. The contingency-table analysis indicated that the proportion of analyses that exceeded 10 pCi/L was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level of 0.002). The largest percentages of analyses that exceeded 10 pCi/L were 61.5 for the Chase-Admire category and 61.0 percent for the deep Garber-Wellington category. The overall percentage of analyses that exceeded 10 pCi/L was 46.3 percent.

The contingency-table statistics for dissolved uranium (not presented) indicated that the proportion of analyses that exceeded 15 μg/L was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level of 0.001). There were no dissolved-uranium data in the deep Garber-Wellington category. The largest percentage of analyses that exceeded 15 μg/L was 28.6 percent for the Hennessey category. The overall percentage of analyses that exceeded 15 μg/L was 13.4 percent.

The contingency-table statistics for the combined data (table 19) indicated that the proportion of

Table 19. — *Contingency table of uranium concentrations by geohydrologic category*

[Data include dissolved uranium concentrations in micrograms per liter and uranium-alpha radioactivity in picocuries per liter. Although no MCL or SMCL has been established for uranium, values of 15 micrograms per liter and 10 picocuries per liter were used for comparison purposes in this contingency table. For the Oklahoma State Department of Health data, if gross-alpha radioactivity was less than 15 picocuries per liter, then uranium-alpha radioactivity was inferred to be less than 10 picocuries per liter. Each analysis represents a distribution system, a well, or a geohydrologic category within a well. The three Garber-Wellington categories were defined on the basis of well depth (or sampling depth, if available): Shallow, less than 100 feet; medium-depth, 100 to 300 feet; and deep, greater than 300 feet. pCi/L, picocuries per liter; μg/L, micrograms per liter; <, less than; > =, greater than or equal; Pct, percent]

Uranium concentration	Statistic	Geohydrologic category								Row totals
					Garber-Wellington					
		Alluvium-terrace	El Reno	Henn-essey	Shallow	Medium-depth	Deep	Chase-Admire	Vanoss	
< 10 pCi/L or < 15 μg/L	Number of analyses	90	44	35	136	53	16	67	42	483
	Expected value	82.0	37.7	40.2	120.5	54.9	33.6	74.6	39.4	
	Cell chi square	0.8	1.0	0.7	2.0	0.1	9.2	0.8	0.2	
> = 10 pCi/L or > = 15 μg/L	Number of analyses	10	2	14	11	14	25	24	6	106
	Expected value	18.0	8.3	8.8	26.5	12.1	7.4	16.4	8.6	
	Pct > = 10 pCi/L or 15 μg/L	10.0	4.3	28.6	7.5	20.9	61.0	26.4	12.5	18.0
	Cell chi square	3.6	4.8	3.0	9.0	0.3	42.1	3.5	0.8	
	Total number of analyses	100	46	49	147	67	41	91	48	589

Overall statistics: chi square 81.8, attained significance level less than 0.001, smallest expected value 7.4, degrees of freedom 7.

analyses that exceeded 10 pCi/L or 15 μg/L was significantly different among the geohydrologic categories (null hypothesis rejected, attained significance level less than 0.001). Sixty-one percent of the analyses of the deep Garber-Wellington, 28.6 percent of the Hennessey, 26.4 percent of Chase-Admire, and 20.9 percent of the medium-depth Garber-Wellington categories exceeded 10 pCi/L or 15 μg/L. Overall, 18.0 percent of the analyses exceeded 10 pCi/L or 15 μg/L. The available analyses indicate that large concentrations of uranium in ground water are common in most parts of the study unit. Large concentrations of uranium occur most commonly in the Hennessey Group; at depths greater than 100 feet in the Garber Sandstone and Wellington Formation; and in the Chase, Council Grove, and Admire Groups.

Organic compounds

Federally regulated MCL's, which apply to public water systems, have been established for 15 organic compounds listed in table 20. The State of Oklahoma water-quality criteria for organic compounds in public water-supply systems (table 20) are equivalent to the Federal MCL's, but include only seven of the compounds (Oklahoma State Department of Health, 1987). The State of Oklahoma water-quality criteria for ground water (table 20) are more stringent and apply to more organic compounds than the Federal MCL's (Oklahoma Water Resources Board, 1985). A total of 36 organic compounds are included in the ground-water regulations.

Ground water from the Central Oklahoma aquifer was analyzed for organic compounds in a sample from a private well (in which deliberate contamination was suspected) and in a study of Tinker Air Force Base. An analysis by the Oklahoma State Department of Health detected 61 μg/L diazinon in the private well. Several sites on Tinker Air Force Base, which is located in south-central Oklahoma County (fig. 2), are known to be contaminated with synthetic organic compounds (U.S. Army Corps of Engineers, 1987). The Base implemented an Installation Restoration Program in order to clean up waste sites that have the potential to contaminate the Central Oklahoma aquifer. Related to this program, the Corps of Engineers analyzed ground-water samples to determine the current state of water quality in the aquifer underlying and surrounding the Base. Samples were analyzed for an extensive suite of organic compounds, including volatile and semi-volatile compounds, PCB's, and pesticides (U.S. Army Corps of Engineers, 1987). The analyses that are discussed in this section were retrieved from EPA's STORET data base during October 1987.

In the Tinker Air Force Base study, 192 wells were sampled for the analysis of various organic compounds (fig. 36). Some sites have several wells of different depth at the same location or several wells that are plotted at the same location. Consequently, there are fewer than 192 locations plotted on the figure.

In the study, 37 synthetic organic compounds were detected in ground-water samples (table 21). Sampling and laboratory contamination are suspected to be the source of four of the compounds that were detected (U.S. Army Corps of Engineers, 1987): bis(2-ethylhexyl)phthalate, methylene chloride, acetone, and chloroform. These four compounds are not considered to be indicative of contamination of the aquifer by synthetic organic compounds and are not considered in the following discussion.

All of the compounds that were detected were volatile or semi-volatile compounds. There were no pesticides or PCB's detected in any of the wells. MCL's were exceeded for six compounds and Oklahoma water-quality criteria for ground water were exceeded for 18 compounds (table 21, excluding bis(2-ethylhexyl)phthalate, methylene chloride, acetone, and chloroform). All of the samples for which synthetic compounds were detected were samples from wells within the perimeter of the Base or at waste disposal sites. No synthetic compounds were detected at any of the 11 off-Base wells (excluding bis(2-ethylhexyl)phthalate, methylene chloride, acetone, and chloroform).

The presence of synthetic organic compounds indicates that there has been contamination of ground water at Tinker Air Force Base. It is not clear from the available data the extent of the contamination in the environs of the Base.

No data for organic compounds were available for any part of the aquifer other than a small area around Tinker Air Force Base. Therefore, at the present time (1988), it cannot be determined whether contamination by organic compounds is a common problem in the Central Oklahoma aquifer.

Table 20.—*List of organic compounds for which maximum contaminant levels (set by the U.S. Environmental Protection Agency), Oklahoma water-quality criteria for public water-supply systems, or Oklahoma water-quality criteria for ground water have been established*

[All concentrations are in micrograms per liter]

Volatile and semi-volatile organic compounds	Maximum contaminant level	Oklahoma water-quality criterion for public water-supply systems	Oklahoma water-quality criterion for ground water
Acetone			2.7
Benzene	[a]5		0.2
Bromodichloromethane			0.3
Bromoform			2.4
Bromomethane			1.7
Carbon disulfide			0.2
Carbon tetrachloride	[a]5		0.4
Chlorobenzene			0.7
Chloroform			10.0
Chloroethane			2.1
2-Chloroethylvinyl ether			0.9
Chloromethane			2.7
Dibromochloromethane			0.4
1,4-Dichlorobenzene	[a]75		
1,1-Dichloroethane			0.3
1,2-Dichloroethane	[a]5		
1,1-Dichloroethylene	[a]7		0.6
Trans-1,2-dichloroethylene			0.4
1,2-Dichloroethylene			0.5
1,2-Dichloropropene			0.3
Trans-1,3-dichloropropene			0.4
Cis-1,3-dichloropropene			0.3
Ethyl benzene			0.4
Methyl ethyl ketone			0.8
Methyl isobutyl ketone			2.915
Methyl-n-butyl ketone			4.1
Methylene chloride			10.0
Styrene			0.8
1,1,2,2-Tetrachloroethane			2.8
Tetrachloroethylene			1.6

[a] Synthetic organic chemicals, MCL's apply to community water systems and non-transient, non-community water systems (U.S. Environmental Protection Agency, 1987).

[b] Total trihalomethanes, MCL applies only to community water systems which serve a population of 10,000 or more individuals and which add an oxidizing disinfectant as part of the drinking water treatment process (U.S. Environmental Protection Agency, 1986a).

[c] Chlorinated hydrocarbons and chlorophenoxys, MCL's apply to all community water systems (U.S. Environmental Protection Agency, 1986a).

Table 20.—*List of organic compounds for which maximum contaminant levels (set by the U.S. Environmental Protection Agency), Oklahoma water-quality criteria for public water-supply systems, or Oklahoma water-quality criteria for ground water have been established* — Continued

Volatile and semi-volatile organic compounds	Maximum contaminant level	Oklahoma water-quality criterion for public water-supply systems	Oklahoma water-quality criterion for ground water
Toluene			0.5
1,1,1-Trichloroethane	[a]200		0.3
1,1,2-Trichloroethane			0.7
Trichloroethylene	[a]5		0.3
Trichlorofluoromethane			0.6
Total trihalomethanes	[b]100	100	
m- + p-Xylenes			0.8
o-Xylene			0.8
Vinyl chloride	[a]2		1.9
Pesticides			
2,4-Dichlorophenoxyacetic acid (2,4-D)	[c]100	100	
Endrin	[c]0.2	0.2	
Lindane	[c]4	4	
Methoxychlor	[c]100	100	
Toxaphene	[c]5	5	
2,4,5-Trichlorophenoxypropionic acid (Silvex)	[c]10	10	

[a] Synthetic organic chemicals, MCL's apply to community water systems and non-transient, non-community water systems (U.S. Environmental Protection Agency, 1987).

[b] Total trihalomethanes, MCL applies only to community water systems which serve a population of 10,000 or more individuals and which add an oxidizing disinfectant as part of the drinking water treatment process (U.S. Environmental Protection Agency, 1986a).

[c] Chlorinated hydrocarbons and chlorophenoxys, MCL's apply to all community water systems (U.S. Environmental Protection Agency, 1986a).

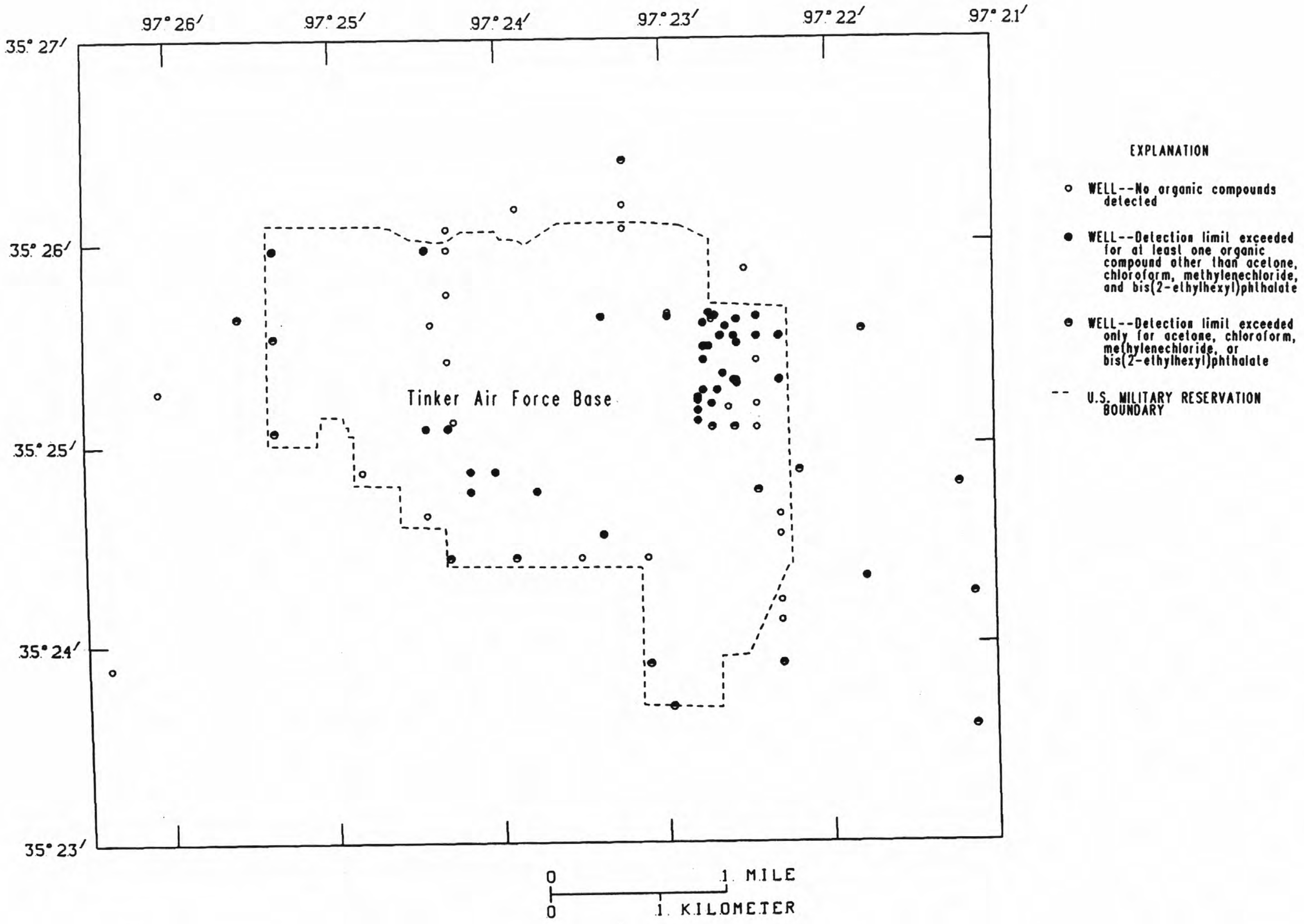

Figure 36. – Locations of wells where organic compounds were analyzed for the Tinker Air Force Base study.

Table 21.—*Organic compounds detected in the Tinker Air Force Base study, number of wells sampled, number of samples analyzed, and number of wells with analyses that exceeded the detection levels, maximum contaminant levels, and Oklahoma water-quality criteria for ground water*

[The columns showing the number of wells with analyses that exceeded the detection level, maximum contaminant level, and Oklahoma water-quality criterion for ground water include any well with any analysis that exceeded the detection level, maximum contaminant level, or Oklahoma criterion for ground water. MCL, maximum contaminant level]

Compound	Number of wells sampled	Number of samples analyzed	Number of wells with analyses that exceeded		
			Detection level	MCL	Oklahoma ground-water criterion
Acetone, total	168	190	54		[a]54
Benzene, total	189	240	35	33	35
Benzoic acid, total	113	114	1		
Bis-2-chloroethylether, total	113	114	1		
Bis-2-ethylhexylphthalate, total	112	113	25		
Carbon tetrachloride, total	168	190	2	2	2
Chlorobenzene, total	168	190	12		12
Chloroethane, total	168	190	2		2
Chloroform, total	168	190	10	[a]1	[a]3
1,2-Dichlorobenzene, total	113	114	3		
1,4-Dichlorobenzene, total	113	114	1		0
1,1-Dichloroethane, total	168	190	7		7
1,2-Dichloroethane, total	168	190	12		11
1,1-Dichloroethylene, total	168	190	7	6	7
Trans-1,2-dichloroethylene, total	168	190	54		54
1,2-Dichloropropane, total	168	190	2		
Diethylphthalate, total	112	113	4		
2,4-Dimethyl phenol, total	113	114	2		
Di-n-butyl phthalate, total	112	113	4		
Di-n-octyl phthalate, total	112	113	3		
Ethyl benzene, total	168	190	4		4
2-Hexanon, total	168	190	2		
Methylene chloride, total	168	190	20		[a]12
Methyl ethyl ketone, total	168	190	5		5
4-Methyl-2-phenolphthalein, total	168	190	1		
Oil and grease, freon-grease	111	112	8		
P-cresol, total	113	114	2		
Phenol, total	113	114	6		
Styrene, total	168	190	1		1
1,1,2,2-Tetrachloroethane, total	168	190	3		3
Tetrachloroethylene, total	168	190	17		16
Toluene, total	189	240	37		37
1,1,1-Trichloroethane, total	168	190	5	0	5
1,1,2-Trichloroethane, total	168	190	1		1
Trichloroethylene, total	168	190	68	64	68
Vinyl chloride, total	168	190	10	10	10
Xylene, total	189	240	24		24

[a] Sampling or laboratory contamination is suspected to be the source of this compound.

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