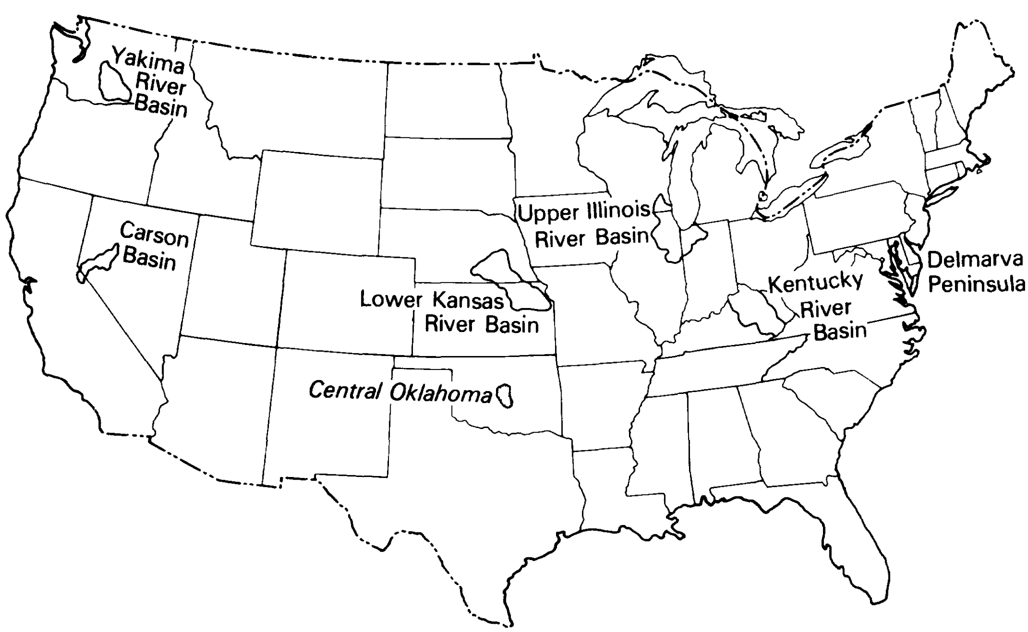
GROUND-WATER QUALITY ASSESSMENT OF THE CENTRAL OKLAHOMA AQUIFER, OKLAHOMA: PROJECT DESCRIPTION

by S.C. Christenson and D.L. Parkhurst



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ILLUSTRATIONS

CONVERSION FACTORS

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

Multiply	By	To obtain
acre-foot	1,233	cubic meter
foot	0.3048	meter
foot per mile	0.1894	meter per kilometer
gallon per minute	0.06309	liter per second
inch	25.40	millimeter
inch per year	25.40	millimeter per year
mile	1.609	kilometer
square mile	2.590	square kilometer

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

$$°F=1.8(°C) + 32$$

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 "Mean Sea Level of 1929."

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By Scott C. Christenson and David L. Parkhurst

ABSTRACT

In April 1986, the U.S. Geological Survey began a pilot program to assess the quality of the Nation's surface-water and ground-water resources. The program, known as the National Water-Quality Assessment (NAWQA) program, is designed to acquire and interpret information about a variety of water-quality issues. The Central Oklahoma aquifer project is one of three ground-water pilot projects that have been started. The NAWQA program also includes four surface-water pilot projects.

The Central Oklahoma aquifer project, as part of the pilot NAWQA program, will develop and test methods for performing assessments of ground-water quality. The objectives of the Central Oklahoma aquifer assessment are: (1) To investigate regional ground-water quality throughout the aquifer in a manner consistent with the other pilot ground-water projects, emphasizing the occurrence and distribution of potentially toxic substances in ground water, including trace elements, organic compounds, and radioactive constituents; (2) to describe relations between ground-water quality, land use, hydrogeology, and other pertinent factors; and (3) to provide a general description of the location, nature, and possible causes of selected prevalent water-quality problems within the study unit; and (4) to describe the potential for water-quality degradation of ground-water zones within the study unit.

The Central Oklahoma aquifer, which includes in descending order the Garber Sandstone and Wellington Formation, the Chase Group, the Council Grove Group, the Admire Group, and overlying alluvium and terrace deposits, underlies about 3,000 square miles of central Oklahoma and is used extensively for municipal, industrial, commercial, and domestic water supplies. The aquifer was selected for study by the 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. Known problems include concentrations of arsenic, chromium, selenium, and gross-alpha activity that exceed drinking-water standards. Suspected problems include possible contamination of the aquifer by oil-field brines and drilling fluids, pesticides, industrial chemicals, septic-tank effluent, fertilizers, and leakage from sewage systems and underground tanks used for storage of hydrocarbons.

There are four major components of the Central Oklahoma aquifer project. The first component is the collection and analysis of existing information, including chemical, hydrologic, and land-use data. The second component is the geohydrologic and geochemical investigations of the aquifer flow system. The third component is the sampling for a wide variety of inorganic, organic, and radioactive constituents as part of a regional survey that will produce a consistent set of data among all ground-water pilot projects. These data can be used to: (1) Define regional ground-water quality within the Central Oklahoma aquifer, and (2) compare water quality in the Central Oklahoma aquifer to the water quality in the other ground-water study units of the NAWQA program. The fourth component is topical studies that will address, in more detail, some of the major water-quality issues pertaining to the aquifer.

INTRODUCTION

Public awareness of the importance of water quality has increased greatly during the last 20 years, and Federal, State, and local legislative bodies have responded by enacting omnibus pollution-control legislation. This commitment to pollution abatement has been supplemented by administrative regulations and the efforts of industry. As a result, the quality of many of the Nation's rivers and streams has improved despite increases in industrial activity and population (Association of State and Interstate Water Pollution Control Administrators, 1984). Most of this improvement, however, has been the result of control of point-source pollution. The decrease of ground-water and surface-water contamination from nonpoint-source pollution, acid precipitation, and the disposal of hazardous waste will be more difficult to achieve. The evaluation of the effectiveness of pollution controls for these sources requires increased knowledge of the nature and extent of contaminants in surface-water and ground-water resources.

The National Water-Quality Assessment Program

To address these needs, the U.S. Geological Survey has begun a pilot program for data acquisition, interpretation, and assessment of the quality of the Nation's surface-water and ground-water resources. The program is known as the National Water-Quality Assessment (NAWQA) program. The long-term goals of the NAWQA program are: (1) To provide a nationally-consistent description of the current status of water quality for a major part of the Nation's water resources; (2) where possible, to define trends in water quality that have occurred during recent decades, and provide a data base for evaluating future trends in water quality; and (3) to identify and describe current water quality in relation to natural factors and human activities.

A key element of the NAWQA program design is the organization of the program into study units on the basis of known hydrologic systems. For ground water, the study units are large parts of aquifers or aquifer systems. For surface water, the study units are large drainage basins or parts of watersheds. The study units of the NAWQA program are large, involving thousands of square miles for ground-water projects and hundreds of miles of river reaches for surface-water projects.

Because the NAWQA program is national in scope, there will be common approaches, methods, and reporting developed 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, the projects will consider the unique geohydrologic and geochemical conditions in the study unit.

At present (1987), the NAWQA program consists of seven pilot projects that will develop and test approaches for water-quality assessments in preparation for a proposed national program. The pilot program also provides an opportunity to evaluate the potential benefits and costs of a fully implemented program. Three pilot ground-water projects have been started: The Central Oklahoma aquifer in Oklahoma, the Carson basin in western Nevada and eastern California, and the Delmarva Peninsula in Delaware, Maryland, and Virginia. Four surface-water pilot projects also have been started: 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 Wisconsin, Illinois, and Indiana.

The Central Oklahoma Aquifer Pilot Project

The Central Oklahoma aquifer was selected for study by the 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: concentrations of arsenic, chromium, selenium, and gross-alpha activity in excess of public drinking-water standards; 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 ground-water quality have not been studied in detail.

The objectives of the Central Oklahoma aquifer project are: (1) To investigate regional ground-water quality throughout the aquifer in a manner consistent with the other pilot ground-water projects, emphasizing the occurrence and distribution of potentially toxic substances in ground water, including trace elements, organic compounds, and radioactive constituents; (2) to describe relations of ground-water quality to land use, hydrogeology, and other pertinent factors; (3) to provide a general description of the location, nature, and causes of selected prevalent water-quality problems within the study unit; and (4) to describe potential for water-quality degradation of ground-water zones within the study unit.

The Central Oklahoma aquifer underlies about 3,000 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,

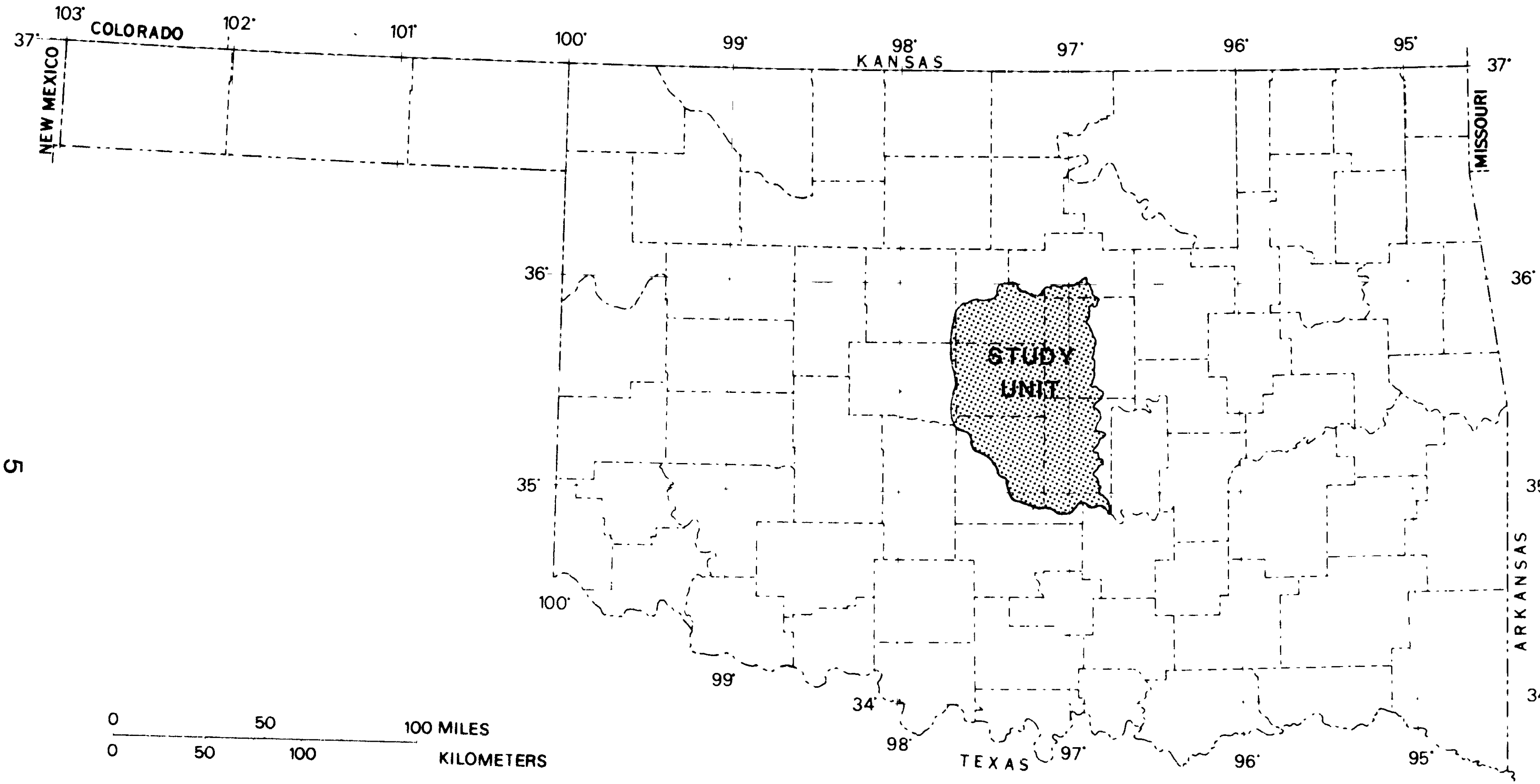

Figure 1.--Location of study unit.

which underlie the Garber Sandstone and Wellington Formation, and in alluvium and terrace deposits, which are associated with the streams in the study unit.

Purpose and Scope

This report is the first publication on the Central Oklahoma aquifer project. The purpose and scope of the report are to describe: (1) The goals, concepts, and general approach of the NAWQA program, particularly with regard to the Central Oklahoma aquifer project; (2) the Central Oklahoma aquifer study unit and its associated ground-water quality issues; (3) the need for a water-quality assessment of the Central Oklahoma aquifer; and (4) the preliminary plan of study.

DESCRIPTION OF THE CENTRAL OKLAHOMA AQUIFER

Physical Setting

The Central Oklahoma aquifer underlies all or parts of Canadian, Cleveland, Kingfisher, Logan, Lincoln, McClain, Oklahoma, Payne, Pottawatomie, and Seminole 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 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 elevations are about 1400 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 where it leaves the study unit.

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 30 inches, most of which falls from April through October.

Oklahoma City, the largest city in Oklahoma, is located in the west-central part of the study unit. Suburban expansion of Oklahoma City has merged with numerous outlying communities to form the Oklahoma City metropolitan area. In 1975, Oklahoma City was the second largest city in the United States in terms of land area (635 square miles) and in 1984 had a population of 443,000, which made it the 27th largest city in the United States in terms of population. The population of the Oklahoma City standard metropolitan statistical area (which includes all of Canadian, Cleveland, McClain, Oklahoma, and Pottawatomie Counties) was 963,000 in 1984 (U.S. Department of Commerce, 1986).

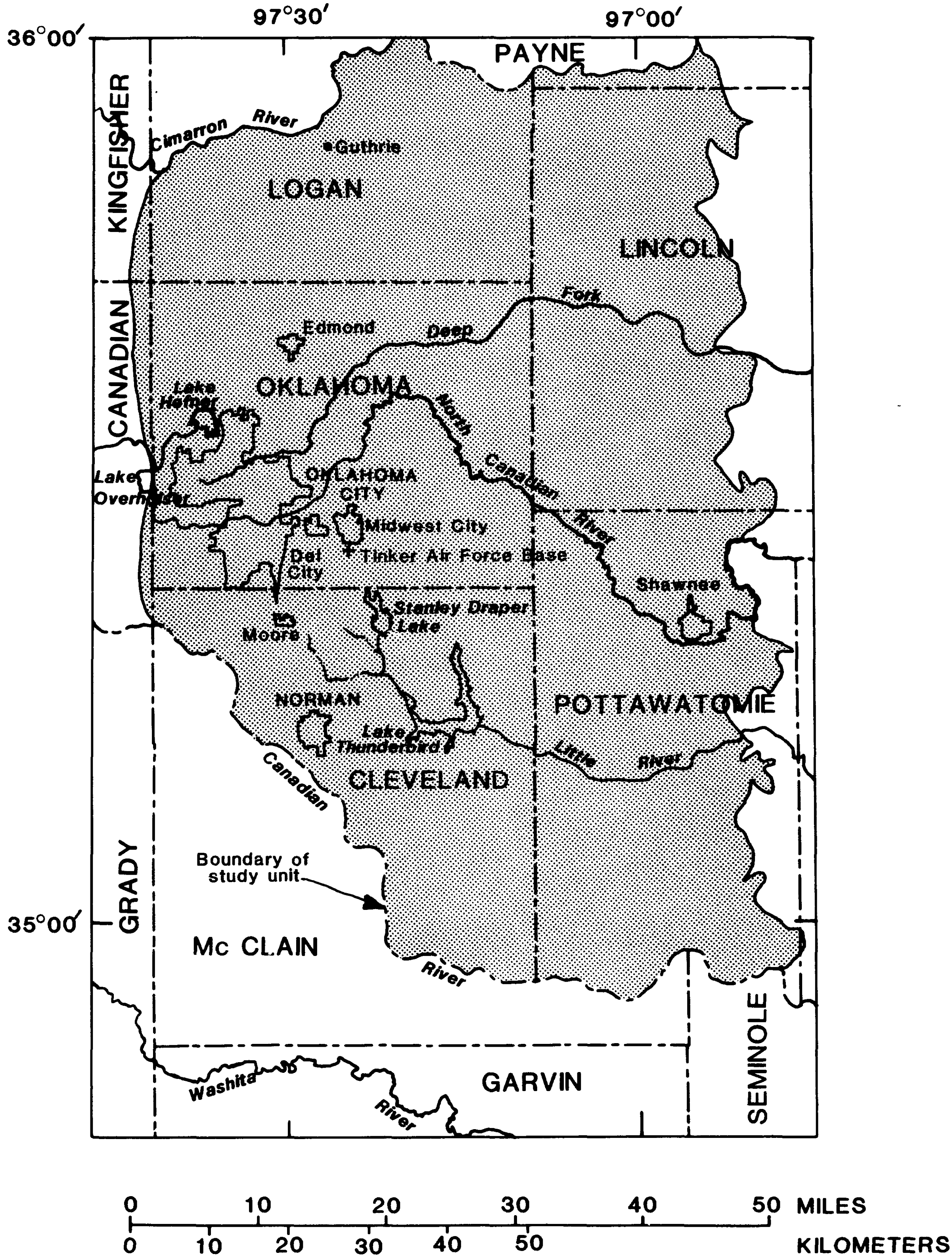

Figure 2.--Geographic features of study unit

Water Use

Water use from the Central Oklahoma aquifer is predominantly for public supplies. 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. Reported water use from the Central Oklahoma aquifer during 1985 was about 40 thousand acre-feet of water. During 1985, the second largest use of water from the Central Oklahoma aquifer was industrial use, accounting for about 15 percent of the total reported water use. Commercial water use and irrigation each accounted for about 5 percent of the total water use during 1985, and 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 10 thousand acre-feet during 1970 to 30 thousand acre-feet during 1985.

Geohydrology

The Central Oklahoma aquifer consists of those geologic formations that yield substantial volumes of water to wells from the extensive, continuous flow system centered around Oklahoma, Cleveland, and Logan Counties in central Oklahoma. Most of the circulation in this flow system is in the Garber Sandstone and Wellington Formation, but substantial circulation also occurs in the Chase, Council Grove, and Admire Groups and the alluvium and terrace deposits along major streams in the study unit (fig. 3). Because the circulation of ground water mainly is 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 has problems associated with it: (1) The Garber Sandstone and Wellington Formation are not everywhere an aquifer, because of a decrease in transmissivity; and (2) the water in the Chase, Council Grove, Admire Groups, and the overlying alluvium and terrace deposits is part of the same flow system. Therefore, for purposes of the Central Oklahoma aquifer project, the term "Central Oklahoma aquifer" is used.

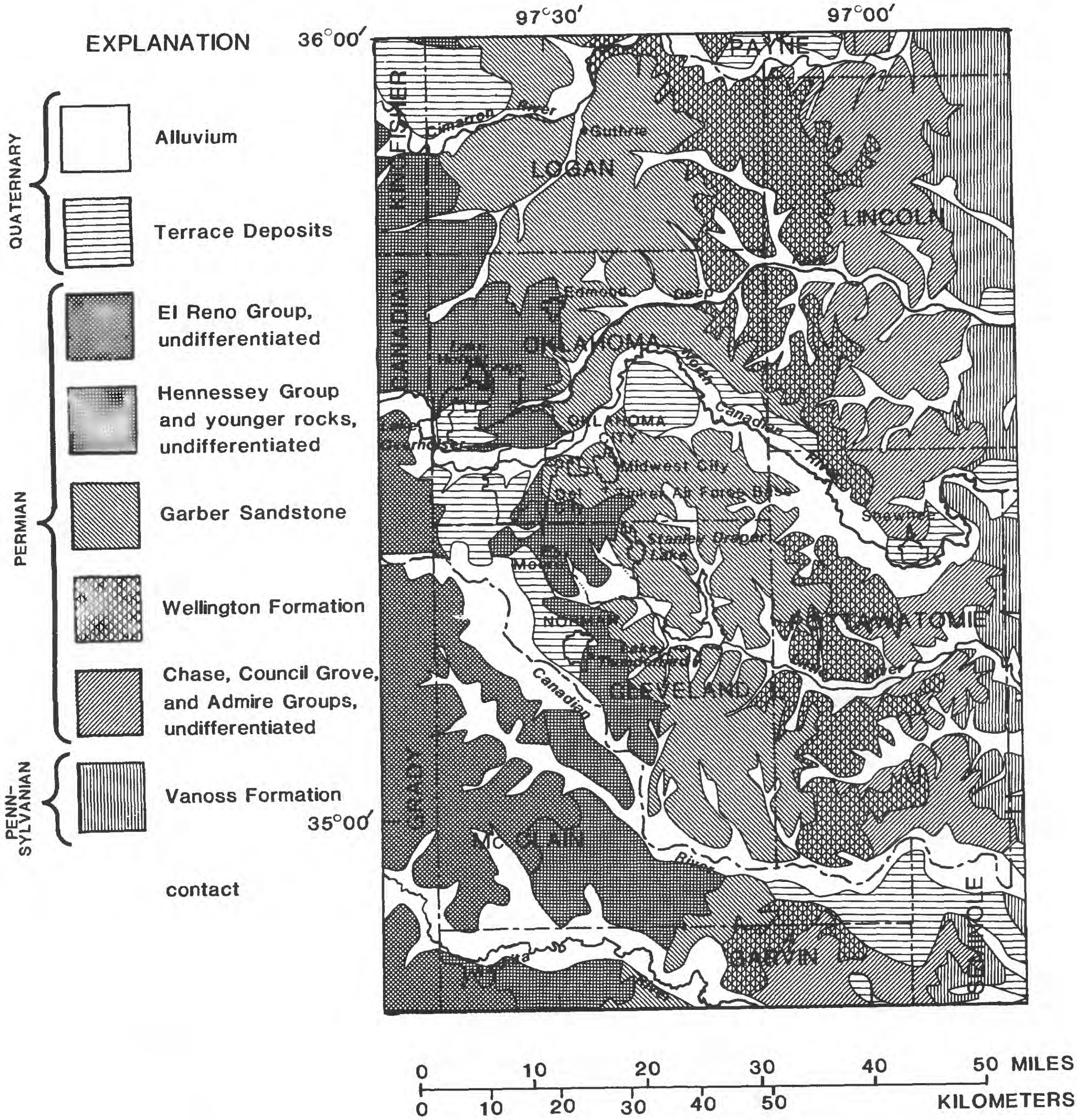

Figure 3.--Geologic map of central Oklahoma

The stratigraphic relation of the geologic units within the study unit is shown below:

Erathem	System	Series	Geologic unit
Cenozoic	Quaternary	Holocene	Alluvium
		Pleistocene	Terrace deposits
Paleozoic	Permian	Lower	El Reno Group
			Hennessey Group
			Garber Sandstone and Wellington Formation, undivided
			Chase, Council Grove, and Admire Groups, undivided
	Pennsylvanian	Upper	Vanoss Formation

The Cimarron River is considered to be the northern boundary of the study unit because: (1) The aquifer is much 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) the river is a significant hydrologic boundary to ground-water movement, allowing little ground water to flow into or out of the study unit. For similar reasons, the Canadian River is considered to be the southern boundary of the study unit. Some data may be collected from the areas beyond these two rivers during the investigation. The western boundary of the study unit is defined to be where the permeability of the aquifer decreases and substantially decreases circulation of water within the aquifer. Because this decrease in permeability has not been studied in sufficient detail to place the boundary on a map, the limit of ground water containing less than 1,000 milligrams per liter dissolved solids is used to mark this decrease in permeability. It is believed that as the circulation of ground water decreases the dissolved-solids concentration increases. The western boundary of the aquifer is located approximately at the Oklahoma-Canadian County line. The eastern boundary of the study unit is the eastern limit of the outcrop of the Admire Group.

The lower boundary of the Central Oklahoma aquifer is considered to be where a decrease in permeability with depth decreases the circulation of the ground-water flow system. The base of active ground-water circulation is inferred to be approximately where the concentration of dissolved solids in ground water is equal to 1,000 milligrams per liter. Hart (1966) refers to this increase in dissolved-solids concentration as the "base of freshwater." The boundary between the freshwater and the underlying saltwater is gradational. The base of the freshwater is deepest in southeastern Oklahoma County in the vicinity of Midwest City. At that location, the depth to the base of freshwater is about 1000 feet. To the north, south, and east, the base of the freshwater slopes upward gradually, until the freshwater zone is about 100 feet thick at the boundaries of the study unit. To the west, the base of freshwater rises gradually to approximately the Oklahoma-Canadian County line. At that line, the base of the freshwater rises abruptly (Hart, 1966). This line marks the western edge of usable water in the Central Oklahoma aquifer.

Alluvium

Alluvium associated with the streams is the youngest geologic deposit in the study unit. Sediment is constantly being eroded, transported, and deposited by streams. Alluvium is present along most of the perennial streams in the study unit, but the most extensive deposits are present along the North Canadian and Canadian Rivers. The alluvium is as much as 3 miles wide along these rivers.

The alluvium consists of lenticular beds of clay, silt, sand, and gravel. The thickness of the alluvium ranges from 0 to about 100 feet. Where the deposits are thickest and contain beds of gravel, wells completed in the alluvium may produce as much as 700 gallons per minute (Bingham and Moore, 1975).

Terrace Deposits

The terrace deposits associated with streams in the study unit are Pleistocene alluvial deposits. Erosion has deepened the stream valleys, leaving the terrace deposits above the present flood plains. Terrace deposits along the Cimarron, North Canadian, and Canadian Rivers may be as much as 8 miles wide.

The terrace deposits consist of lenticular beds of clay, silt, sand, and gravel. The thickness of the terrace deposits in the study unit ranges from 0 to 100 feet and wells completed in the most productive deposits may yield up to 300 gallons per minute (Bingham and Moore, 1975).

El Reno Group

Rocks of the El Reno Group of Permian age crop out in the western part of the study area. Because they are separated from the Central Oklahoma aquifer by low permeability rocks in the Hennessey Group, rocks in the El Reno Group are not considered in this report.

Hennessey Group

The Hennessey Group (undifferentiated in this report) of Permian age consists of reddish-brown shale and siltstone with a few thin beds of very fine-grained sandstone. Because the Hennessey is composed mainly of shale and siltstone, it has little transmissivity and, thus, is not considered to be part of the Central Oklahoma aquifer. The Hennessey Group overlies the aquifer in the western one-third of the study unit, but has been removed by erosion in the eastern two-thirds. Where the Hennessey Grounp overlies the Central Oklahoma aquifer, it forms a confining unit. Even though it has little transmissivity, a few small-yield wells, such as domestic and stock wells, are completed in the Hennessey Group.

Garber Sandstone and Wellington Formation

In central Oklahoma, it is difficult to distinguish between the Garber Sandstone and the Wellington Formation of Permian age. Although it is possible to map the contact between the two geologic units on the land surface (Bingham and Moore, 1975), it virtually is impossible to detect the contact in the subsurface (Carr and Marcher, 1977). Therefore, the two geologic units are not differentiated in this report.

The Garber and Wellington sequence generally is thought to have been deposited in a deltaic environment (Carr and Marcher, 1977). It consists 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 thickness of the Garber Sandstone and Wellington Formation is approximately 800 to 1000 feet. The geologic units dip to the west into the Anadarko Basin in western Oklahoma at about 50 feet per mile.

Shallow wells may be completed in either the Garber Sandstone or Wellington Formation, but wells with the largest yields from the Central Oklahoma aquifer are completed in both geologic units. A few wells completed in both units will yield as much as 600 gallons per minute, but because of the fine-grained nature of the sandstone in both geologic units, maximum well yields generally range from 100 to 300 gallons per minute.

Chase, Council Grove, and Admire Groups

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, these groups appear to be virtually identical to the overlying Garber Sandstone and Wellington Formation. The combined thickness of these groups ranges from 300 to 600 feet.

In the eastern 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 completed only in the Chase, Council Grove, and Admire Groups generally yield 10 to 50 gallons per minute, with a few wells yielding as much as 100 gallons per minute.

Bingham and Moore (1975) referred to this stratigraphic sequence of 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, Lindberg (1987), refers to Bingham and Moore's Oscar Group as the Chase, Council Grove, and Admire Groups. This terminology follows the usage of the U.S. Geological Survery and is used in this report.

Vanoss Formation

The Vanoss Formation of Pennsylvanian age underlies the Chase, Council Grove, and Admire Groups. The Vanoss 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 not considered to be part of the Central Oklahoma aquifer.

Water Chemistry

In terms of major-ion chemistry, water within the Central Oklahoma aquifer generally is suitable for public water supplies. The concentrations of chloride, sulfate, and dissolved solids (Carr and Marcher, 1977; Bingham and Moore, 1975) generally are less than the recommended concentrations of the U.S. Environmental Protection Agency's (1982b) secondary standards. Water in the Hennessey Group generally has large concentrations of sulfate and dissolved solids that make the water unsuitable for most uses (Carr and Marcher, 1977; Bingham and Moore, 1975; and Gates and others, 1983).

The variation in ground-water composition in the study unit is the result of lithologic variations and flow patterns. The least-mineralized water is a calcium magnesium bicarbonate water with relatively small concentrations of dissolved solids. Calcium, magnesium, or sodium sulfate water is present mostly in the western part of the study unit where the Hennessey Group crops out. Sodium bicarbonate water is common in shallow ground water and sodium chloride water is present below the freshwater throughout the study unit. Circulation of ground water through the aquifers of the study unit causes water of differing composition to mix, producing water of varying composition and a complex evolutionary history.

NEED FOR A GROUND-WATER QUALITY ASSESSMENT

The Central Oklahoma aquifer is a major source of water for public, industrial, commercial, irrigation, and domestic supplies, and, thus, the quality of the resource is significant to the economy and welfare of central Oklahoma. Rapid urban and industrial development in the area have caused the potential for ground-water contamination and many naturally occurring contaminants exist within the study unit. Little scientific study has been devoted to the many water-quality problems that are known or are expected to exist within the aquifer. The available chemical and hydrogeologic data need to be used to address the nature and extent of water-quality problems and new data need to be collected where information is lacking.

Water-Quality Problems

Water in the Hennessey Group and saltwater at depth are potential threats to freshwater supplies. Wells completed in the confined part of the Central Oklahoma aquifer and screened near the top of the Garber Sandstone may yield water with large sulfate and dissolved-solids concentrations derived from the Hennessey Group (Gates and others, 1983). Likewise, wells throughout the study unit that are screened within the zone of transition from freshwater to saltwater may yield water with large chloride and dissolved-solids concentrations.

Chromium and selenium occur naturally in geologic formations within the study unit. Chemical analyses from the Oklahoma State Department of Health of about 450 municipal water supplies have indicated the presence of one or both of these trace elements in water from about 80 municipal wells. Naturally occurring radioactive constituents, including radium, thorium, uranium, and their associated daughter products, cause excessive gross-alpha radioactivity at some places within the study unit. At least two municipal wells have been closed because gross-alpha radioactivity exceeded the U.S. Environmental Protection Agency's (1982a) primary drinking-water standards. Wallace (1983) noted at least 18 wells throughout the study unit that yielded water with relatively large concentrations of uranium.

Extensive oil exploration and production have resulted in the drilling of about 14,000 wells in the study unit. A number of known and suspected problems are related to oil-field activity. Many of the wells date back to the late 1920's, when large oil fields were first developed in Oklahoma City. Improperly plugged or leaking casings from production and exploration wells could result in the introduction of hydrocarbons and oil-field brine into the freshwater aquifer. Similarly, saltwater contamination could occur if saltwater disposal wells leak brine into the freshwater aquifer. A recent report (Whittemore, 1986) documents an occurrence of contamination of the Central Oklahoma aquifer by oil-field brines, and other instances of contamination may have occurred. Contamination of shallow ground water could occur from improper handling of brines and hydrocarbons at the well heads and storage tanks.

Many residential areas within the study unit are not serviced by public sewer systems, but have private septic systems. These septic systems could cause contamination of shallow ground water with nitrate and bacteria. Some chemical analyses indicate large concentrations of nitrate in local areas. Fertilizer use in the urban, suburban, and agricultural areas also could contribute to nitrate contamination.

Other suspected water-quality problems, for which there is little information, are contamination of ground water by pesticides and industrial organic compounds. Pesticides are used widely in suburban and urban areas in addition to agricultural areas. Few, if any, analyses exist to determine whether widespread use of these chemicals has affected the ground-water quality adversely. Industrial facilities within the study unit have changed during the years. At one time, there were several oil refineries near Oklahoma City, but none exist today (1987). Large military facilities were established in the Oklahoma City area in the 1940's and Tinker Air Force Base currently (1987) is a major military base. Tinker Air Force Base is now the site of an extensive study and clean-up project related to trichloroethylene (TCE) and other organic compounds in ground water. Apart from this locally contaminated area, little is known about possible historical and current (1987) contamination of ground water by industrial activity.

Finally, some water-quality problems may exist that are related to urban and suburban development. These areas have numerous underground tanks used for storing hydrocarbons, which could potentially leak and cause ground-water contamination. Leaking sewage systems, sanitary landfills, pesticides, or recharge by runoff from urban areas are other potential causes of water-quality degradation in the urban and suburban environment.

Status of Water-Quality Knowledge

During the past 50 years, considerable data pertaining to the water quality of the Central Oklahoma aquifer has been accumulated. Since 1940, at least 3,000 ground-water samples collected in the study unit have been analyzed. Several local, State, and Federal agencies have collected and are continuing to collect chemical data: The Association of Central Oklahoma Governments, the Oklahoma State Department of Health, the Oklahoma Water Resources Board, the Oklahoma Geological Survey, and the U.S. Geological Survey. As part of the National Uranium Resource Evaluation (NURE) program of the U.S. Department of Energy, about 500 ground-water samples from the study unit were collected and analyzed (Union Carbide Corp., 1978).

Until the 1970's, most chemical analyses included the major ions plus hardness, nitrate, and fluoride. Unfortunately, these data are not distributed so that the major-ion chemistry of the entire resource can be evaluated. Only a few scattered chemical analyses are available for substantial parts of the study unit. A particular problem is that the vertical variation in water composition is not well defined. The quality of shallow ground water is better known than is the quality of deeper ground water because of the NURE data, which tend to be analyses from shallow wells.

Beginning in the 1970's, analyses commonly have included the trace elements barium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver, and zinc. The distribution of trace elements is defined by fewer samples than the major-ion chemistry samples, and the trace-element analyses are restricted mostly to municipal water-supply wells for the deeper ground water and NURE data for the shallow ground water. The NURE water samples were analyzed for most major ions, a large suite of trace elements, and uranium.

Radioactivity analyses are less common than trace-element analyses, and organic-compound analyses are available for only a few wells. Water samples collected for studies at Tinker Air Force Base have been analyzed for several organic compounds, but these studies involve only a small area.

In addition, there are significant problems with the quality of the available data. Many of the available analyses are of little use because they are incomplete (lacking one or more major ions and trace metals), the sampling locations are unknown, the sampling methods are suspect, the analytical methods were inappropriate, or because of other problems.

Changes in land use and chemical use within the study unit are occurring rapidly, requiring reassessment of hydrologic and chemical data. The older chemical data are not adequate to assess the effect of major suburban expansion during the past 30 years. Many synthetic organic compounds that may threaten the aquifer today did not exist when water-quality sampling was first begun and for many of these compounds little information exists. Concentration data are needed for pesticides, pesticide derivatives, and other organic compounds.

To date, no comprehensive analysis of the water quality in the Central Oklahoma aquifer has been made. Although much information exists for the geology, hydrology, and chemistry of the aquifer, and for land use in the study unit, this information has not been assembled into a unified interpretive report. In addition to the existing information, new information needs to be obtained to assess the water quality of the Central Oklahoma aquifer. This new information will be used along with existing data to evaluate not only the water quality of the aquifer, but also the physical, chemical, and human-induced causes of the water quality.

STUDY APPROACH

The NAWQA program is a new undertaking of the U.S. Geological Survey. The organization of the effort is complex because of the large areas involved, the expensive costs of field work and chemical analyses, and the substantial degree of spatial variability of ground-water quality. The program needs to address the problems on a national scale, yet be responsive to the particular ground-water quality problems of specific aquifers.

The large size of the ground-water study units limits the scale of water-quality problems that can be investigated. Although some individual contaminant plumes and localized contamination problems may be identified during the project, the project is not designed to locate and describe individual cases of point-source contamination. The Central Oklahoma aquifer project will emphasize regional ground-water quality problems within the aquifer, such as might occur from nonpoint sources of pollution or from numerous point sources in a relatively small area.

In order to efficiently use the available financial resources, the project will use existing data whenever possible. Data available in published reports for factors such as land use, soil types, pesticide application, and cultivated acreage will be used. The available water-quality data, however, will not be sufficient to conduct a water-quality assessment without additional sampling and chemical analyses.

Two distinct, but complementary, approaches will be undertaken for the additional sampling. The first approach is a regional survey of a variety of water-quality constituents. This survey will provide a representative set of ground-water samples from the aquifer. The regional surveys of all ground-water projects will be done in a consistent manner to provide comparability of results among the study units. The survey data will be supplemented by the second approach, which will consist of topical studies that address water-quality problems of particular concern within each study unit.

In addition to the regional survey and topical studies, the Central Oklahoma aquifer study will include investigations of the geohydrology and geochemistry of the aquifer. The fate and movement of chemical constituents in ground water depend both on the ground-water flow system and on the geochemical environment of the aquifer. One of the objectives of the NAWQA program is to determine the relation between water quality and hydrologic characteristics of the aquifer. The present (1987) state of knowledge of the geohydrology and geochemistry of the aquifer is not sufficient to meet this objective. During the early stages of the project, geohydrologic and geochemical investigations will be conducted to develop this knowledge.

There are, thus, four major components of the Central Oklahoma aquifer project. The first component is the collection and analysis of existing information, including geologic, hydrologic, chemical, and land-use data. The second component is the geohydrologic and geochemical investigations of the aquifer flow system. The third component is the sampling for a variety of inorganic, organic, and radioactive constituents as part of a regional survey that will produce a consistent set of data among all ground-water pilot projects. The fourth component is topical studies that will address, in more detail, some of the prominent water-quality problems in the aquifer.

Compilation and Analysis of Existing Data

The first component of the project will be to compile and analyze existing data on the Central Oklahoma aquifer. Because of the importance of the aquifer for water supplies in central Oklahoma, considerable data already exist. However, it will require a large effort to assemble all the data needed for a comprehensive water-quality assessment and to compile it into a usable format.

Data of five general types will be needed to perform a water-quality assessment of the Central Oklahoma aquifer: (1) Chemical analyses of ground water; (2) geologic and hydrologic data; (3) well data; (4) water-use data; and (5) land-use data.

The first and most obvious type of data that will be used to perform the water-quality assessment is chemical analyses of ground-water samples. Any analyses of major ions, trace elements, radioactive constituents, or organic compounds will be useful to the study. Several Federal, State, and local agencies maintain computerized data bases of chemical analyses. Additional sources of data are the State universities and previous investigations (Mogg and others, 1960; Hart, 1966; Wood and Burton, 1968; Hart, 1974; Bingham and Moore, 1975; Carr and Havens, 1976; Carr and Marcher, 1977; Wickersham, 1979; Union Carbide Corp., 1978; Gates and others, 1983; and McBride, 1985).

Geologic and hydrologic data are needed to develop a comprehensive understanding of the aquifer flow system that will be required to evaluate water-quality data and trends. Geologic information on the extent of aquifers and confining layers will be derived from geophysical logs of water and oil wells, drillers' logs, and previous geologic investigations (Wood and Burton, 1968; Hart, 1974; Bingham and Moore, 1975; Carr and Marcher, 1977; Wickersham, 1979; and Gates and others, 1983). The hydrologic data include water levels and the hydraulic characteristics of the aquifer material, such as hydraulic conductivity, transmissivity, and specific storage.

Knowledge of well location, depth, producing zones, and construction specifications is extremely important in devising methods for collecting representative water samples from the aquifer. The Ground-Water Site Inventory part of the U.S. Geological Survey's National Water Information System (NWIS) will be the primary source of well information. The Oklahoma Water Resources Board, the Oklahoma State Department of Health, and the Association of Central Oklahoma Governments also maintain files of well data.

Because many communities withdraw water from the aquifer, the flow system has been altered substantially by pumpage. The main resource for water-use information is the Oklahoma Water-Use Data System, which is a computerized data base maintained by the Oklahoma Water Resources Board.

The water-quality data that are collected during the NAWQA program will be compared to land-use data to determine if any significant relations exist between water quality and land use. Land-use data are available from the U.S. Geological Survey and other Federal and local agencies.

Data Management

One of the major tasks of the NAWQA project will be to store, retrieve, manipulate, and analyze numerous chemical and geographic data. The NWIS will be the primary repository of well information and chemical data. Land-use and other geographic information will be stored and manipulated by a geographic information system (GIS).

The NWIS provides the capability of storing and accessing numerous chemical and well data. The advantages of using the NWIS is that it is an established system, is easily accessible, and is merged periodically with the U.S. Environmental Protection Agency's Storage and Retrieval (STORET) water-quality file. Additional computer programs will be used to perform statistical analyses, contouring, ground-water flow modeling, and many other interpretive functions.

A GIS will be used for developing maps and studying the geographical relations among the various types of data. This system incorporates point, line, and polygon data and is extremely useful in subdividing, displaying, and mapping data. This technology will be used in the Central Oklahoma aquifer project to test hypotheses about the spatial distribution of water-quality data and to produce graphical presentations of the data.

Geohydrologic and Geochemical Investigations

Assessment of water quality in the Central Oklahoma aquifer will be enhanced greatly by knowledge of the flow system and geochemical environments of the aquifer. The fates of chemical contaminants in ground water depend both on the ground-water flow system and on the geochemical environment of the aquifer. Knowledge of the hydrology and geochemistry of the aquifer will aid in determining contaminant sources and the vulnerability of ground water to various types of contaminants. During the early stages of the project, geohydrologic and geochemical investigations will be conducted to develop this knowledge.

The geohydrologic study will include compilation and analysis of data on the geology and hydrology of the study unit. Stratigraphic information will be used to produce structure-contour and thickness maps. Data will be compiled on the porosity, lithology, mineralogy, and depositional environments of rocks underlying the study unit. Hydrologic information to be collected will include hydraulic head, well yields, well depths, aquifer transmissivity, and aquifer storage. Hydraulic-head data are particularly important, as they can be used to determine the direction of water flow in the aquifer. The hydraulic-head data will include both available data and data collected during the study. Mapping of the hydraulic-head distribution will necessitate field inventories and water-level measurements. As part of the study, it will be necessary to determine the extent and significance of producing zones, to map the confining units, to produce a base-of-freshwater map, and to define the distribution of aquifer permeability.

Because the Central Oklahoma aquifer has been used extensively for public, industrial, commercial, and irrigation supplies for many years, the natural ground-water flow system has been altered considerably. Data for current (1987) and historic use of water from the Central Oklahoma aquifer will have to be obtained.

Characterization of streamflow and surface-water quality in the study unit will provide information for the ground-water flow system. In particular, there are several small drainage basins in the eastern one-half of the study unit that have drainage areas that are entirely within the boundaries of the Central Oklahoma aquifer. Data on base flow and stream-recession rates for these streams could provide information on recharge and discharge rates for the aquifer.

The best tool to verify a conceptual model of the geohydrology of an aquifer system is a numerical ground-water flow model. As information on the geohydrologic framework is assembled and a conceptual model is formulated, a ground-water flow model may be constructed. The flow model could be used to guide water sampling and to assess the pathways of contaminant migration.

The geochemistry of the major elements explains the natural chemical reactions that are occurring within the aquifer. These chemical reactions will help to determine where naturally occurring contaminants will be found and, in general, how contaminants will react. Knowledge of the geochemistry of the aquifer will help to guide the extensive water-quality sampling of the Central Oklahoma aquifer.

The initial effort in the geochemical study will be to produce maps of the major-element concentrations and maps of water types in the study unit. Some water-quality problems will be evident in these plots, large sulfate and chloride concentrations, for example. Statistical summaries of the major-element data will be made, checking correlations with depth, geologic formation, land use, and geographic area. The major-element data will be compared to the initial results from measurements of water levels and from ground-water modeling to corroborate hypothesized recharge areas, flow directions, and discharge areas.

About 40 sites will be sampled as part of the geochemical study. From 4 to 8 samples will be collected along each of 4 to 6 projected ground-water flow paths. In addition to major elements, these samples will be analyzed for radioactive isotopes, fluorocarbons, stable isotopes, trace elements, and dissolved gases.

Radioactive isotopes and fluorocarbons will be used to estimate the age of ground water, potentially limiting the parts of the study unit that need to be sampled for synthetic contaminants. Stable carbon isotopes provide important auxiliary information used in estimating the age of ground water. Stable isotopes of sulfur, carbon, hydrogen, and oxygen provide information on a large number of ground-water processes including: The sources of water; the location of ground-water mixing zones; the sources of carbon and sulfur in ground water; the importance of evaporation in the soil zone; the effect of plants in the ground-water carbon system; and the degree of microbial sulfate reduction. The distribution of trace elements and dissolved gases will help determine the redox environment, which is important in the chemistry of uranium and other toxic trace elements.

The goal of the geochemical study is to understand the chemical reactions involved in the evolution of water throughout the Central Oklahoma aquifer. Particular emphasis will be placed on dating of ground water, flow-path evaluation, and chemical properties that can be used to evaluate the likelihood of natural contamination.

Regional Survey

The regional survey of the Central Oklahoma aquifer project is designed to obtain nationally consistent data for the NAWQA program. The survey consists of collecting samples from a statistically designed network and analyzing the samples for a variety of chemical constituents. The survey is needed because the existing chemical data usually have been collected to study specific problem areas, not the overall ground-water resource. In addition, there are few data for many potentially toxic constituents, particularly trace elements and synthetic organic compounds. The survey is designed to examine regional water-quality characteristics of the Central Oklahoma aquifer and to analyze ground-water samples for a comprehensive suite of chemical constituents.

The suite of chemical constituents and analytical methods selected for the Central Oklahoma pilot project will be the same as those for all the pilot projects of the NAWQA ground-water program. The suite of constituents will focus on substances that have potential human-health effects. The list of substances will include trace elements, several radionuclides, and numerous pesticides and other organic compounds.

As part of the analytical procedures for the survey, one or more analytical techniques that screen a sample for the presence or absence of individual organic compounds or classes of organic compounds will be tested on an experimental basis. If the screening techniques are successful in identifying the presence of organic compounds, the cost of future water-quality assessments could be greatly decreased.

Sampling locations for the regional survey will be selected by using a statistical design with sampling points chosen throughout the central Oklahoma aquifer. Sampling points will be selected based on a random sampling strategy. In order to achieve a comprehensive geographical distribution of sampling points, a grid will be used, followed by random selection of locations within each grid. All NAWQA ground-water pilot projects will use similar statistical designs to ensure comparability of results among the projects.

For each well selected in the regional survey, information on a large number of hydrogeologic and land-use factors will be collected. This information will be used in conjunction with the chemical analyses to explore statistical relations between the ground-water quality and hydrogeologic and land-use factors.

The regional survey is designed to develop a consistent set of water-quality data that are suitable for a national water-quality assessment. The data also will be used to: (1) Determine the regional distribution of a variety of constituents in the Central Oklahoma aquifer; (2) identify chemical constituents causing prevalent water-quality problems in the aquifer and to locate problem areas; and (3) make statistical comparisons between chemical constituents and geohydrologic, geochemical, land-use, and other factors.

Topical Studies

The regional survey only will provide a limited description of water-quality problems within the Central Oklahoma aquifer. Topical studies are needed to provide characterizations of individual water-quality problems. Because of limited financial resources, only a few topical studies can be undertaken, and these need to concentrate on a smaller set of selected constituents.

The topical studies will include only water-quality problems that are suspected to be widespread within the study unit. Each topical study will be limited to specific constituents and may be restricted to a part of the study unit. The narrower focus of the topical studies will allow a more intensive sampling network and a more thorough investigation of the selected constituents than could be achieved through the regional survey.

The objectives of the topical studies are to: (1) Determine the distribution of selected constituents within the study unit or within a part of the study unit; (2) evaluate the spatial extent of prevalent water-quality problems caused by the selected constituents; and (3) investigate the natural or anthropogenic sources, the causes of mobilization, and the movement of these constituents.

A number of water-quality problems are candidates for study in the Central Oklahoma aquifer. At present (1987), two problems tentatively have been selected for topical studies: (1) A study of the natural occurrence of arsenic, chromium, selenium, uranium, radium, radon, and gross-alpha; and (2) a study of the effects of urban and suburban development on ground-water quality (this study will focus on synthetic organic compounds within the metropolitan Oklahoma City area)

Quality Assurance

A quality-assurance plan is being developed under the auspices of the national program to maintain and document the reliability of the results of the pilot projects. The plan will include all aspects of sample collection, data analysis, and reporting needed to produce reliable data in a nationally consistent manner. The plan will be based on the extensive quality-assurance policies and procedures now used by the U.S. Geological Survey, including material described in manuals by the Office of Water Data Coordination (1977) and Friedman and Erdmann (1982).

Agency Coordination

Coordination between U.S. Geological Survey personnel and other interested scientists and water-management personnel is an important component of the NAWQA program. A National Coordinating Work Group has been established by the Director of the U.S. Geological Survey to advise the U.S. Geological Survey on the coordination of the NAWQA program. The work group functions under the general auspices of the Interagency Advisory Committee on Water Data and the Advisory Committee on Water Data for Public Use. The general purposes of the work group are to advise the U.S. Geological Survey on: (1) Water-quality information needs of non-Federal and Federal communities of water users; and (2) coordination procedures for making the data and information resulting from the NAWQA program timely and appropriately available. The work group currently consists of the Chief Hydrologist of the U.S. Geological Survey, eight Federal members, seven non-Federal members, and members from the liaison committees for induvidual pilot projects. Organizations represented include: American Water Resources Association, Association of American State Geologists, Association of State and Interstate Water Pollution Control Administrators, Chemical Manufacturers Association, Interstate Conference on Water Policy, National Association of Conservation Districts, U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, U.S. Council on Environmental Quality, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, U.S. Forest Service, and U.S. Soil Conservation Service.

The Central Oklahoma aquifer pilot project will have a liaison committee to ensure that the scientific information produced by the program is relevant to local and regional interests. Specific activities could include: (1) Exchanging information about local and regional water-quality and water-data management issues; (2) identifying water-quality constituents and study locations of local and regional interest; (3) discussing adjustments in NAWQA, other U.S. Geological Survey, and other agencies' sampling-program objectives; and (4) reviewing and commenting on draft planning documents and reports from the study. Organizations currently represented in the Central Oklahoma aquifer liaison committee include: The Association of Central Oklahoma Governments, the Directorate of Environmental Management from Tinker Air Force Base, the Environmental and Ground Water Institute at the University of Oklahoma, Oklahoma Corporation Commission, Oklahoma Department of Pollution Control, Oklahoma Geological Survey, Oklahoma State Department of Health, Oklahoma Water Resources Board, U.S. Army Corps Of Engineers, U.S. Bureau of Reclamation, U.S. Environmental Protection Agency, and the University Center For Water Research at Oklahoma State University.

SUMMARY

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

Certain strategic choices have been made in designing the Central Oklahoma aquifer pilot project. For example, the project can only address prevalent water-quality problems. Although some individual contaminant plumes and localized contamination problems may be identified during the project, the project is not designed to locate and describe individual cases of point-source contamination. The Central Oklahoma aquifer project will emphasize regional degradation of ground-water quality within the aquifer, such as might occur from nonpoint sources of pollution or from numerous point sources in a relatively small area. For efficient use of the available financial resources, the project will use existing data whenever possible. Data available in published reports for factors such as land use, soil types, pesticide application, and cultivated acreage will be used. However, the water-quality data that are available will not be sufficient to conduct a water-quality assessment without additional sampling and chemical analyses.

A regional survey will be conducted to obtain nationally consistent data for a variety of water-quality constituents. The regional survey will provide a representative sampling of ground-water analyses for comparison of ground-water quality among all the NAWQA ground-water pilot projects. The survey data will be supplemented by a sampling program that addresses water-quality issues of particular concern within each study unit by means of topical studies.

In addition to the regional survey and topical studies, the Central Oklahoma aquifer study will include investigations of the geohydrology and geochemistry of the aquifer. The fate and movement of chemical constituents in ground water depend both on the flow system and on the geochemical environment of the aquifer. One of the objectives of the NAWQA program is to determine the relations between water quality and hydrologic properties of the aquifer. The present (1987) state of knowledge of the geohydrology and geochemistry of the aquifer

is not sufficient to meet this objective. During the early stages of the project, geohydrologic and geochemical investigations will be conducted to develop this knowledge.

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