Hydrogeologic Investigation Report of the Boone Groundwater Basin, Northeastern Oklahoma

By Noel I. Osborn

Oklahoma Water Resources Board
Technical Report GW2001-2
July 2001

On the cover: photograph of the Boone Formation in Natural Falls State Park, Delaware County, Oklahoma; courtesy of Michael Hardeman.

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INTRODUCTION

The Boone Groundwater Basin covers about 3,065 square miles in portions of Adair, Cherokee, Craig, Delaware, Mayes, Ottawa, Sequoyah, and Wagoner counties in northeastern Oklahoma (Figure 1). Although well yields average less than 10 gallons per minute (gpm), the basin supplies more than 1,400 households with water. Located within one of Oklahoma's most scenic regions, the area has experienced some of the highest growth rates in the state during the last decade.

The purpose of this study is to provide the public with general information on the Boone aquifer, and to provide the Oklahoma Water Resources Board (OWRB) with the information needed to allocate the amount of water withdrawn from the basin.

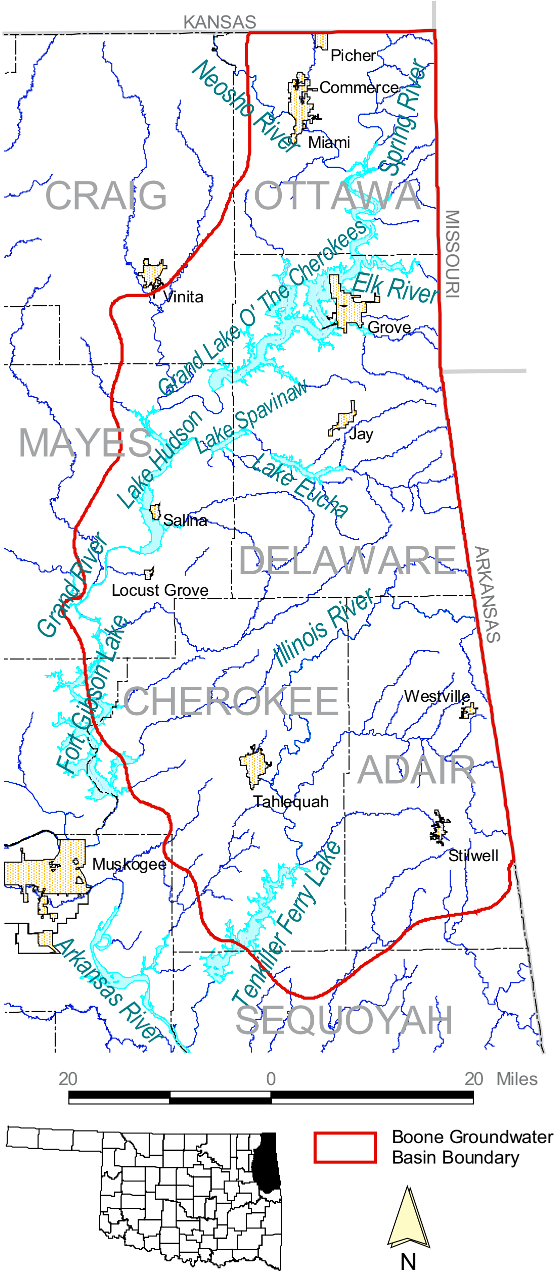

Figure 1. Location map of the Boone Groundwater Basin, northeastern Oklahoma.

PHYSICAL SETTING

Streams and Lakes

The major rivers that drain the basin are the Grand (Neosho) River, the Spring River, and the Illinois River. The Grand River is usually called the Neosho River above its confluence with the Spring River, and the Grand River below the confluence. The Neosho River begins in Kansas and flows south and southeasterly, joined by the major tributaries of Labette Creek, Spring River, Spavinaw Creek, and Pryor Creek before it joins the Arkansas River. The Spring River originates in Missouri, where it flows westerly into Kansas, then southwesterly into Oklahoma. The Illinois River begins in northwest Arkansas and then flows in a southwesterly direction toward the Arkansas River. It is joined by the main tributaries of Ballard Creek, Flint Creek, Barren Fork, and Caney Creek. The Illinois River, Flint Creek, and Barren Fork have been designated as scenic rivers by the Oklahoma State Legislature.

Six major impoundments are in the basin: Fort Gibson Lake, Lake Hudson, and Grand Lake O' the

Cherokees are on the Grand (Neosho) River. The Grand River Dam Authority operates the lakes, primarily for flood control and hydroelectric power generation. Eucha and Spavinaw Lakes are on Spavinaw Creek and provide water for the City of Tulsa. Tenkiller Ferry Lake is on the lower part of the Illinois River.

Physiography

The majority of the basin lies within the Spring-field Plateau section of the Ozark Plateaus province, where Mississippian age rocks crop out (Fenneman, 1946). The Ozark Plateaus province is a geologic uplift that rises above surrounding lowlands. Erosion has cut the limestones and cherty limestones, forming a rugged topography with deep, v-shaped valleys separated by narrow, flat-topped ridges (Christenson and others, 1994; Marcher and Bingham, 1971).

The northwestern portion of the basin, west of the Spring and Grand rivers, lies within the Osage Plains section of the Central Lowland province (Fenneman, 1946). The Osage Plains is underlain by younger, late Mississippian and Pennsylvanian age rocks consisting of soft shales interbedded with sandstone and limestone. Erosion of these rocks has produced a gently rolling surface interrupted by low east-facing escarpments and isolated buttes capped by resistant limestone and sandstone (Christenson and others, 1994; Marcher and Bingham, 1971).

Climate

The basin has a humid and temperate climate. Examination of data from the Oklahoma Climatological Survey (1997) indicates that average annual precipitation ranges from about 42 inches in the northwest portion of the basin to about 48 inches in the southeast. The average precipitation for the basin is about 44 inches per year. The wettest months are May through June and September, and the driest months are December through February. Average monthly temperatures range from 35o in January to 80o in July, with an average annual temperature of 58-60oF.

Soils

The major soil in the Springfield Plateau is the Bodine-Baxter association, which developed in cherty limestones. The Bodine-Baxter soils are low in fertility and have a low water-holding capacity. They contain an abundance of coarse chert fragments, making cultivation difficult. The soils are often forested with oaks and hickory (OWRB, 1971).

The major soil in the Osage Plains is the Parsons-Dennis-Bates association. The Dennis and Bates soils are well drained, deep, dark, and loamy. The Dennis soil developed in interbedded siltstones and shales, and the Bates soil developed in sandstones in gently sloping landscapes. The Parsons is a slowly drained, deep soil underlain with very slowly permeable claypan subsoils. Because of strong horizonation and leaching, the soils are low in fertility. Native grasses are managed for cat-tle production (OWRB, 1971).

Land Use

Land use in the basin is predominantly agriculture and forest (Figure 2). The dominant agricultural uses

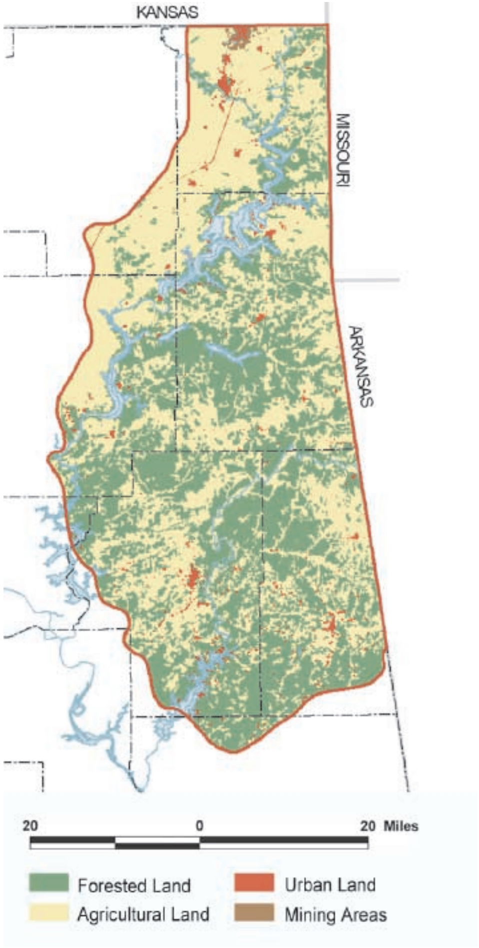

Figure 2. Generalized land use in the Boone Groundwater Basin (modified from U.S. Geological Survey, 1990).

are cropland, pasture, and confined poultry operations (Figures 3 and 4). The Springfield Plateau is forested with some cropland and pasture, and the Osage Plains is largely cropland and pasture (U.S. Geological Survey, 1990). Major crops are hay, wheat, soybeans, and sorghum. Poultry operations are the primary agricultural use in Delaware and Adair counties (Oklahoma Agricultural Statistics Service, 1997).

Mining

Lead and zinc ores were mined from the Boone Formation in Ottawa County. The mining area was part of the tristate mining district that extended from northeastern Oklahoma, through southeast Kansas, and into southwest Missouri. In Oklahoma, most mining occurred in the vicinity of the City of Picher (Figures 5 and 6). Mining in the Picher mining district began in the early 1900s, peaked about 1925, and ceased in the mid 1970s (Christenson and others, 1994; Imes and Emmett, 1994; Reed and others, 1955).

Population

There are no large urban areas within the basin. According to the 1990 census, only two towns have populations exceeding 10,000: Miami (13,000) and Tahlequah (10,400). Other incorporated towns include Commerce, Grove, Jay, Locust Grove, Picher, Salina, Stilwell, and Westville.

The estimated population of the basin in 1997 was more than 150,000 people. Adair, Cherokee, Delaware, and Mayes counties had some of the highest growth rates in the state between 1990 and 1997. Delaware County led the state with a 20.7 percent increase in population (U.S. Census Bureau, 1998).

A significant portion of the population is Native American. The percent Native American population for Adair, Cherokee, and Delaware counties is 43, 33, and 25 percent, respectively (U.S. Census Bureau, 1998). The basin lies within the Cherokee Nation. Several other Indian nations are located in the northeastern portion of Ottawa County. These include the Ottawa, Quapaw, Peoria, Modoc, Shawnee, Wyandotte, and Seneca tribes (Cherokee Nation, 1999).

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Figure 3. Hay harvest in Delaware County.


Figure 4. Cattle grazing in Delaware County.


Figure 5. Mining tailings near the City of Picher.

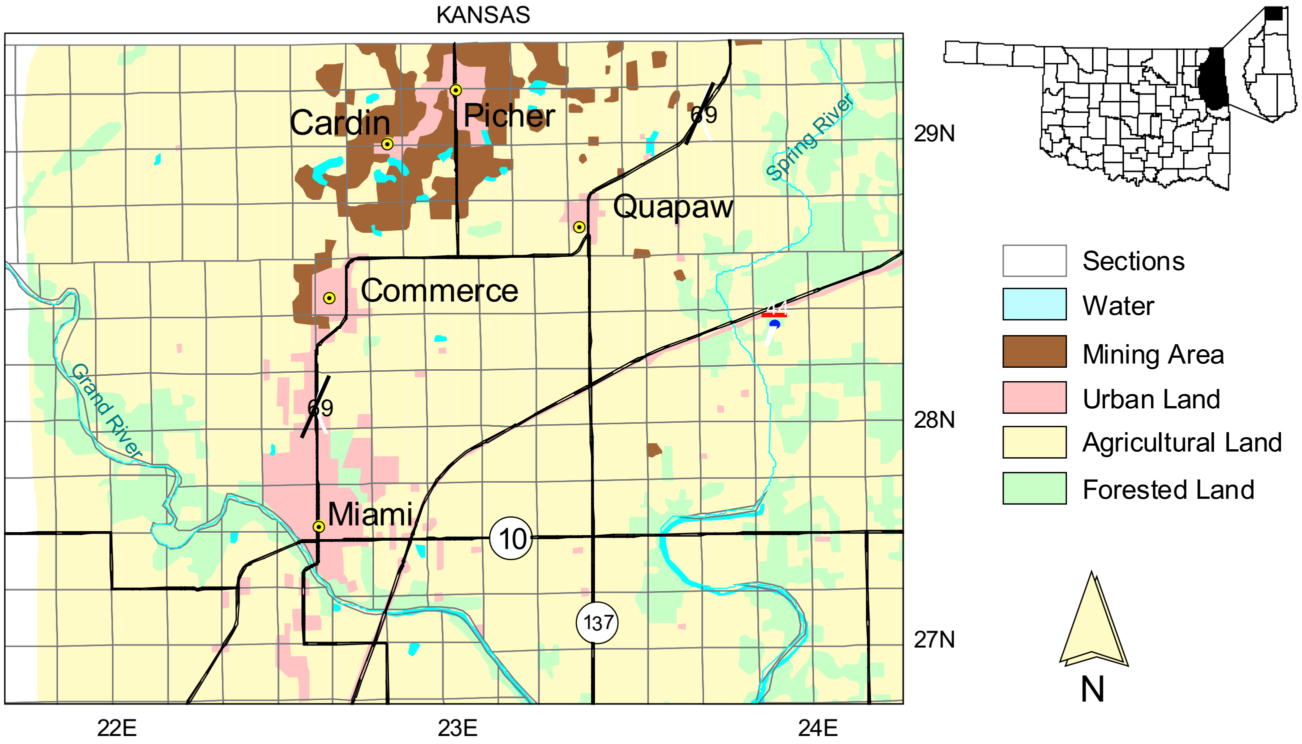

Figure 6. Land use map of the Picher mining district area (modified from U.S. Geological Survey, 1990).

GEOLOGIC SETTING

Structure

The Boone Groundwater Basin lies along the southwestern flanks of the Ozark uplift, a structural dome that covers about 40,000 square miles in Missouri, Arkansas, and Oklahoma (Warth and Polone, 1965). The regional dip is westward and averages about 15 to 20 feet per mile.

Rocks along the margin of the uplift are folded and broken by faults. Most of the faulting occurred during middle Pennsylvanian time as a result of the uplift (Marcher and Bingham, 1971). One of the most prominent faults is the Seneca fault, which begins in Missouri and extends southwestward across Ottawa County, northwestern Delaware County and diagonally across Mayes County. It is part of a graben made by two faults, and is sometimes called a syncline. Another structural feature is the Miami syncline, which trends north-northeast from Afton, passes west of Miami and Picher, and extends into Kansas (Christenson and others, 1994; Reed and others, 1955).

Stratigraphy

The basin overlies rocks ranging from Precambrian to Quaternary age. The stratigraphic column of northeastern Oklahoma is displayed in Table 1. The stratigraphic nomenclature was compiled from the Oklahoma Geological Survey and the U.S. Geological Survey (USGS). Figure 7 shows the surface geology of the basin.

The basement material underlying the Boone Groundwater Basin consists of volcanic and granitic rocks of Precambrian age. Five small hills of granite outcrop in the Town of Spavinaw, in Mayes County. The Precambrian surface is very irregular; depth to basement ranges from zero, where it outcrops, to as deep as 3,000 feet (Christenson and others, 1994; Imes and Emmett, 1994).

Overlying the Precambrian basement are the Cambrian-age Lamotte Sandstone, Reagan Sandstone, and Doe Run Dolomite. These rock units are overlain by a thick sequence of water-bearing dolomite, limestone, and sandstone formations ranging in age from Late Cambrian to Ordovician. The primary water-bearing formations are the Gasconade Dolomite, the

Table 1. Stratigraphic column of northeastern Oklahoma

Period	Geologic Unit	Geohydrologic Unit
Quaternary	Alluvium	major and minor terrace and alluvium aquifers
Tertiary	Terrace Deposits	
Pennsylvanian	Marmaton Group Cabiniss Group Krebs Group Atoka Formation Bloyd Shale Hale Formation	Northeastern Oklahoma Minor Groundwater Basin (Western Interior Plains Confining System)
Mississippian	Pitkin Limestone Fayetteville Shale Batesville Sandstone Hindsville Limestone Moorefield Formation	
	"Boone Formation": Keokuk Limestone Reeds Spring Formation St. Joe Group	Boone Aquifer (Springfield Plateau Aquifer)
	Northview Shale Compton Limestone	(Ozark Confining Unit)
Devonian	Chattanooga Shale	
Ordovician	Burgen Sandstone Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Gunter Sandstone Member	Roubidoux Aquifer (Ozark Aquifer)
Cambrian	Eminence Dolomite Potosi Dolomite	
	Doe Run Dolomite	(St. Francois Confining Unit)
	Reagan Sandstone Lamotte Sandstone	(St. Francois Aquifer)
Precambrian	Precambrian basement rocks, undivided Spavinaw Granite	(Basement Confining Unit)

Geohydrologic unit names in parenthesis refer to USGS nomenclature from the study of the Ozark Plateaus Aquifer System (Imes and Emmett, 1994).

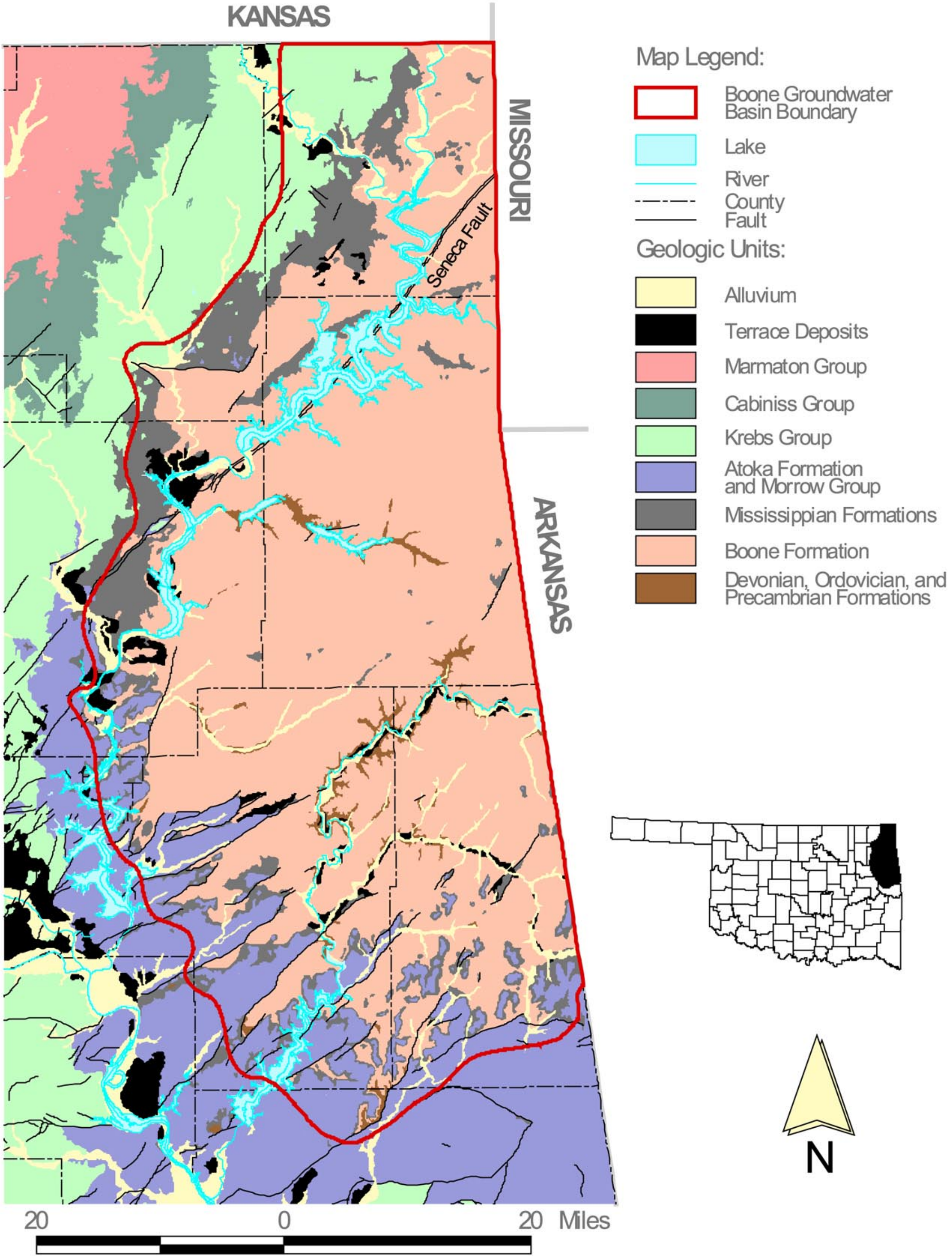

Figure 7. Surface geology of the Boone Groundwater Basin (modified from Cederstrand, 1996a,b).

Roubidoux Formation, and the Jefferson City and Cotter Dolomites. The Cotter Dolomite crops out around Spavinaw Lake. The Burgen Sandstone rests unconformably upon the Cotter Dolomite, and crops out along the Illinois River.

Because the highest yielding wells are completed in the Roubidoux Formation, the water-bearing units are collectively called the Roubidoux aquifer (Christenson and others, 1994). The thickness of the Roubidoux aquifer is highly variable over short distances due to the irregular Precambrian surface. The thickness of the Roubidoux Formation in Oklahoma ranges from zero, where the Precambrian granite outcrops in Spavinaw, to greater than 1,000 feet (Imes and Emmett, 1994).

Overlying the Ordovician-age units is the Chattanooga Shale of Devonian age. The Chattanooga Shale is a black, carbonaceous, fissile shale, 0-80 feet thick. It contains pyrite, phosphate, glauconite, and minor amounts of uranium. In a few locations, the Northview Shale and the Compton Limestone of Mississippian age overlie the Chattanooga Shale. These low-permeable formations comprise a confining layer for the Roubidoux aquifer (Adamski and others, 1995; Christenson and others, 1994).

The Mississippian-age Keokuk and Reed Spring formations and St. Joe Group overlie the Chattanooga and Northview shales and outcrop over much of the basin area. These geologic units are commonly called the Boone Formation, and will be referred to as such in this report. The rocks consist of highly fractured, fine-grained limestone and massive gray chert, and comprise the Boone aquifer. Secondary mineralization is extensive in the limestones. The Boone Formation is the host rock for the lead and zinc sulfide ores, principally galena and sphalerite, that were mined in Ottawa County (Imes and Emmett, 1994; Marcher and Bingham, 1971).

The Boone Formation is overlain by younger Mississippian and Pennsylvanian formations along the western and southern edges of the basin. Formations include the stratigraphic sequence from the base of the Mississippian Moorefield Formation to the Pennsylvanian Marmaton Group. These formations consist of alternating sequences of low-permeability shale and low-permeability to permeable limestone, sandstone, and coal (Imes and Emmett, 1994). Black shales of Pennsylvanian age can bear uranium. The Cherokee and Marmaton Groups contain some bituminous coal beds, and produce oil and gas in places (Adamski and others, 1995).

Regionally, these rocks are part of the Western Interior Plains confining system that impedes the flow of water to and from the underlying Boone aquifer (Imes and Emmett, 1994). Locally, however, the confining system contains permeable zones and aquifers that comprise the Northeastern Oklahoma Minor Groundwater Basin (Wilkins, 1997).

The thickness of the Western Interior Plains confining system increases away from the Ozark region, at a greater rate to the south than to the west. Near the Kansas-Oklahoma border, the confining system thickens to the west at a rate of about 25 feet per mile. It thickens about 80 feet per mile to the southwest and about 180 feet per mile to the south where it is as thick as 6,000 feet (Imes and Emmett, 1994).

Quaternary-age alluvium and terrace deposits occur locally along the rivers and larger streams. These deposits consist of unconsolidated gravel, sand, silt, and clay, and yield small to moderate amounts of water (Marcher and Bingham, 1971).

GROUNDWATER

Regional Setting

The Boone aquifer is part of a large groundwater system that encompasses parts of southern Missouri, southeastern Kansas, northeastern Oklahoma, and northern Arkansas. Referred to as the Springfield Plateau aquifer by the USGS, this system is comprised of water-bearing Mississippian limestone and chert that forms the uppermost geohydrologic unit in the Ozark Plateaus aquifer system. The western boundary of the aquifer system is in a broad, topographically low area where fresh water moving westward from the Ozark Plateaus aquifer system meets saline water moving eastward through the Mississippian and Pennsylvanian formations that comprise the Western Interior Plains confining system (Imes and Emmett, 1994).

Basin Boundaries

The OWRB defines a groundwater basin as a distinct underground body of water overlain by contiguous land and having substantially the same geological and hydrological characteristics. The OWRB classifies the Boone Groundwater Basin as a minor basin because the average basinwide yield from wells in the bedrock aquifer is less than 50 gpm.

The Boone Groundwater Basin consists of the Mississippian-age Boone Formation and the overlying Quaternary-age alluvium and terrace deposits that are not included in the Neosho River Minor Groundwater Basins (as described in Wilkins, 1997). The basin is bordered on the north by the State of Kansas and on the east by the State of Arkansas. The boundary to the south and west is delineated by the 200 foot contour on the thickness map of the Western Interior Plains confining system (Imes, 1990c). Beyond this boundary, the top of the Boone Formation is more than 200 feet deep and water quality of the aquifer deteriorates. The total land area overlying the basin is 1,961,600 acres, or 3,065 mi^2.

Where the Boone Formation crops out at the surface or is overlain by alluvium and terrace deposits, the aquifer is unconfined, and the top of the basin is the water table surface. Where the aquifer is overlain by younger Mississippian and Pennsylvanian formations, it is confined, and the top of the basin corresponds to the top of the Boone Formation. The top of the underlying Chattanooga Shale, easily identified on well drillers' logs, defines the base of the basin. Figure 8, modified from Imes, 1990a, is a map showing the elevation of the base of the Boone Groundwater Basin.

The Boone Formation is absent from erosion along portions of streams and rivers in Adair, Cherokee, Delaware, and Mayes counties. In these areas, Precambrian, Ordovician, and Devonian rocks are exposed at the surface.

Karst

Due to its cavernous and fractured nature, the Boone aquifer is considered a karst aquifer. Karst features, such as caves, sinkholes, disappearing streams, and springs, occur where the Boone Formation crops out. These features provide direct conduits for precipitation and runoff to transport contaminants to the water table, making the aquifer highly vulnerable to contamination from surface sources (Osborn and Hardy, 1999). Other characteristics common to karst aquifers are the rapid recharge rate and groundwater flow rate. Water levels in wells and discharge from springs can increase rapidly after a rainstorm. Groundwater flow can cross topographic divides, making determination of the recharge basins for lakes and springs difficult.

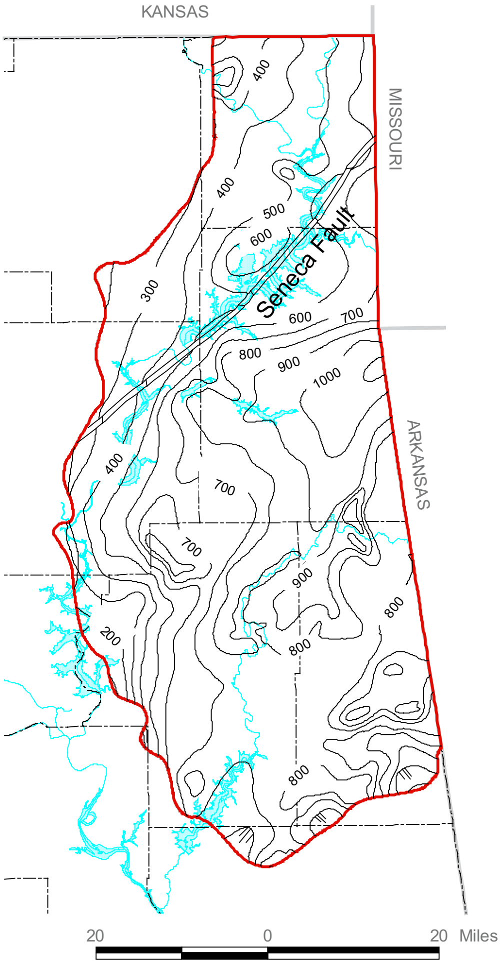

Figure 8. Elevation map of the base of the Boone Groundwater Basin (modified from Imes, 1990a). Contour interval is 100 feet.

Recharge

Recharge to the Boone aquifer is almost entirely from infiltration of precipitation in areas where the Boone Formation crops out. Precipitation may infiltrate the unsaturated zone quickly because soil and subsoil in the Ozarks is thin, near-surface faults and fracture systems are common, and dissolution of the carbonate rocks is widespread. Although slopes are often steep, the trees, grass, and other vegetation hold the water, reducing the loss through runoff. Sinkholes in parts of the area can take large amounts of water from disappearing streams. In the mining area, abandoned mine shafts, wells, and test holes can be conduits for water to enter the aquifer (Reed and others, 1955).

Dugan and Peckenpaugh (1986) estimated the amount of recharge to the water table based on climate, soil type, slope, land use, and consumptive water use by crops and vegetation. They estimated the mean annual groundwater recharge in the Oklahoma portion of the Ozarks to be about 10 inches. Imes and Emmett (1994) used a regional groundwater flow model of the Ozark Plateaus aquifer system to determine that 25% of the mean annual precipitation recharges the Boone aquifer. In the Boone Groundwater Basin, 25% of the mean annual precipitation is 10.5-12 inches.

Discharge

Groundwater discharges naturally to streams, rivers, and springs. The Grand (Neosho), Spring, and Illinois rivers are perennial, and receive substantial base flows from the Boone aquifer. Perennial streams include Beaty, Brush, Honey, Spavinaw, and Spring Creeks.

Most of the springs flow from water-filled cavities along bedding planes in the Reeds Spring Formation. Measurements of 25 larger springs made in September and October 1968 revealed discharges ranging from 30 to 3,600 gpm, with a median of about 390 gpm (Bingham, 1969; Marcher and Bingham, 1971).

Some groundwater also discharges downward through the underlying Chattanooga Shale into the Roubidoux aquifer (Imes and Emmett, 1994). This occurs in the mining area, where the hydraulic head in the Boone aquifer is higher than the head in the Roubidoux aquifer. Water moves from the mine workings in the Boone downward through pores and fractures in the rock units, toward the Roubidoux aquifer (Christenson and others, 1994).

Groundwater Flow and Water Level Fluctuations

Figure 9 is a potentiometric map of the Boone aquifer. Groundwater flows perpendicular to water level contours, from high to low elevations. As illustrated in Figure 9, groundwater flows laterally from topographic highs to streams, where it discharges to springs and seeps. The regional direction of flow is west, toward the Spring and Grand (Neosho) rivers.

Because of the fractured nature of the Boone aquifer, water levels rise rapidly in response to rainfall, and decrease rapidly due to pumpage. Water levels measured in the winter months, when rainfall and well pumpage are less, are more representative of ambient conditions. Hydrographs for three wells that the OWRB measured annually from 1979 to 1999 are shown in Figure 10.

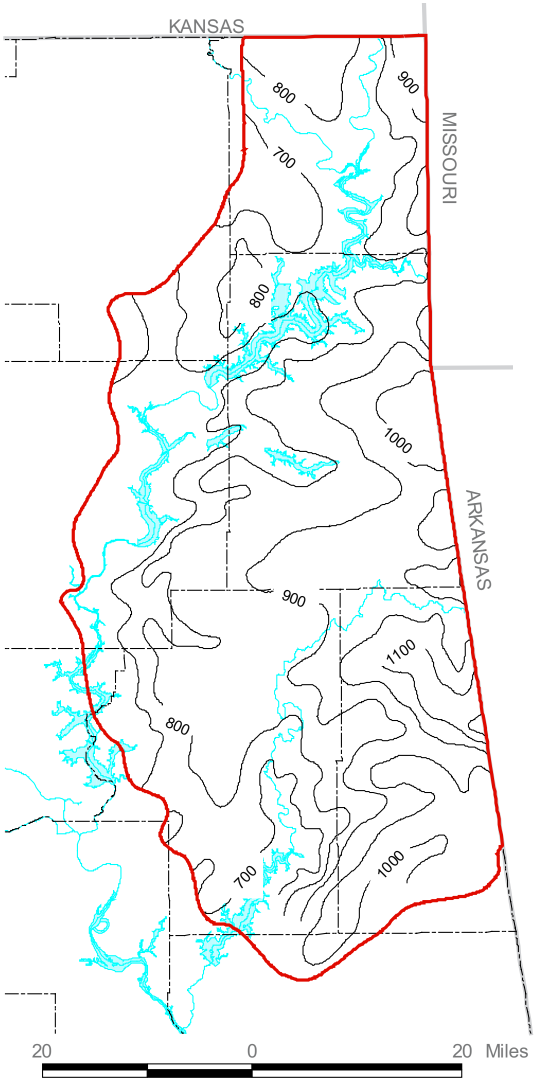

Figure 9. Potentiometric map of the Boone Groundwater Basin (modified from Imes, 1990b). Contour interval is 100 feet.

Aquifer Parameters

Most of the aquifer's porosity and permeability result from fracturing of the chert and dissolution of the limestone. The distribution of porosity and permeability is very heterogeneous, and varies widely. Using a regional groundwater flow model of the Ozark Plateaus aquifer system, Imes and Emmett (1994) estimated an average hydraulic conductivity of the Boone aquifer of about 22 ft/day, and a specific yield of 0.07.

Saturated thickness ranges from zero, where it is absent from erosion along portions of streams and rivers, to greater than 400 feet in parts of Ottawa County (Imes, 1990b). The average saturated thickness in Oklahoma is estimated to be about 200 feet.

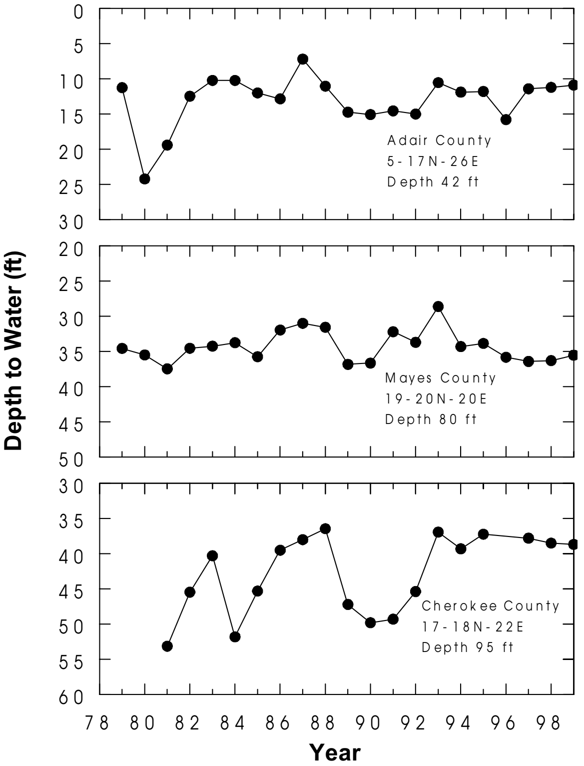

Figure 10. Hydrographs of three wells in the Boone Groundwater Basin.

The transmissivity of the aquifer is the product of the hydraulic conductivity and the saturated thickness, and defines the rate at which water can move through the aquifer. Assuming an average hydraulic conductivity of 22 ft/day and an average saturated thickness of 200 feet, the average transmissivity of the aquifer is 4,400 ft^2/day.

The storage of the basin, calculated by multiplying the area of the basin (1,961,600 acres) by the specific yield (0.07) and the saturated thickness (200 feet) is about 27 million acre-feet.

GROUNDWATER PRODUCTION

Well Construction

Wells in the Boone Groundwater Basin typically have an open-borehole construction, in which they are left open below the surface casing. Well screens or perforations are not required because the geologic units are competent enough that the well bore stays open without casing. Wells that are not cased through the Boone, and that are drilled into the underlying Roubidoux aquifer, produce water that is a mixture of Boone and Roubidoux waters.

Well Yields

An examination of well drillers' logs in Oklahoma indicates that Boone wells yield from 0.3 to more than 100 gpm and average less than 10 gpm. Yields of more than 100 gpm are possible where fractures or caverns occur. For example, a well completed in the Boone aquifer in Adair County is the primary source of water for the City of Westville. The well is 23 feet deep, and encounters a cavern that is about three feet high and 300 feet long. The pump capacity of the well is 500 gpm. In 1989, the city produced more than 100 million gallons of water from the well (OWRB and OSDH, 1993).

Wells in the mining district reportedly had very high yields, which Reed and others (1955) attribute to the joints and fissures along the Miami syncline. About 13 million gallons a day were produced from the Oklahoma-Kansas field in 1935. The Eagle-Picher central pumping station at Picher pumped nearly 5,000 gpm! Unfortunately, this high-yield area is not typical of the aquifer.

Water Use

At the time of this study, about 3,100 drillers' logs of water wells in the basin were on file at the OWRB. About 1,400 of the wells were completed in only the Boone aquifer. Most wells in the Boone aquifer are used for domestic purposes, although some are used for agriculture (such as poultry operations), commercial, and public water supply purposes.

Groundwater allocation from the Boone and Roubidoux aquifers has not been differentiated. However, most of the higher yielding wells produce from the Roubidoux aquifer. As of June 1999, the OWRB had issued more than 200 groundwater permits totaling about 13,000 acre-feet per year from the two aquifers. The number of permits issued has been on the rise. As illustrated in Figure 11, 12 were issued in the 1970s, 40 in the 1980s, and 153 in the 1990s. Prior groundwater rights (established before July 1, 1973) within the Boone and Roubidoux aquifers total 1,786 acre-feet per year. Of these, 1,327 acre-feet are in Ottawa County.

WATER QUALITY

General Chemistry

In areas where the Boone Formation crops out, water type in the aquifer is calcium bicarbonate, resulting from dissolution of carbonate rocks. Dissolved solids concentrations are generally within the range of 100-300 milligrams per liter (mg/L). Chloride and

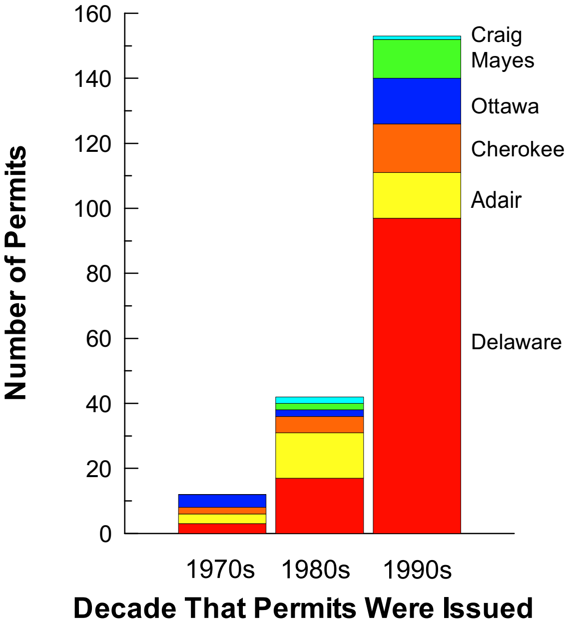

Figure 11. Graph showing number of groundwater permits in the Boone and Roubidoux aquifers, by county.

sulfate concentrations are generally less than 10 mg/L (Imes and Davis, 1990; Imes and Emmett, 1994).

Water in the Boone aquifer is a sodium chloride type along the western boundary, where the aquifer is confined. In this area, westward flowing, fresh water of the Boone aquifer mixes with eastward flowing, saline water of the Western Interior Plains confining system (Imes and Emmett, 1994). Concentrations of dissolved solids increase abruptly to greater than 500 mg/l in the confined portion of the aquifer. Chloride concentrations increase to greater than 100 mg/L, and sulfate concentrations increase to greater than 50 mg/L (Imes and Emmett, 1994).

As part of a statewide monitoring program, the OWRB collected groundwater samples from 12 domestic wells in the Boone aquifer in July 1991 (Figure 12). Well information is listed in Appendix A, and the chemical analyses are listed in Appendix B. Not included in Appendix B are the analyses for arsenic, cadmium, chromium, copper, lead, manganese, silver, and selenium because the concentrations of these constituents were all below the detection limit. Summary statistics of the analyses are listed in Table 2. For those constituents with censored data (values below the detection limit), only the minimum and maximum concentrations are listed.

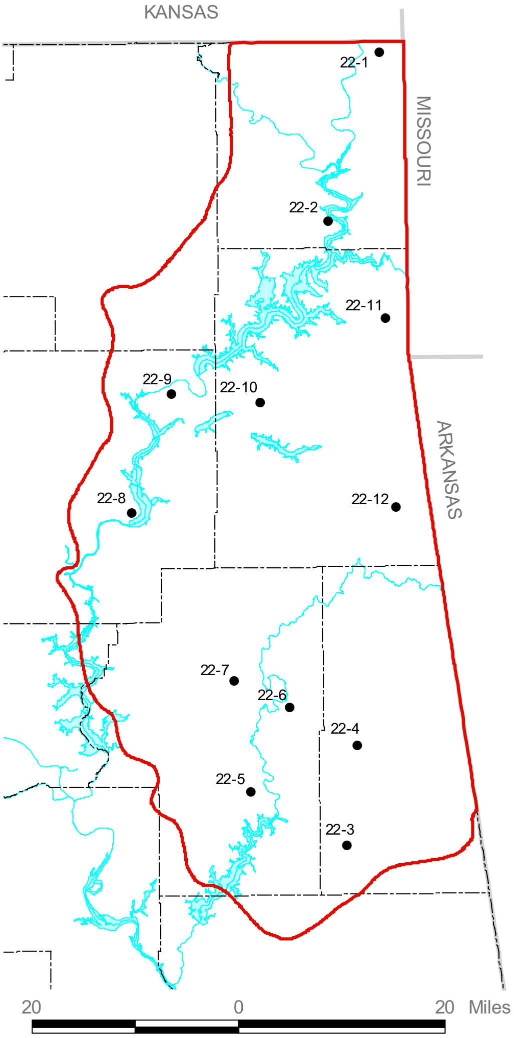

Figure 12. Location of wells completed in the Boone Groundwater Basin that were sampled in July 1991.

The USGS conducted a water-quality study of the Ozark Plateaus aquifer system in Oklahoma, Arkansas, Kansas, and Missouri as part of the National Water Quality Assessment (NAWQA) Program. From 1993 through 1995, groundwater samples were collected from 215 springs and wells in the unconfined portions of the Boone and Roubidoux aquifers (Adamski, 1997; Peterson and others, 1998).

Samples from 61 springs and 50 wells in the Boone aquifer were analyzed for tritium (^{3}H) concentrations to determine the age of recharge. Samples from all springs and from 36 wells had detectable concentrations of tritium, indicting that some portion of the water was recharged to the groundwater system in the past 40 years. Fifty-eight of the samples appear to

Table 2. Descriptive statistics for chemical analyses of 12 groundwater samples collected in July 1991 from wells completed in the Boone Groundwater Basin (units in mg/L)

Parameter	Minimum	25th Percentile	50th Percentile Median	75th Percentile	Maximum
Hardness	79	125.3	185.0	221.0	236
Alkalinity	59	108.5	177.0	196.5	221
Total Dissolved Solids	77	139.0	197.5	237.8	255
Calcium	14	30.8	49.0	64.0	76
Magnesium	<1	-----	-----	-----	7
Sodium	<10	-----	-----	-----	10
Chloride	<10	-----	-----	-----	12
Fluoride	<0.10	-----	-----	-----	0.21
Nitrate as N	<0.05	-----	-----	-----	3.0
Sulfate	<20	-----	-----	-----	49
Arsenic	<0.01	-----	-----	-----	<0.01
Barium	<0.010	-----	-----	-----	1.106
Cadmium	<0.005	-----	-----	-----	<0.005
Chromium	<0.010	-----	-----	-----	<0.010
Copper	<0.010	-----	-----	-----	<0.010
Iron	<0.010	-----	-----	-----	0.178
Lead	<0.045	-----	-----	-----	<0.045
Manganese	<0.01	-----	-----	-----	<0.01
Silver	<0.007	-----	-----	-----	<0.007
Selenium	<0.005	-----	-----	-----	<0.005
Zinc	<0.005	-----	-----	-----	0.056

represent water that recharged 2 to 6 years prior to sample collection (Adamski, 2000).

Adamski (2000) concluded that the young age for most groundwater samples is consistent with other geochemical findings from the NAWQA study. The relatively high dissolved oxygen concentrations of most groundwater samples (median of 7.1 mg/L) indicate rapid recharge or short residence time. Groundwater samples generally had low calcite saturation indices ($\leq$ -0.1) and high partial pressure of carbon dioxide ($\geq 10^{-2}$ atm), indicating rapid flow through large conduits and/or having short flow paths.

Field measurements indicate that water issuing from springs interacts less with the aquifer, and follows more shallow flow paths along fractures and solution openings, than water in wells. In general, specific conductance and alkalinity, which are related to ionic concentrations resulting from dissolution of the rock, were greater in samples from wells than in samples from springs. Dissolved oxygen, which is supplied by recharge, was greater in samples from springs than in samples from wells.

Adamski (1977) determined background concentrations of nutrients in the Boone and Roubidoux aquifers in samples collected from 25 relatively pristine sites. Background concentrations were determined to be as follows: nitrite plus nitrate was 0.98 mg/L; nitrite was less than 0.01 mg/L; ammonia was 0.02 mg/L; and phosphorus was 0.02 mg/L. The median nitrate concentration from samples collected from wells in the Boone aquifer was 1.0 mg/L, and the median phosphorus concentration was 0.01 mg/L.

Water Quality Problems

Nitrate and Pesticides

Results from the NAWQA study indicate that the groundwater quality of the Boone aquifer is susceptible to surface contamination and is being affected by increased concentrations of nitrate and the presence of pesticides. Elevated concentrations of nitrate in groundwater of the Boone aquifer are widespread, particularly in areas where land use is predominantly agricultural. However, very few samples exceeded the maximum contaminant level (MCL) of 10 mg/L, established by the U.S. Environmental Protection Agency (EPA). Pesticides were detected in 18 of 36 (50 percent) samples from the Boone aquifer (Peterson and others, 1998).

Peterson and others (1998) concluded that water from springs generally is more susceptible to surface contamination than water from wells. The median nitrate concentration was greater and pesticides were detected statistically more often in samples collected from springs than in samples collected from wells.

Radon

As part of the NAWQA program, the USGS also analyzed groundwater in the Boone and Roubidoux aquifers for radon. Radon, a naturally occurring element, can enter buildings through the water system, and from surrounding rock and soil through foundation cracks. Exposure to radon has been recognized as a cause of lung cancer (Peterson and others, 1998).

Samples collected from 73 wells in the Boone and Roubidoux aquifers had radon levels ranging from 99 to 2,065 picocuries per liter (pCi/L) and a median of 269 pCi/L. Radon levels exceeded the proposed MCL of 300 pCi/L in nearly one-half of the samples. Radon levels were substantially higher in samples from the Boone aquifer and unconfined part of the Roubidoux aquifer, than from the confined part of the Roubidoux aquifer (Peterson and others, 1998).

Dissolved Solids, Chloride, and Sulfate

Concentrations of dissolved solids, chloride, and sulfate increase west of the basin boundary, making the water unsuitable for most purposes. Groundwater withdrawals along the western boundary could induce eastward encroachment of saline groundwater into freshwater areas. This situation occurred in Missouri, in the northwestern part of the aquifer system (Adamski and others, 1995). Therefore, care should be taken while pumping wells located near the western boundary of the basin so as not to induce saline groundwater.

Hydrogen Sulfide

The presence of a rotten-egg odor, characteristic of hydrogen sulfide (H_2S), has been observed in many wells completed in the Boone aquifer. Most people can detect the rotten-egg odor of hydrogen sulfide in waters that have concentrations as little as 0.5 parts per million (ppm). A 1-2 ppm hydrogen sulfide concentration gives water a disagreeable taste and odor and makes the water very corrosive to plumbing. Hydrogen sulfide is a gas that is dissolved in water, and readily dissipates when water is exposed to the atmosphere (Varner and others, 1996). Wells are commonly vented to allow the hydrogen sulfide gas to escape (Reed and others, 1955). Laboratory analysis of hydrogen sulfide in water requires the sample be stabilized or the test be conducted at the water source site (Varner and others, 1996). To date, hydrogen sulfide concentrations have not been determined in the Boone aquifer.

Mine-Water Contamination

Water in the abandoned zinc and lead mines in Ottawa County is contaminated. In the early 1980s, the EPA designated the area where mine water discharged into Tar Creek as a Superfund site. Water in the abandoned mines has a low pH and contains high concentrations of sulfate, fluoride, cadmium, copper, iron, lead, manganese, nickel, and zinc (Christenson, 1995). Water samples collected between 1983 and 1985 from mine shafts and boreholes in the Picher mining district had concentrations of cadmium as high as 93 µg/L, lead as high as 130 µg/L, and zinc as high as 240,000 µg/L (Parkhurst, 1987). These concentrations are much greater than the drinking water standards; the MCL is 5 µg/L for cadmium and 50 µg/L for lead, and the secondary maximum contaminant level (SMCL) is 5,000 µg/L for zinc (U.S. Environmental Protection Agency, 1992).

The larger concentrations of sulfate in the mining district are most likely the product of the oxidation of sulfite minerals that took place when the mineshafts were dewatered. Later refilling of the mineshafts with groundwater allowed dissolution of the sulfate ions, resulting in larger concentrations of sulfate (Imes and Emmett, 1994).

Because the groundwater flows westward in the vicinity of the Picher mining district, the contaminated mine water is expected to migrate slowly to the west. As the contaminated water migrates away from the mining district, it will mix with uncontaminated water with a higher pH. Dispersion and dilution will allow neutralization to take place, increasing the alkalinity and pH. Although dissolved heavy metals may be affected by dispersion, adsorption, and precipitation, they may still exceed drinking water standards (Hittman Associates, 1982).

Contaminated water from the mining district has the potential to degrade the quality of freshwater from both vertical and lateral flow. Contaminated mine water could flow vertically into the overlying Pennsylvanian minor groundwater basin or the underlying Roubidoux aquifer if wells are not properly cased and sealed through the Boone aquifer. Pumping wells completed in the Boone aquifer have the potential to change the direction of lateral water movement and induce the encroachment of contaminated mine water into uncontaminated water.

ALLOCATION OF WATER RIGHTS

Oklahoma water law requires the OWRB to conduct hydrologic investigations of groundwater basins to characterize the availability, extent, and natural hydrologic conditions of the resource. Upon completion of the hydrologic investigation, the OWRB must determine the maximum annual yield of fresh water to be produced from the basin and the equal proportionate share to be allocated to each acre of land overlying the basin, based on a minimum life of 20 years. The maximum annual yield of a minor groundwater basin shall be based upon present and reasonably foreseeable future use of groundwater from the basin, recharge and total discharge, the geographical region in which the basin is located, and other relevant factors.

Information on the Boone Groundwater Basin that should be considered in determining the maximum annual yield and equal proportionate share are summarized below:

1. The total land area overlying the basin is 1,961,600 acres.
2. The average saturated thickness of the basin is estimated to be 200 feet; the average hydraulic conductivity is estimated to be 22 ft/day; the average transmissivity is estimated to be 4,400 ft^2/day; and the average specific yield is estimated to be 0.07.
3. The amount of water in storage in the basin is estimated to be 27 million acre-feet.
4 The average rate of recharge is estimated to be 10.5 inches/year, or 25 percent of the average annual precipitation (43 inches) and totals about 1,716,400 acre-feet.
5. Pollution from natural sources could occur along the western boundary of the basin, where pumping could induce eastward encroachment of saline groundwater.
6. The Boone Groundwater Basin is an important source of water for domestic purposes, supplying more than 1,400 households with water. Due to increasing population in the area, domestic use is predicted to increase. However, the low well yields typical of the basin will continue to limit its use for agricultural, municipal, and commercial purposes in the foreseeable future.

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APPENDICES

APPENDIX A: INFORMATION ABOUT SAMPLED WELLS

Site ID	County	Well Owner				Legal Location			Well Depth (ft)
						Section	Township	Range	
22-1	Ottawa	Jay Inman	SE	SE	NE	23	29N	24EIM	180
22-2	Ottawa	Kenneth Blalack	NW	NE	NW	30	26N	24EIM	303
22-3	Adair	Calvin Clay	SE	NE	SE	04	14N	24EIM	100
22-4	Adair	Danny Wolf	SW	NE	SW	11	16N	24EIM	75
22-5	Cherokee	Dan Mortan	SE	NW	SW	02	15N	22EIM	200
22-6	Cherokee	James Woodward	NW	NW	SW	21	17N	23EIM	110
22-7	Cherokee	Doyle Tinnen	SE	SE	NE	05	17N	22EIM	120
22-8	Mayes	Don Woodward	SW	SE	SW	33	21N	20EIM	140
22-9	Mayes	Cecil Pullen	SE	SE	SE	30	23N	21EIM	140
22-10	Delaware	Andy Evans	SE	SE	SE	35	23N	22EIM	118
22-11	Delaware	Larry Sanders	NW	SW	SW	17	24N	25EIM	100
22-12	Delaware	Marilyn Duncan	NE	NE	SE	32	21N	25EIM	200

APPENDIX B: CONCENTRATIONS (MG/L) OF CHEMICAL CONSTITUENTS IN GROUNDWATER SAMPLES COLLECTED IN JULY 1991

Site ID	Hardness	Alkalinity	TDS	Calcium	Magnesium	Sodium	Chloride	Fluoride	Nitrate as N	Sulfate	Barium	Iron	Zinc
22-1	187	180	204	58	2	<10	<10	<0.1	1.1	32	0.044	0.056	0.023
22-2	221	194	236	67	1	<10	<10	<0.1	1.8	49	0.067	0.113	<0.005
22-3	183	136	161	40	7	<10	<10	<0.1	<0.5	<20	0.048	0.069	<0.005
22-4	218	204	243	14	3	10	10	0.21	0.5	<20	0.106	<0.01	0.056
22-5	172	174	191	60	<1	<10	<10	0.12	<0.5	<20	0.053	0.014	<0.005
22-6	117	101	124	38	<1	<10	<10	<0.1	1	<20	0.031	0.062	<0.005
22-7	81	59	77	21	<1	<10	<10	<0.1	0.5	<20	<0.01	0.178	<0.005
22-8	236	214	255	76	1	<10	<10	<0.1	2.9	36	0.069	0.023	<0.005
22-9	236	221	251	72	2	<10	12	0.21	<0.5	31	0.042	0.011	<0.005
22-10	79	59	81	21	<1	<10	<10	<0.1	0.5	<20	0.031	0.081	<0.005
22-11	221	191	225	63	1	<10	<10	0.11	<0.5	<20	0.068	0.031	0.016
22-12	128	111	144	34	<1	<10	<10	<0.1	3	33	0.046	0.019	<0.005