In cooperation with the Oklahoma Water Resources Board

Geochemistry of the Arbuckle-Simpson Aquifer

Introduction

The Arbuckle-Simpson aquifer (fig. 1) in south-central Oklahoma provides water for public supply, farms, mining, wildlife conservation, recreation, and the scenic beauty of springs, streams, and waterfalls. A new understanding of the aquifer flow system was developed as part of the Arbuckle-Simpson Hydrology Study, done in 2003 through 2008 as a collaborative research project between the State of Oklahoma and the Federal government (Oklahoma Water Resources Board, 2003). The U.S. Geological Survey collected 36 water samples from 32 wells and springs (fig. 2) in the Arbuckle-Simpson aquifer in 2004 through 2006 for geochemical analyses of major ions, trace elements, isotopes of oxygen and hydrogen, dissolved gases, and dating tracers (Christenson and others, 2009). The geochemical analyses were used to characterize the water quality in the aquifer, to describe the origin and movement of ground water from recharge areas to discharge at wells and springs, and to determine the age of water in the aquifer.

Is the Water Safe to Drink?

Most of the water in the Arbuckle-Simpson aquifer is suitable for all regulated uses, including public drinking water supplies. Median concentration for dissolved solids was 347 milligrams per liter (mg/L), equivalent to parts per million. Hardness of water samples from the Arbuckle-Simpson aquifer ranged from 210 to 610 mg/L as calcium carbonate, which is considered to be very hard (Hem, 1985). Although not a health hazard, hard water can cause scaling in pipes and water fixtures. Two domestic wells produced water with nitrate concentrations that exceeded the nitrate maximum contaminant level (MCL) of 10 mg/L (U.S. Environmental Protection Agency, 2006), a health concern primarily for infants and pregnant women.

Samples from two wells exceeded the secondary maximum contaminant level (SMCL) for chloride of 250 mg/L, and also exceeded the SMCL of 500 mg/L for dissolved solids (U.S. Environmental Protection Agency, 2006). These two wells are flowing artesian wells located at the edge of the freshwater flow system and water from these wells is not used for public supply.

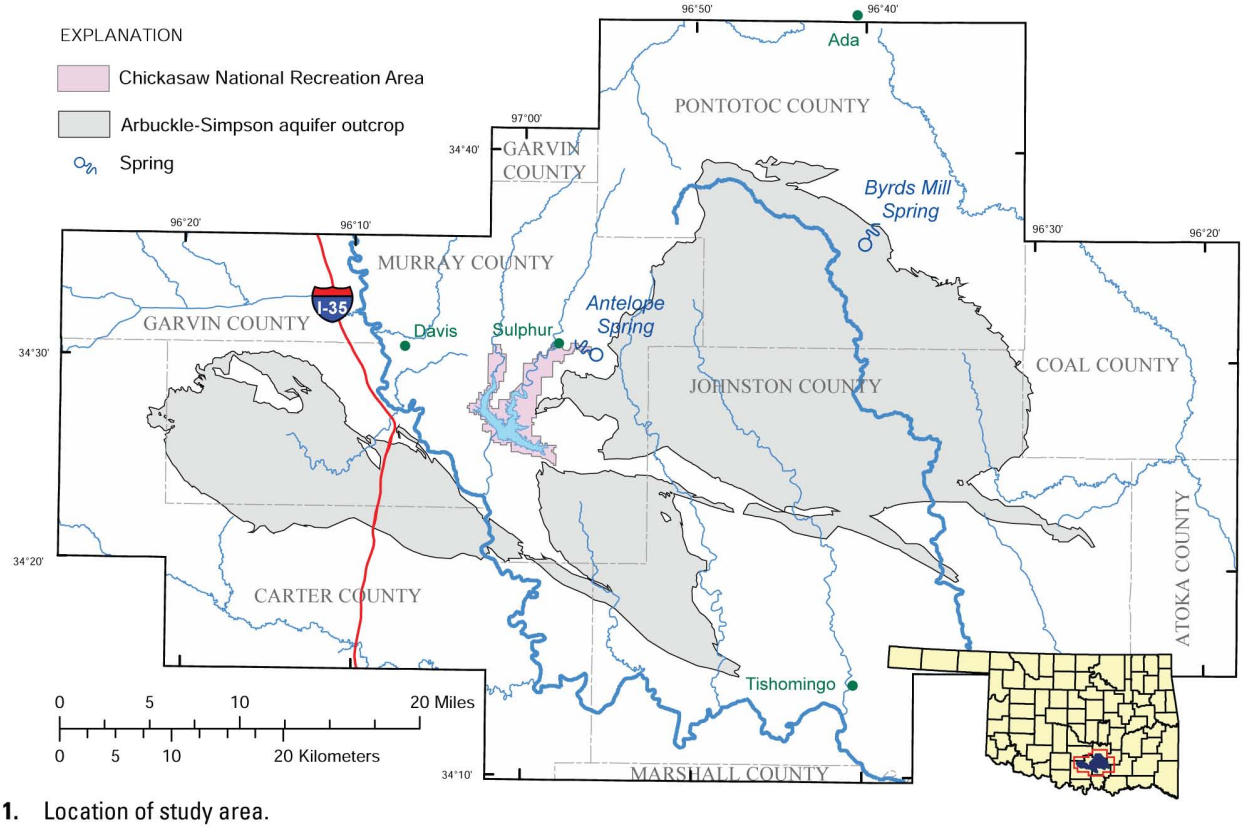


Figure 1. Location of study area.

Secondary maximum contaminant levels are established only as guidelines to assist public water systems in managing the drinking water for aesthetic considerations, such as taste, color, and odor. These chemical constituents are not considered to present a risk to human health.

No other water samples collected as part of the Arbuckle-Simpson Hydrology Study exceeded MCLs or SMCLs. However, not every chemical constituent for which the U.S. Environmental Protection Agency has established a MCL or SCML was analyzed as part of this investigation.

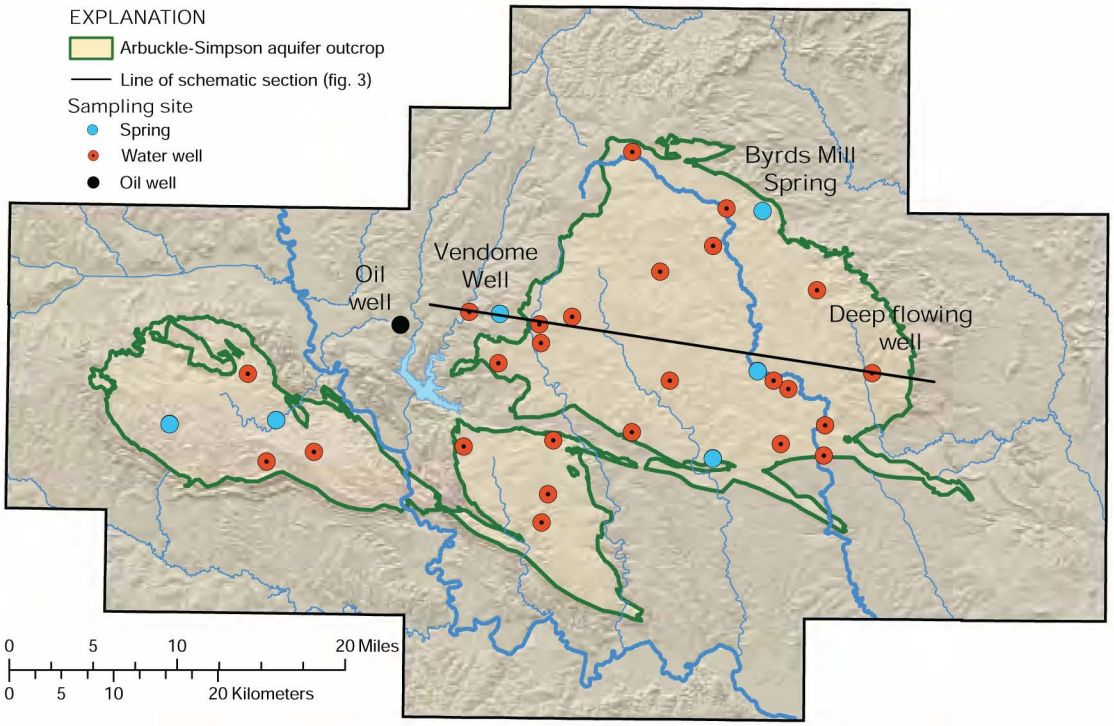


Figure 2. Geochemical sampling sites in the study area.

Origin and Movement of Water in the Aquifer

Ground water in the Arbuckle-Simpson aquifer originates as precipitation falling on the aquifer outcrop (where the Arbuckle and Simpson geologic units are found at the land surface). Thus, water in the aquifer is of local origin and does not come from great distances. Precipitation falling on the outcrop infiltrates into the soil zone, where the water evaporates or is transpired by plants back to the atmosphere, or continues down into the aquifer to become ground water.

The dominant rock types of the Arbuckle-Simpson aquifer are limestone (calcium carbonate) and dolomite (calcium magnesium carbonate). The water chemistry is produced by dissolving small amounts of minerals in these rocks primarily through the action of carbon dioxide (in the form of carbonic acid) introduced in the soil zone. The dissolution of the carbonate minerals causes the water to be very hard. Water containing mostly calcium bicarbonate is found in the western part of the aquifer, where the Arbuckle-Simpson aquifer is predominantly limestone. Calcium magnesium bicarbonate water is found in the eastern part of the aquifer, where the rock type is predominantly dolomite.

Water in the aquifer is constantly flowing and generally flows in the same direction as runoff, from topographically high areas to topographically low areas, to discharge at springs and streams. Typically, the time from precipitation entering the Arbuckle-Simpson aquifer to discharge at springs, streams, or wells is less than 60 years, which for ground water is a rapid flow system. However, not all water in the Arbuckle-Simpson aquifer discharges in a short period of time. Some of the water may take a deeper and longer flow path before discharging. Water flowing along these longer paths may take thousands of years to reach a discharge point.

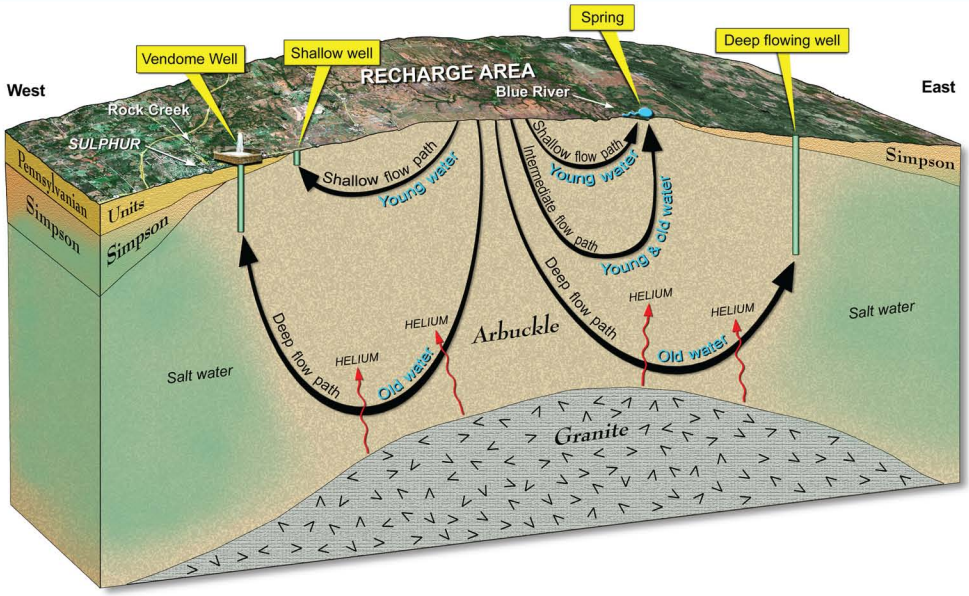


Figure 3. Schematic section showing flow paths of water in the Arbuckle-Simpson aquifer.

How do We Know the "Age" of Ground Water?

The age of a water sample is not really an age, but rather is the period of time since the water was in contact with the atmosphere. Water entering the aquifer has naturally occurring radioactive constituents that are produced only in the atmosphere and these constituents decay as the water moves through the aquifer. For the Arbuckle-Simpson Hydrology Study, ages were determined by using analyses of the isotopes tritium, helium-3, and carbon-14.

Tritium is a short-lived radioactive isotope of hydrogen with a half-life of 12.32 years. Tritium forms naturally as cosmic radiation interacts with nitrogen in the upper atmosphere and was a by-product of above-ground nuclear testing from the 1950s through the 1960s. Free tritium atoms are incorporated into water molecules in the atmosphere. This water, in the form of precipitation, falls to Earth containing small amounts of tritium and ultimately recharges the aquifer. Tritium is transformed by radioactive decay to daughter product helium-3, a rare isotope of helium. By measuring the tritium and helium-3 content from a ground-water sample, an apparent age can be determined because the rate that tritium decays to helium-3 is known. Eventually the tritium in a sample decays to the point that tritium can no longer be detected with instruments. Samples that contain detectable amounts of tritium are considered to be modern, meaning that the sample has been in the aquifer less than about 60 years. Samples that contain no detectable tritium are termed sub-modern and are older than 60 years. Most of the ground-water samples collected as part of the Arbuckle-Simpson Hydrology Study contained measurable tritium and are considered to be modern ground water with ages of a few decades or less. Even a deep test hole drilled as part of the Study had modern ground water at depths more than 1,490 feet. Aquifers that contain mostly modern water are vulnerable to contamination because contaminants introduced at the land surface may travel quickly through the aquifer.

Carbon-14 is the radioactive isotope of carbon with a half-life of 5,730 years. Carbon-14 is well known to the public as a tool for dating archeological sites, but carbon-14 also can be used to date ground water. Like tritium, carbon-14 is produced naturally in the upper atmosphere. Tritium dating of ground water is appropriate for ages of tens of years; whereas, carbon-14 dating of ground water is appropriate for ages of thousands of years. Water from Vendome Well (see sidebar) was about 10,500 years old as measured by using carbon-14.

How Deep is the Arbuckle-Simpson Aquifer?

The freshwater in all aquifers is underlain by saline water (water with dissolved-solids concentrations greater than about 10,000 mg/L) or by rocks of very low permeability that do not produce large quantities of water. The total thickness of an aquifer is not important to most users of ground water. Wells are drilled until a sufficient supply of freshwater is found and most wells in Oklahoma, including in the Arbuckle-Simpson aquifer, are less than 200 feet deep. A few wells in the Arbuckle-Simpson aquifer that produce large quantities of water, such as for municipal supplies, were drilled to about 1,000 feet. However, the maximum depth of freshwater in the Arbuckle-Simpson aquifer is still (2009) not known. A test well drilled as part of the Arbuckle-Simpson Hydrology Study to 1,820 feet found only freshwater.

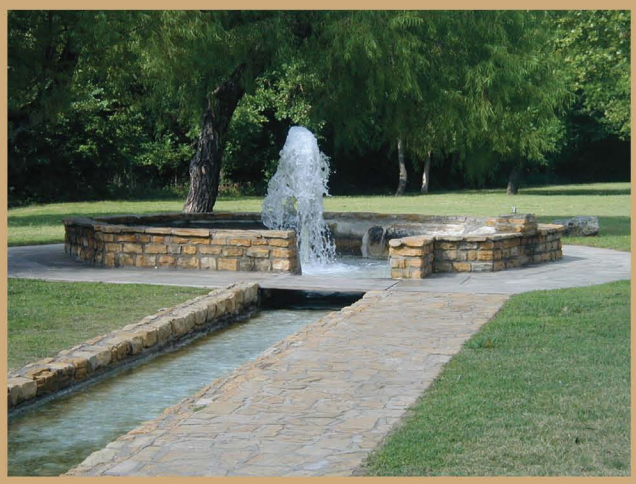
Water samples collected as part of this study provide information that water may be traveling at great depths in the aquifer. All naturally occurring water contains dissolved gases, such as the oxygen dissolved in lakes and streams needed for the survival of fish. Water samples from the Arbuckle-Simpson aquifer were analyzed for dissolved gases. Excess amounts of dissolved

Vendome Well

Vendome Well, in Chickasaw National Recreation Area near the town of Sulphur (figs. 2 and 3), may be the best-known well in Oklahoma (more than 3 million people visit the park each year). Vendome Well is an artesian well that naturally flows about 400 to 500 gallons per minute. The dissolved-solids concentration from a water sample from Vendome Well was 1,250 mg/L on October 20, 2004. Vendome Well produces water from the aquifer at the boundary of the freshwater and saline water zones. Water samples collected as part of the Arbuckle-Simpson Hydrology Study reveal that water discharging from Vendome Well is a mixture of about 99 percent water from the freshwater zone in the Arbuckle-Simpson aquifer and 1 percent brine from the saline water zone. Vendome Well produces small amounts of hydrogen sulfide gas, which is often described as a "rotten egg" smell. Hydrogen sulfide is consistent with the water from Vendome Well including some amount of brine. The brine component of the water from Vendome Well is likely responsible for the large concentrations of several of the trace elements (potassium, fluoride, bromide, iodide, ammonia, arsenic, boron, lithium, selenium, and strontium) found in water from the well.

Water from Vendome Well was dated at about 10,500 years before present by using carbon-14. The age of water from most of the other water samples collected as part of the Arbuckle-Simpson Hydrology Study were less than about 60 years old. The old water at Vendome Well indicates that the water that discharges at the well flows along long flow paths deep in the aquifer; whereas, younger water flows along shorter flow paths at shallower depths.

Concentrations of dissolved argon, neon, and xenon in water samples were used to determine the temperature of the water when it recharged the aquifer. The recharge temperature of water samples from Vendome Well was 6.6 degrees Celsius (44 degrees Fahrenheit), too cold to be associated with present day temperatures. The colder recharge temperature is consistent with recharge from an earlier, cooler time period.



Vendome Well in Chickasaw National Recreation Area near Sulphur.

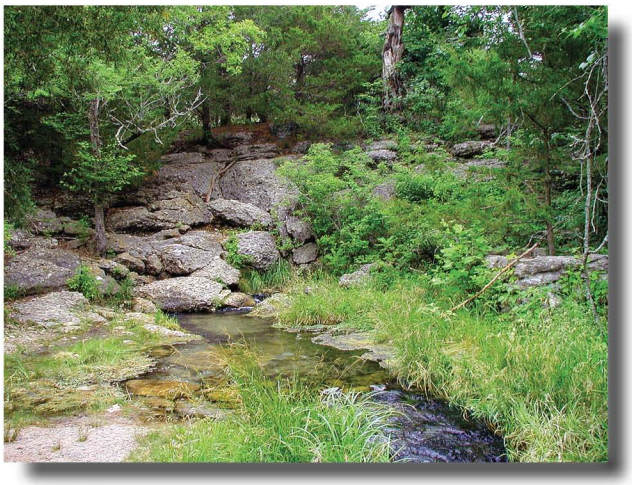
The mineral springs in the Chickasaw National Recreation Area were not studied as part of this investigation. However, based on location, the springs are almost certainly like Vendome Well in that the water discharged from the springs represents a mixture of water from the freshwater and saline zones of the Arbuckle-Simpson aquifer.

helium gas were measured in samples from some wells and springs. Excess helium in water samples is probably derived by the uptake of helium from crustal rocks as water travels along flow paths deep in the aquifer prior to arriving at the sampled site. At most locations, the crustal rocks are igneous rocks, such as granite, and are at least 3,500 feet below the land surface (fig. 3). Water samples from Vendome Well had high concentrations of excess helium indicating that the water flows along long flow paths deep in the aquifer (see Vendome Well sidebar).

Five springs had high concentrations of excess helium. Multiple flow paths often converge at springs. Although the water samples from these springs had modern ground-water ages, the excess helium in these samples indicated that at least some fraction of the water from these springs has flowed along a long, deep flow path before being discharged at the spring (fig. 3).

Springs

The springs of the Arbuckle-Simpson aquifer are well known for beauty, clarity, and good quality water. More than 140 springs discharge water from the Arbuckle-Simpson aquifer. Antelope and Buffalo Springs are major freshwater springs in the Chickasaw National Recreation Area. Byrds Mill Spring, the largest spring in Oklahoma, is the primary source of water for public supply for the city of Ada. The average flow from Byrds Mill Spring from 1989 to the present is about 8,000 gallons per minute.



Antelope Spring.

Springs are locations where water flowing through the aquifer discharges to the land surface. Thus, water samples from springs should chemically resemble water samples collected from wells completed in the same aquifer. Water samples were collected and analyzed from six springs in the freshwater zone of the Arbuckle-Simpson aquifer, including Byrds Mill Spring. Chemical analyses of spring-water samples closely resembled the analyses from wells, with dissolved-solids concentrations ranging from 322 to 361 mg/L.

Beyond the Freshwater Zone

The rocks that compose the Arbuckle-Simpson aquifer underlie most of Oklahoma, often at great depths. These rocks contain freshwater only where the rocks are at or near the land surface. Outside the freshwater zone, the water chemistry changes quickly and becomes saline. An oil well, completed in the Simpson Group about 4 miles west of Sulphur, Oklahoma, was sampled as part of the Arbuckle-Simpson Hydrology Study. The dominant dissolved constituents in the water were sodium and chloride, the same dominant constituents as seawater. Water from this oil well has a chloride concentration of 54,400 mg/L and is classified as brine (water with dissolved-solids concentration greater than about 35,000 mg/L). By comparison, seawater has a chloride concentration of about 19,000 mg/L. The large chloride concentrations and the ratios of other trace-element concentrations indicate that the brine formed by evaporation of seawater. This brine subsequently migrated into the geologic formations of the Arbuckle-Simpson aquifer and is still present in places.

The freshwater part of the Arbuckle-Simpson aquifer was, in the geologic past, buried at great depth and contained brine. These rocks were subsequently thrust to the land surface by tectonic (geologic) forces many millions of years ago, which allowed precipitation to infiltrate the aquifer and freshwater displaced the brine.

Selected References

Christenson, Scott, Hunt, A.G., and Parkhurst, D.L., 2009, Geochemical investigation of the Arbuckle-Simpson aquifer, south-central Oklahoma, 2004–06: U.S. Geological Survey Scientific Investigations Report 2009–5036.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Oklahoma Water Resources Board, 2003, The Arbuckle-Simpson Hydrology Study: Oklahoma City, Oklahoma Water Resources Board Fact Sheet, 4 p.

U.S. Environmental Protection Agency, 2006, Drinking water contaminants: accessed June 24, 2006, at *http://www.epa.gov/safewater/contaminants/index.html#listmcl*

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This fact sheet is based on U.S. Geological Survey Scientific Investigations Report 2009–5036, "Geochemical investigation of the Arbuckle-Simpson aquifer, south-central Oklahoma, 2004–06" by Scott Christenson, Andrew G. Hunt, and David L. Parkhurst.

Copies of that report can be purchased from U.S. Geological Survey, Information Services, Box 25286, Denver, CO 80225–0286.

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