# Kansas Geological Survey

## THE SOUTHEAST KANSAS OZARK AQUIFER WATER SUPPLY PROGRAM

## PHASE 1 PROJECT RESULTS

**By**

**P. A. Macfarlane, J.M. Healey, and B.B. Wilson**

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**Executive Summary**

Historically, the Ozark Plateaus aquifer system has been the single most important source of water in the Tri-State region of southeast Kansas, southwest Missouri, and northeastern Oklahoma. Recent concerns have been raised that the available supply from this source may become inadequate, rendered unusable, or require additional water treatment in the near future because of: (1) recent and projected population growth that will create increased demand for water by public supplies and some industries; (2) potential upward vertical or eastward migration of saline water into public supply wells due to pumping, if pumping rates or wellfield size are increased to keep up with demand; and (3) possible contamination of ground-water supplies by downward moving leachate derived from mine tailings piles and the mine water contained in the abandoned open shafts.

In response to these concerns the Kansas Water Office contracted with the Kansas Geological Survey (KGS) to evaluate and redesign the existing ground-water-level monitoring network in southeast Kansas. To meet the project goal, spring and fall 2004 surveys were conducted to measure the depth to water in municipal, rural water district, and industrial wells tapping sources in the Ozark aquifer portion of the Ozark Plateaus aquifer system. The 2004 depth to water measurements were made in many of the wells visited in 1979-81 as part of a previous KGS research effort. Analyses of water-level trends in the hydrographs from monitoring wells in southeast Kansas and southwest Missouri were conducted along with water use and population trends in Crawford and Cherokee counties to assess long-term impacts from development.

The results showed significant water-level declines in the Pittsburg-Frontenac area and significant water-level rises in one of the Galena and two of the Baxter Springs wells. The depth to water remained relatively unchanged in the other wells of eastern Cherokee and Crawford counties. Analysis of the hydrographs from Crawford and Cherokee county wells and from wells in adjacent southwest Missouri reveals long-term trends consistent with the water-level changes determined from a comparison of the 1979-81 and 2004 surveys. Changes in water use and in population from 1981-2003 and projected changes in county population suggest that water demand may increase in eastern Crawford County into the future.

Recommendations for the redesign of the Ozark aquifer monitoring network in southeast Kansas were based on (1) the water-level declines in wells tapping the Ozark aquifer, (2) the past and projected water-use and population trends for Crawford and Cherokee counties, (3) the location

of pumping centers in southwest Missouri near the border with Kansas, and (4) the effect of aquifer properties and local pumping on the long- and short-term water-level trends.  The recommendations are:

- Semi-annual water-level surveys are needed for Cherokee and Crawford counties and in the adjacent counties of southwest Missouri to monitor short- and long-term water level changes in Ozark aquifer wells.

- On-going targeted data collection needs to be conducted in the Pittsburg and in the Baxter Springs-Galena areas to monitor ground-water withdrawals from the Ozark aquifer and water-level declines. A regional scale Ozark aquifer coalesced cone of depression continues to expand and deepen in southeastern Crawford and northeastern Cherokee counties in Kansas and southwestern Barton and northwestern Jasper counties in Missouri.

- Observation wells need to be installed or unused wells need to be secured for dedicated long-term monitoring of water levels in the Ozark Plateaus aquifer system.  In Crawford County, one site should be located east of Pittsburg on the Kansas-Missouri border and another located west of Kansas Highway 7.  In Cherokee County, a new site to monitor water levels in the Ozark and Springfield Plateaus aquifers should be installed in the Baxter Springs-Galena area if existing unused wells in proximity to each other cannot be secured for this purpose.

## Introduction

Historically, the Ozark Plateaus aquifer system has been the single most important source of water in the Tri-State region of southeast Kansas, southwest Missouri, and northeastern Oklahoma. Beginning in the late 19$^{th}$ century pumping from the Ozark Plateaus aquifer system dewatered the lead-zinc mines in the Picher and Joplin fields. Ground water was primarily used for mining and milling activities in the Joplin and Picher fields and the coal fields farther north in Cherokee and Crawford counties. The Ozark aquifer was secondarily used for drinking water by public supplies. With the decline of the mining industry in the mid 20$^{th}$ century the primary use of water from the Ozark aquifer has been for drinking water for public supplies and for industries other than mining (Stramel, 1957). Macfarlane and Hathaway (1987) reported that all of the municipal and most of the rural water districts in Crawford and Cherokee counties in Kansas and in the adjacent Missouri and Oklahoma counties relied primarily or solely on sources from this regional aquifer system. In 2004 some of the public supplies in western Crawford and Cherokee counties had abandoned the Ozark Plateaus aquifer system as a source of supply because of poor water quality.

Concerns have been raised in the Tri-state region that the available supply from the Ozark Plateaus aquifer system may become inadequate, rendered unusable, or require additional water treatment in the near future because of:

1. Recent and projected population growth that will create increased demand for water by public supplies and some industries;
2. Potential upward vertical or eastward migration of saline water into public supply wells due to pumping, if pumping rates or wellfield size are increased to keep up with demand; and
3. Possible contamination of ground-water supplies by downward moving leachate derived from mine tailings piles and the mine water contained in the abandoned open shafts.

The Missouri-American Water Company contracted with Wittman Hydro Planning Associates to assess future regional aquifer system water supply availability in the area of Joplin, Missouri (Wittman, et al., 2003). Wittman et al. cited the need to expand to water utilities; the increased reliance of public supplies on the regional aquifer to meet those demands; and the limitations imposed by the aquifer on water availability because of well interference. The consultants also speculated on the potential for future contamination of the deep aquifer (the Ozark) from past mining activities in the Joplin field. Four recommendations from their report are worth mentioning here:

1. Additional data are required for reliable management of the groundwater resource;
2. A cooperative effort will be needed to protect the Ozark aquifer from contamination;
3. Only a cooperative regional response will create new water-supply options; and
4. Missouri DNR should collect additional data and encourage cooperation.

In response to the 3 concerns cited previously, recent water supply problems that have occurred in southeast Cherokee County, and the conclusions of the Wittman et al. (2003) report, the Kansas Water Office contracted with the Kansas Geological Survey (KGS) to evaluate and redesign the existing ground-water-level monitoring network in southeast Kansas. The goals of the study are to:

1. Determine how water levels have changed in wells tapping the Ozark Plateaus Aquifer System in Crawford and Cherokee counties, southeast Kansas, since the 1980 KGS survey and determine seasonal water-level changes.
2. Determine if the wells in the existing monitoring network adequately characterize water-level changes since 1980 and are located in the areas of the aquifer experiencing the greatest changes.
3. During the study conduct high-frequency water-level data collection in 2 unused wells to assess in detail water-level fluctuations caused by turning the pumps in nearby wells on and off, and from seasonal water use near the Kansas-Missouri border.

The KGS was able to complete a May and December 2004 survey of water levels in wells producing from the Ozark Plateaus aquifer system. Hydrographs of monitored wells in southeast Kansas and southwest Missouri and water-use and population data were obtained and analyzed to address the second study goal. The third study goal was not completed because only two unused wells were located in Cherokee County and these were judged not to be suitable for long-term monitoring.

To help put in perspective the results of the 2004 water-level surveys of wells in southeast Kansas, the report begins with summary background information on the pre-development hydrogeology of the Ozark Plateaus aquifer system in the Tri-state region. Following this section we present the results of the spring and fall 2004 water-level surveys and compare the 2004 data with results obtained from similar surveys conducted in 1980 by the KGS. The next section of the report summarizes previous efforts to establish and maintain a water-level monitoring network for the Ozark aquifer in southeast Kansas and provides an evaluation of the results. The final section of the report contains recommendations for long-term water level and water quality monitoring based on the results of the 2004 water-level surveys and other data.

## Ozark Plateaus Aquifer System Hydrogeology in the Tri-state Region

### Aquifer and confining units

Ozark Plateaus Aquifer System in Kansas and Missouri consists of karstified and fractured carbonate rock units of Upper Cambrian, Lower Ordovician, and Mississippian age and has been subdivided into the Springfield Plateau, Ozark, and St. Francois regional aquifers (Jorgensen et al., 1993; Macfarlane, 2000; Table 1). Ozark Plateaus aquifer system thickness ranges from 1,735 feet in the Joplin, Missouri, area to 1,390 feet at Parsons, Kansas (Macfarlane and Hathaway, 1987). One or more low-permeability stratigraphic units separate these regional aquifers and act as a confining layer above and below the Ozark aquifer (Figure 1). The Ozark Plateaus aquifer system is confined above by a sequence of Pennsylvanian shales and limestones and below by rocks of Precambrian age. The strata that form the Ozark Plateaus aquifer system are at the surface or at shallow depths in southwest Missouri and progressively increase in depth in the direction of southeast Kansas (Figure 2). In southeast Cherokee County, the strata that

| Era | System | Rock Stratigraphic Unit | Aquifer/Confining Unit | |
|---|---|---|---|---|
| Paleozoic | Pennsylvanian | | Confining unit | Confining unit |
| | Mississippian | | Springfield Plateau aquifer | Ozark Plateaus aquifer system |
| | | Northview Shale Compton Limestone | Confining unit | |
| | Mississippian-Devonian | Chattanooga Shale | | |
| | Ordovician | Powell Dolomite | Ozark aquifer | |
| | | Cotter Dolomite | | |
| | | Jefferson City Dolomite | | |
| | | Roubidoux Formation | | |
| | | Gasconade Dolomite | | |
| | Cambrian | Eminence Dolomite | | |
| | | Potosi Dolomite | | |
| | | Derby-Doe Run Dolomoite | Confining unit | |
| | | Davis Formation | | |
| | | Reagan Sandstone | St. Francois aquifer | |
| Precambrian | | | Confining unit | Confining unit |

Table 1. Rock units and aquifer and confining units that form the Ozark Plateaus aquifer system in the Tri-state region of southeast Kansas, southwest Missouri, and northeast Oklahoma.

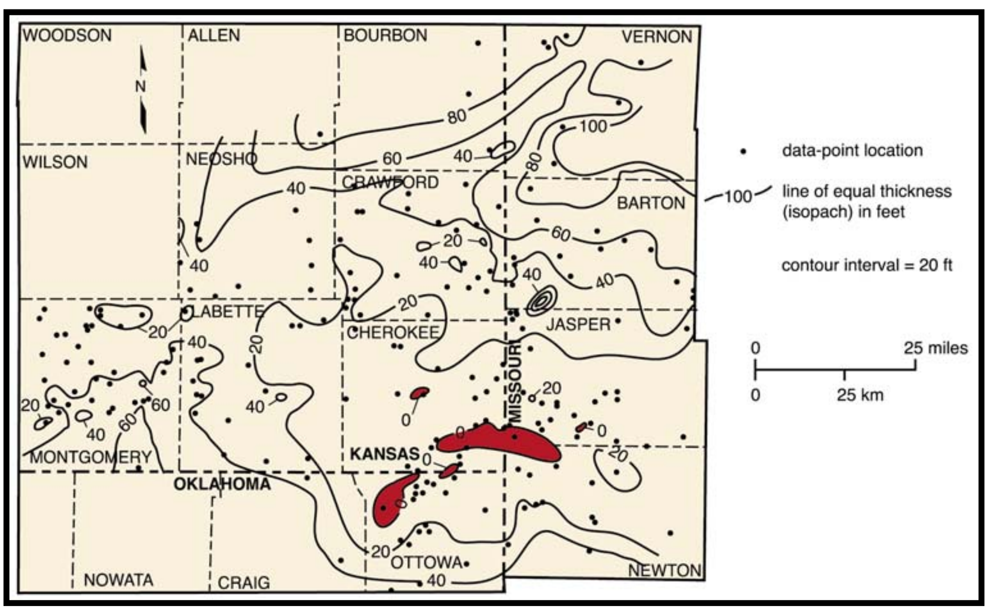



Figure 1. Thickness of the confining layer separating the Springfield Plateau aquifer from the underlying Ozark aquifer in the Tri-state region of southeast Kansas, southwest Missouri, and northeast Oklahoma. Taken from Macfarlane and Hathaway (1987).

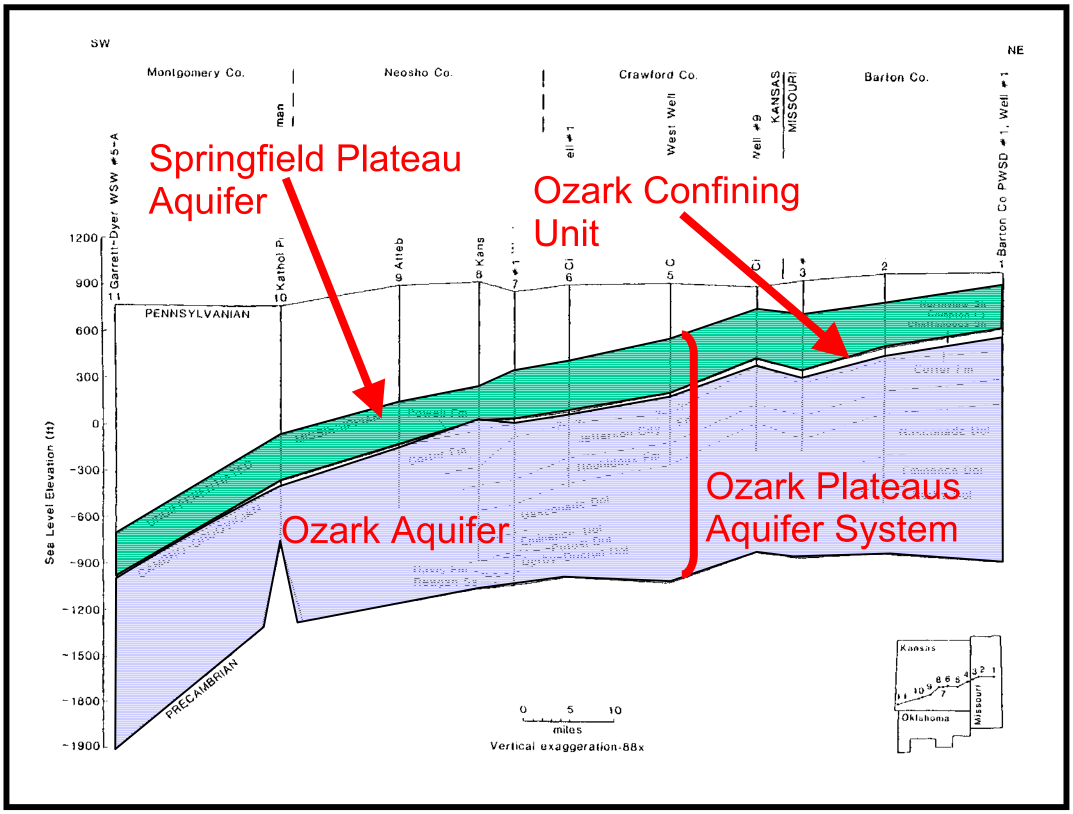



Figure 2. Hydrogeologic vertical section from southwest Missouri across southeast Kansas showing the increasing depth to the top of the Ozark Plateaus aquifer system.

from the Springfield Plateau aquifer are at the surface and the top of the Ozark aquifer is within 300 feet of the surface. At Pittsburg the top of Springfield Plateau aquifer is within 200 feet of the surface and the depth to the top of the Ozark aquifer from the surface is on the order of 450 feet.

Lower Ordovician and the Cambrian rock units above the Reagan Sandstone are referred to collectively as the Arbuckle Group in southeast Kansas (Zeller, 1968). Westward of the Tri-state region the Ozark Plateaus aquifer system has been referred to as the Western Interior Plains aquifer system and the hydrologic boundary between these aquifer systems has been defined as the 2,500-mg/L isochlor (Jorgensen et al., 1993; Hansen and Jurachek, 1995). In this report, the Western Interior Plains aquifer is not recognized as an aquifer separate from the Ozark Plateaus aquifer system following the aquifer nomenclature in established in Macfarlane (2000).

## Predevelopment Ground-water Flow System

To define the pattern of moving ground water in a flow system, hydrogeologists use measurements of water-level elevation taken in wells scattered throughout the aquifer system. In most cases, the water-level elevation above mean sea level in a well is equal to the hydraulic head in the region of the aquifer adjacent to the well screen. For a confined aquifer the mapped hydraulic head surface is referred to as the potentiometric surface, which is analogous to but not the same as the water table for an unconfined aquifer situation. In a confined aquifer the hydraulic head is above the top of the aquifer. As long as water levels remain above the top of the aquifer, changes in water level in wells represent changes in fluid pressure within the aquifer and not changes in the amount of water in storage.

The predevelopment potentiometric surface of the confined Ozark Plateaus aquifer system provides information on ground-water flow patterns as they existed prior to large-scale pumping of the aquifer and serves as a base line to gauge hydraulic head changes in the system due to well pumping. The earliest available measurements of water-level elevation reported on logs and literature for the Tri-state region were used to produce the pre-development potentiometric surface map shown in Figure 3. The pattern of decreasing hydraulic head away from the Ozark region of southern Missouri shows the westerly and northwesterly direction of regional ground water flow. In Cherokee and Crawford counties in Kansas hydraulic heads were slightly higher than or at the same elevation in the Springfield Plateau aquifer as those in the Ozark aquifer indicating a slight tendency for downward movement of ground water across the confining layer as leakage (Imes and Emmett, 1994). Using the US Geological Survey CM RASA ground-water flow model for the Ozark region, Witmann et al., (2003) estimated that Springfield Plateau aquifer leakage provided less than 30 million gallons per day (less than 0.5 in per year) of recharge to the Ozark aquifer and the total flow moving through the Ozark aquifer in Jasper and Newton counties in Missouri was in the range of 50-60 million gallons per day under pre-development.

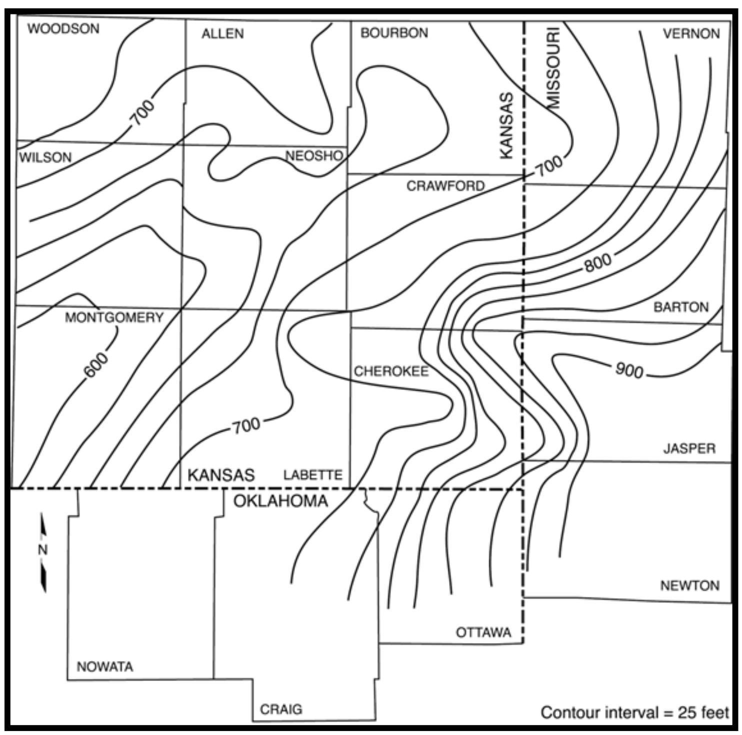



Figure 3. The predevelopment potentiometric surface of the Ozark aquifer in the Tri-state region of southeast Kansas, southwest Missouri, and northeast Oklahoma. Taken from Macfarlane et al. (1981).

## Aquifer Properties

The transmissivity and storativity aquifer properties quantify the ease with which water is transmitted through the entire thickness of the aquifer and the volume of water released from the aquifer to a pumping well per unit surface area per unit decline in hydraulic head, respectively (Freeze and Cherry, 1979). Few values of the properties are available from pumping tests in the Tri-state region and the published data are listed in Table 2.

## Water Quality

The chemical quality of ground water in the Ozark Plateaus aquifer system evolves along the flow path from southwest Missouri into southeast Kansas (Figure 4) and based on very limited data it is presumed that a similar change in chemical quality occurs vertically with depth within the aquifer system. Where the aquifer is in the near-surface environment the ground water is a calcium-bicarbonate to calcium-magnesium bicarbonate type with low concentrations of total dissolved solids (generally less than 500 mg/L). Farther west where the aquifer system is in the deep subsurface and isolated hydraulically from the near-surface environment, the ground water is a sodium chloride type with high concentrations of total dissolved solids (generally greater than 5,000 mg/L). In between these two areas is a 20-mile to 30-mile wide zone where the water quality changes gradually from one end member to the other.

It is likely that a water-quality transition vertically separates lower salinity ground water near the top of the aquifer from higher salinity ground water deeper in the aquifer. Water quality data from vertical sampling during drilling is largely unavailable, except in a few cases reported in

| Location | Aquifer(s) | Type of Test | Aquifer Properties | | Source |
|---|---|---|---|---|---|
| | | | Transmissivity ($ft^2$/day) | Storativity (Dimensionless) | |
| B.F. Goodrich Plant Miami, OK | Ozark | Multiple drawdown & recovery pumping tests | 5,100 | $8.00 \times 10^{-5}$ | Reed et al. (1955) |
| Municipal wells Pittsburg, KS | Springfield Plateau & Ozark | Multiple drawdown & recovery pumping tests | 33,800 | $7.8 \times 10^{-4}$ | Stramel (1957) |
| Municipal wells Webb City, MO | Ozark | 24-hr Well interference test | 540 | $2 \times 10^{-4}$ | Feder et al. (1969) |

Table 2. Aquifer properties values derived from well tests in the Tri-state region. Taken from Macfarlane and Hathaway (1987).

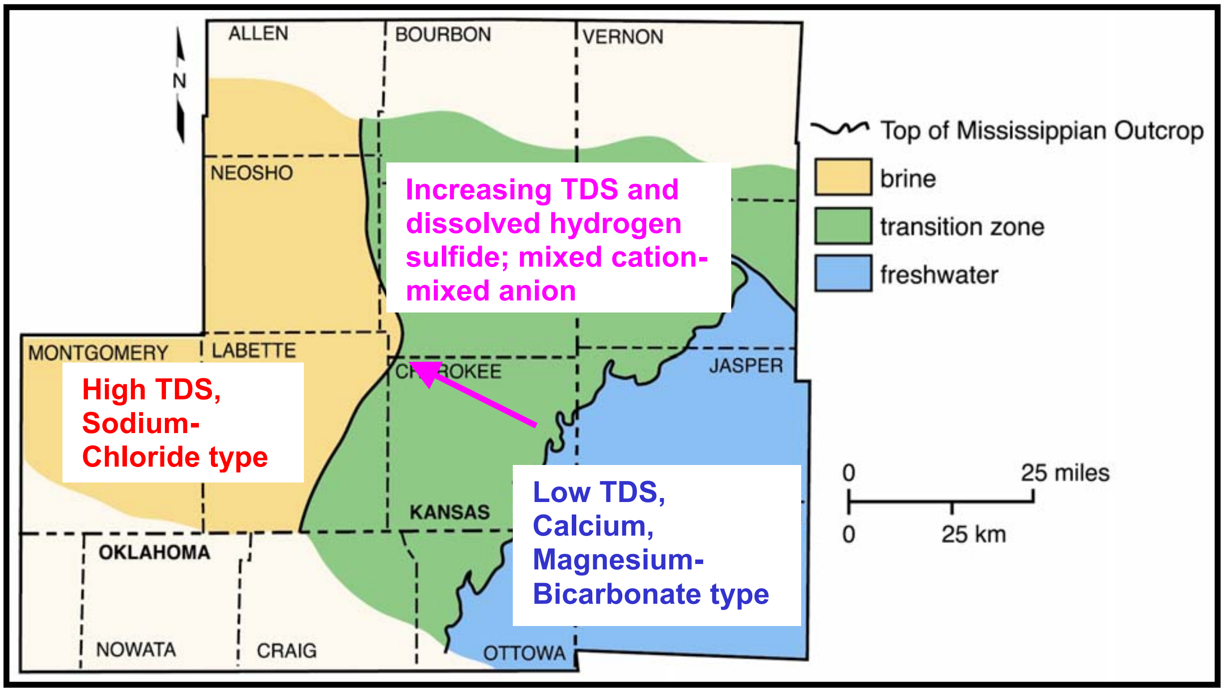



Figure 4. General characterization of ground-water quality in the Ozark aquifer in southeast Kansas, southwest Missouri, and northeast Oklahoma. Taken from Macfarlane and Hathaway (1987).

Macfarlane et al. (1981). More telling is the change in well completion depth relative to the Ozark aquifer top from eastern to western Crawford and Cherokee counties. Presumably municipal and rural water district suppliers would seek the best water quality possible at a given location, but would want to have their wells completed an acceptable vertical distance (a buffer interval) above the poorer quality water in the aquifer. Near the state line with Missouri, wells in the Ozark aquifer generally have open-hole completions through the upper 500 feet to 800 feet of the aquifer. Open-hole completions through the Ozark aquifer are less than 100 feet in west central and northwest Crawford County and 472 feet to 584 feet in northwestern Cherokee and southwestern Crawford counties.

**Impact of Water Use on the Ozark Plateaus Aquifer System**

Distribution of Wells in the Tri-state Region Visited in the 1979-81 KGS Surveys

KGS personnel visited wells tapping the Ozark Plateaus aquifer system in 1979-1981 in southeast Kansas and the adjacent counties in Missouri and Oklahoma to obtain depth-to-water data (Appendix 1). Depth-to-water measurements were taken in 71 wells. September 1979 and May 1980 depth-to-water measurements are available for most of the wells used for public water supply. Depth to water measurements were taken in oil-field water supply wells in Neosho and Bourbon counties during June 1981. Wells included in the surveys tapped sources of water either in the Ozark or the Ozark and the Springfield Plateau aquifers. Some of the multiple-completion wells were also open to the local aquifers within the lower part of the Pennsylvanian age sequence of rocks. Additional depth-to-water data were found in records from completed and abandoned wells and added to the water-level database. Most of these data come from areas where the aquifer system is little used for water supply primarily because of water quality issues.

1979-81 Ozark Aquifer Potentiometric Surface Map

The Ozark Plateaus aquifer system has been used extensively for water supply since the early 19th century. Withdrawals from the aquifer have resulted in a lowering of the aquifer potentiometric surface. This lowering is clearly illustrated when the 1979-1981 potentiometric surface (Figure 5) is compared with what is believed to be the predevelopment potentiometric surface (Figure 3). In southeast Kansas outside of the main areas where development has been ongoing since the early 1900s, potentiometric surface declines were lower, on the order of 50 feet or less. Where many users in localized areas tap the Ozark for water supply, declines have been much greater, such as at Pittsburg where water levels in wells had declined by more than 150 feet from 1880 to 1980 (Figure 6). Frontenac, Girard, and Rural Water Districts 4 and 5 on the Kansas side of the state line and Empire District Electric and Mindenmines on the Missouri side all withdraw water from wells in the vicinity of the older and newer Pittsburg wellfields. Farther south between Baxter Springs, Kansas, and Miami, Oklahoma, an extensive and very deep cone of depression had formed due to water use for mining, manufacturing at

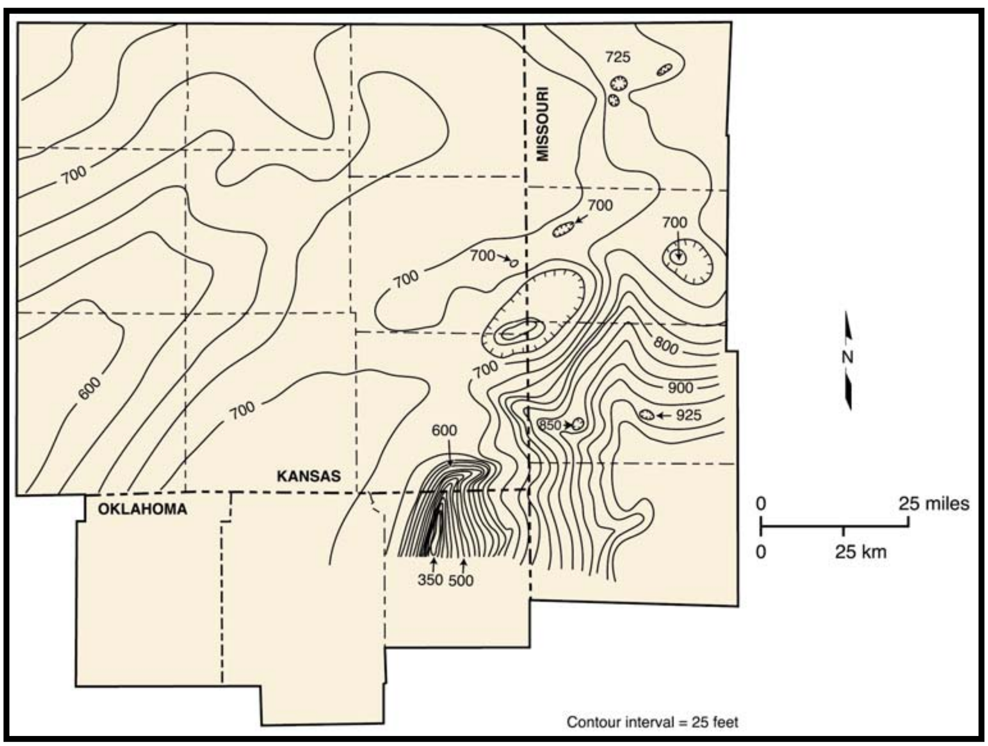



Figure 5. 1979-81 Configuration of the potentiometric surface in the Ozark aquifer in southeast Kansas, southwest Missouri, and northeast Oklahoma. Taken from Macfarlane and Hathaway (1987).

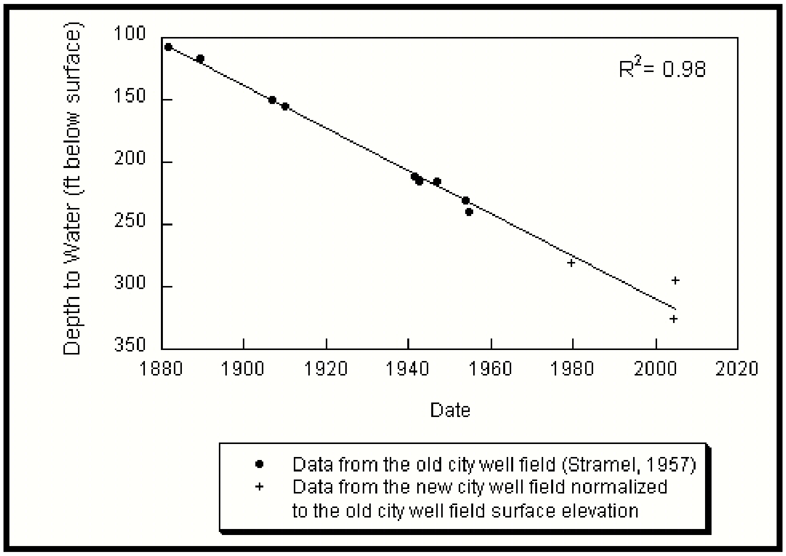



Figure 6. Water level hydrograph for the Ozark Plateaus aquifer system in the Pittsburg, Kansas, area.

Miami, electric power generation, and public water supplies on both sides of the Kansas-Oklahoma border, including Miami, Commerce, and Picher in Oklahoma and Baxter Springs and Treece in Kansas. Static water levels in the vicinity of the B.F Goodrich plant in Miami had in 1980 declined by more than 450 feet since development began. It appears that declines in the potentiometric surface had not been very large in the Joplin area by 1981, perhaps because of low demand on the aquifer. Feder et al. (1969) estimated the total average 1965 water use public supplies and industrial use in the Joplin area to be 18.4 million gallons per day of which only one-third was supplied by deep wells tapping sources in the Ozark aquifer (approximately 62,000 acre-feet per year). Mines, springs, and surface water supplied the remainder.

## The 2004 Surveys of Ozark Plateaus Aquifer System Wells in Southeast Kansas

Water-level surveys of wells tapping the Ozark Plateaus aquifer system were conducted in May and December 2004 in Crawford and Cherokee counties in southeast Kansas. Prior to the spring survey, a reconnaissance was taken to locate new wells that would be included in the surveys and to eliminate wells from the surveys that had been plugged or were otherwise unsuitable for measurement. Appendix 1 contains a list of the wells that were to be included in the surveys along with their latitude and longitude (determined from their global positioning system [GPS] location). Depth-to-water measurements were taken in 33 wells and 31 wells during the May and December surveys, respectively.

Not all the wells visited in the 1979-81 water-level surveys were available or could be visited during both 2004 surveys. In Crawford County the Rural Water District #7 wells had been abandoned and plugged and the district was no longer in existence. The city of Girard had abandoned and plugged its well at the city water plant in favor of its more recently constructed wellfield several miles south of town. Crawford County Rural Water District #2 abandoned its deep well for water supply. The well was not plugged but had been used by the Division of Water Resources, Kansas Department of Agriculture, as a monitoring point. Because there was no access to the well for the spring survey, only a December depth-to-water measurement was made in this well. Because a suitable time for measurement could not be arranged during the surveys, depth-to-water measurements were not made in December at the Cherokee County Rural Water District #1 wells and in May and December at the supply wells for Mulberry and Capaldo in Crawford County. At Baxter Springs, city well #1 had been abandoned and a December measurement was not taken in city well #6. A total of 18 wells were included in the 2004 well surveys that had been measured during the 1979-81 period.

Several new wells had been constructed and new rural water districts had formed since the 1979-81 surveys. In Crawford County Arcadia, Girard, and Rural Water Districts #4 and #5 had each added new wells to their existing fields and Consolidated Rural Water District #1 had formed and had drilled 2 new wells less than 100 feet apart. To the south in Cherokee County, a new supply well had been completed at Jayhawk Fine Chemicals and the old Jayhawk Ordnance Works well had been abandoned, but not plugged. Cherokee County Rural Water Districts #8 and #9 had formed. District #8 had drilled 2 new wells and District #9 at Riverton buys water from Empire District Electric, Riverton, and obtains it from a new well near the plant site.

For most of the wells depth-to-water measurements were made using a chalked steel tape. The elevation of the land surface in the vicinity was estimated using 7.5-minute quadrangle US Geological Survey topographic maps with a 10-foot contour interval. The height of the measurement point for the depth-to-water measurement above or below land surface was estimated using a measurement tape. The elevation of the water level in the well above sea level was calculated as the difference between the elevation of the measurement point above sea level and to depth to the water level from the measurement point. In a few cases only an air line was available. To estimate the height of the water column above the bottom of the air line (usually at the level of the top of the pump) compressed air was added to the air line until a maximum reading on a gauge in feet of water or pressure was attained. Knowing the depth to the bottom of the airline from surface, the depth to water in the well was calculated as the sum of the elevation of the bottom of the airline and the height of the column of water in the well above the bottom of the airline. With one exception, none of the operators could provide KGS personnel with information from their records on the depth to the bottom of the airline in their wells from surface. As a result most of the airline measurements could not be used meaningfully.

Conditions inside the well bore and the timing of the depth to water measurement with respect to when the pump last shut down influence the accuracy of determining the true static hydraulic head in the aquifer. For some of the wells it was difficult to determine the water level on the chalked part of the tape. This could have happened for several reasons, including partial wetting of the tape above the static water level from water clinging to the inside of the casing, the buildup of iron oxide slime on the pump column and casing, casing leaks, and oil at top of the water column in the well.

Recovery of the water level back to static condition in the well depends on the transmissivity and storativity of the aquifer, and the rate and duration of pumping that precedes the recovery.

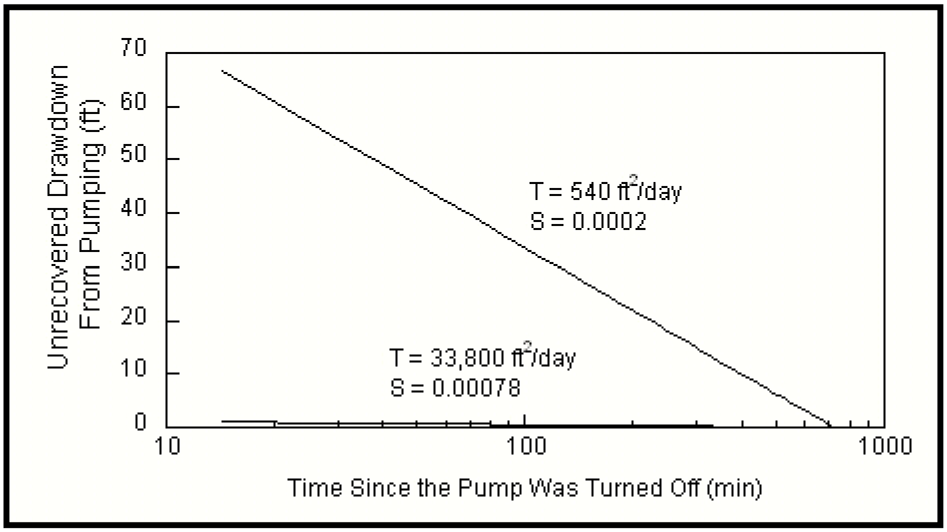
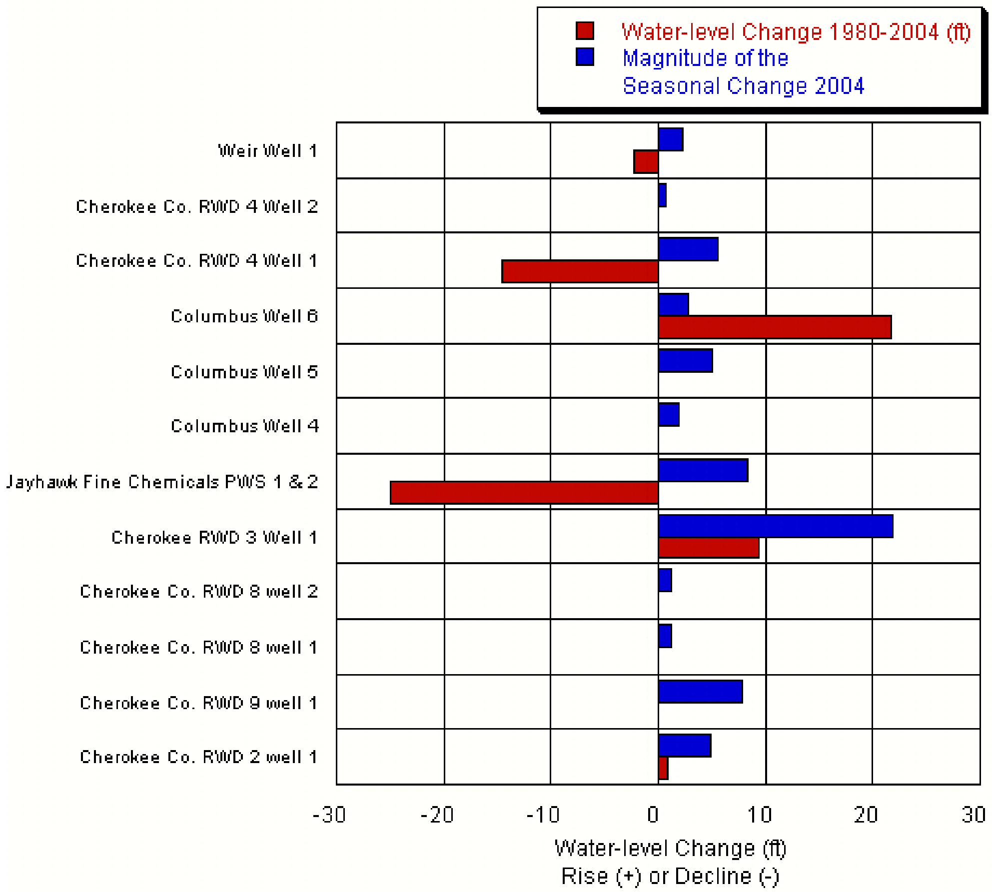



Figure 7. Theoretical unrecovered drawdown from pumping a well at 600 gallons per minute for 6 hours in two homogeneous and isotropic confined aquifers with differing transmissivity and storativity properties values. Curves calculated using the Cooper and Jacob (1946) approximate solution to the equation for flow in a confined aquifer in radial coordinates.

Recovery is more rapid where aquifer transmissivity and storativity are higher (Figure 7). The recovery period is also longer if the rate of pumping is high or the well is pumped for longer periods of time. To evaluate or compare water levels it is important know when the pump shut down and for how long the well had been pumped, assuming a constant pumping rate. Whenever possible, some estimate of the time interval between pump shut down and measurement was made and recorded in the field notes. In most cases, the wells pump water from the well on demand and not on a fixed schedule. Typically, estimates of pumping duration and timing are highly uncertain.

## Results of the 2004 Surveys

The spring 2004 depth-to-water measurements in wells that also were measured in the spring of 1980 in southeast Kansas are presented in Appendix 1 and the changes in the depth to water below surface are illustrated as bar graphs in Figures 8 and 9. Also shown for each well is the magnitude of the net change in depth to water between the May and December measurements. Taken at face value, the 1979-81 and the 2004 measurements for each well are only two points in time and provide no information on water-level fluctuations that occurred during the time between measurements. Hence, the water-level changes derived from the data should not be interpreted in isolation as indicating a trend in the measurements but should be considered as net changes. Some indication of the significance of these changes in depth to water can be determined by comparing them to the magnitude of the May to December 2004 water-level change for each well.



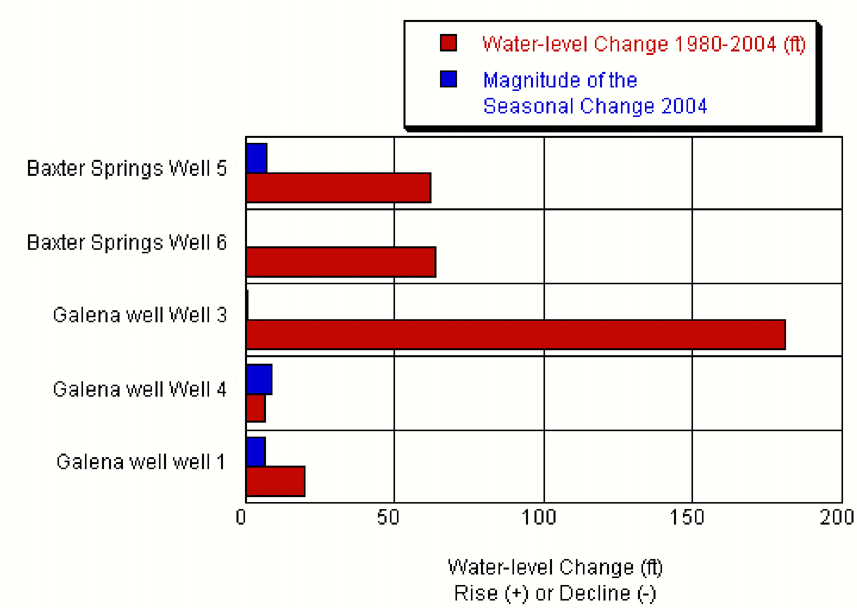




Figure 8. Long term (1980-2004) and the 2004 seasonal water-level changes in wells tapping the Ozark aquifer in Cherokee County, Kansas.

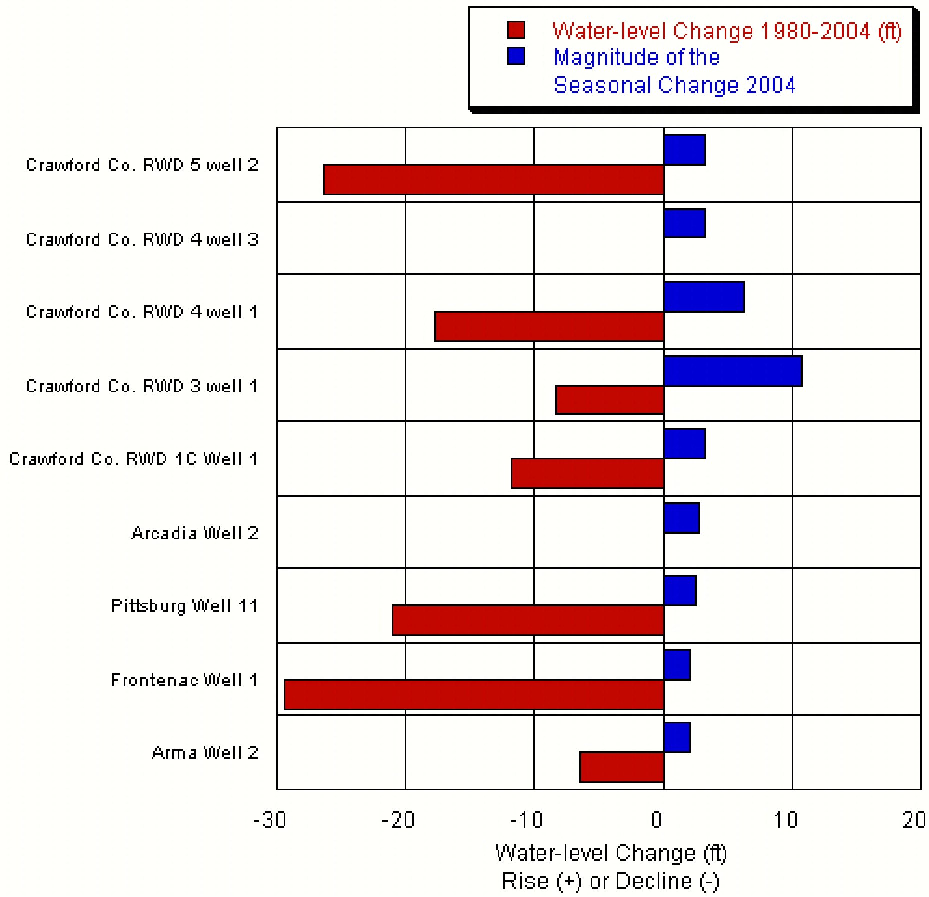



Figure 9. Long term (1980-2004) and the 2004 seasonal water-level changes in wells tapping the Ozark aquifer in Crawford County, Kansas.

The most pronounced water-level change has occurred in the Galena supply well 3, which has not been in use for more than 18 months. In this well the water level has recovered more than 150 feet since it was last measured in May 1980. The large water-level recovery value is misleading in that Galena 3 and other nearby wells on the Eagle Picher Agricultural Chemicals Division plant site were in operation. None of these wells were in operation at the time of the 2004 measurements. Galena has been purchasing water from the Missouri American Water Company since late in 2002.

Baxter Springs supply wells 5 and 6 also appear to have recovered more than 50 feet since depth-to-water measurements were taken in May 1980. Smaller water-level rises have occurred Columbus supply well 6.

In eastern Crawford County net water-level declines have occurred in the more populated urban areas of Pittsburg (21 feet), Frontenac (29.4 feet), in well 1 of Crawford County Rural Water District 5 (26.4 feet), and in well 1 of Crawford County Rural Water District 4 (17.7 feet).

The Effect of Pumping on Water Levels in Low Transmissivity Aquifer near Galena

The specific capacity is a means to assess well capacity (discharge per unit time) in reference to the drawdown associated with pumping and is expressed as the discharge per unit time per unit of drawdown (Domenico and Schwartz, 1990). This parameter depends on the transmissivity and storativity of the aquifer, the length of the pumping period,and the effective radius of the well. Most of the Ozark aquifer wells in the Tri-state region have approximately the same effective radius of 0.5 ft in the open borehole below the well casing. The time interval during which the well is pumped before the discharge and drawdown are measured is typically 1 hour to 12 hours and as shown in Table 2, the variability of storativity is less than an order of magnitude, but the transmissivity can vary over two orders of magnitude. As a result, specific capacity in wells tapping the Ozark aquifer can be used as a surrogate to show gross variation in aquifer tranmissivity.

Following completion of the old 901-foot deep Jayhawk Ordnance Works well in the 1940s, it was pump tested and the specific capacity of the well was estimated to be 0.48 gallons per minute per foot of drawdown (Abernathy, 1943). Following a series of acid treatments, the well was pumped at a constant 300 gallons per minute and after 30 minutes the drawdown was 92 feet (a specific capacity of approximately 3.2 gallons per minute per foot of drawdown). In 2000 the new well was constructed 300 feet to the north of the old well for Jayhawk Fine Chemicals. The WWC-5 well record shows a well depth of 901 feet and the depth to the static water level of 174 feet below surface on completion. After 23 hours of pumping at 400 gallons per minute, the drawdown in the new well was 181 feet (a specific capacity of 2.2 gallons per minute per foot of drawdown). The specific capacities from Jayhawk plant site are some of the lowest specific capacities calculated from production tests of wells in the region (Figures 10 and 11).

The historic and the most recent water-level measurements for the old and new wells at the plant site are presented in Table 3. The low values of specific capacity relative to values elsewhere in the region suggest lower aquifer transmissivity at this location than elsewhere. Low aquifer transmissivity implies the likely formation of a small, but very deep cone of depression from pumping at typical production rates. If it is assumed that the static water level at the plant site is close to 100 feet below surface, the slope of the cone of depression between the old and the new Jayhawk plant wells is approximately 100 feet or more vertically over a horizontal distance of approximately 300 feet.

A few miles away at Galena a production test of the city well 1 yielded a specific capacity of 7.48 gallons per minute per foot of drawdown (Macfarlane and Hathaway, 1987). The computed specific capacity for this well is higher than the values determined at the Jayhawk plant site and exceeds the Tri-state region average of 5.75 gallons per minute per foot of drawdown (Figure 10). Both the Galena public-supply well 1 and the Jayhawk plant site wells are located in a part of the aquifer where specific capacities are less than 10 gallons per minute per foot of drawdown

| Date | Depth to Water from Surface (ft) | | Remarks | Data Source |
|---|---|---|---|---|
| | Jayhawk Ordnance Works Well | Jayhawk Fine Chemicals Well | | |
| 2/25/1942 | 65 | -- | Static water level on initial completion of the well | Abernathy (1943) |
| 9/27/1979 | 229.45 | -- | Pump off 28 minutes | Macfarlane and Hathaway (1987) |
| 8/4/2000 | -- | 174 | Pumping status or water level in the old well not recorded | WWC-5 record of well completion |
| 5/26/2004 | 100.8 | 205.66 | Pump in the new well off for 1 hour prior to measurement | Spring 2004 Water-level Survey |
| 12/8/2004 | 97.33 | 226.07 | Pump in the new well off for an unknown period of time prior to measurement | Fall 2004 Water-level Survey |

Table 3. Historic and 2004 survey depth to water measurements in wells at the Jayhawk Fine Chemicals (the former Jayhawk Ordnance Works) plant site in Sec. 4, T. 34 S., R. 25 E.

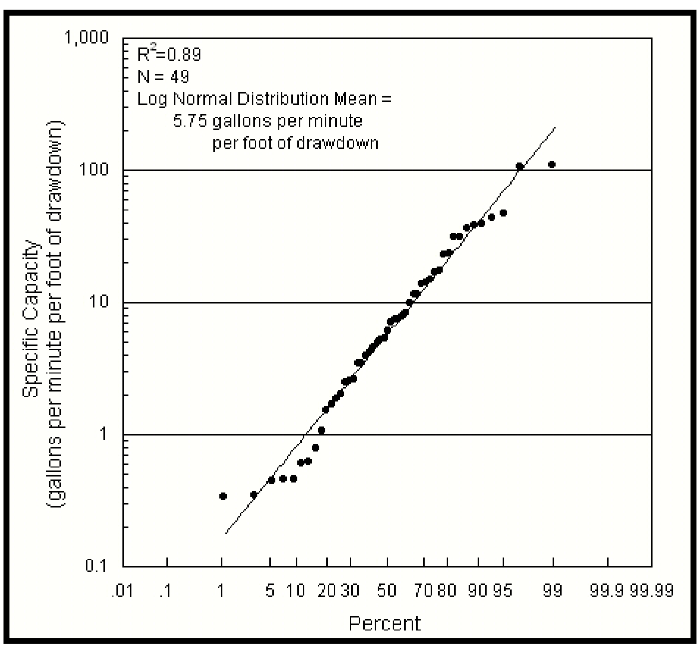



Figure 10. Specific capacities calculated from production tests of wells tapping the Ozark aquifer in southeast Kansas, southwest Missouri, and northeast Oklahoma.

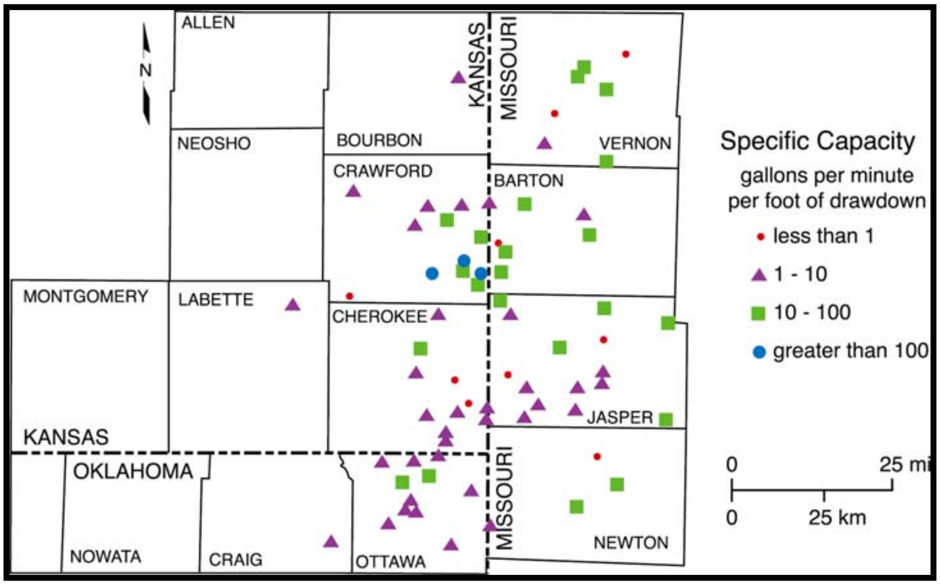



Figure 11. Distribution of specific capacity values derived from production tests of wells tapping the Ozark aquifer in southeast Kansas, southwest Missouri, and northeast Oklahoma. Taken from Macfarlane et al. (1981).

(Figure 11). This suggests large values of drawdown from pumping in wells located in this part of the aquifer.

**Water-level Monitoring Network**

History of Monitoring in Southeast Kansas

Since the 1930s used and unused or abandoned wells have served as water-level observation points for the Ozark Plateaus aquifer in Cherokee, Crawford, and southeastern Bourbon counties in Kansas (Table 4). The Division of Geology and Land Survey, Missouri Department of Natural Resources, has followed similar practices in southwest Missouri. Overall, the monitoring of ground-water conditions has been sporadic and relatively short term, with the exception of those well entries shaded in gray in the table. In many instances, documentation on well construction is lacking or concerns exist about well casing integrity. The remainder has been actively used for public supply during the period of monitoring.

Water-level Trends Revealed by the Longer-term Hydrographs

The monitoring well in 25S-24E-36ADB located within the city of Fort Scott, has a depth of 700 feet. The KGS WIZARD well database contains no information on well construction. On the basis of its shallow depth and the estimated depth to the top of the Springfield Plateau and Ozark aquifers in its vicinity, the well is likely open to both aquifers.

| County | Location | Well Depth | Use | Observation Period (DD/MM/YY – DD/MM/YY) | Number of Observations |
|---|---|---|---|---|---|
| Cherokee | 35S 23E13BAC | 1,210 | Public supply | 01/01/36 – 10/01/71 | 13 |
| Cherokee | 35S 23E 02DCD | 206 | Unknown | 13/08/81 – 18/03/82 | 4 |
| Cherokee | 35S 25E 02CC | 181 | Domestic | 01/09/64 – 31/07/81 | 2 |
| Cherokee | 35S 23E 02DCDA | 1,050 | Unknown | 13/08/81 – 18/03/82 | 4 |
| Cherokee | 34S 24E 36CDB | 1,020 | Unused | 01/01/26 – 10/11/75 | 7 |
| Cherokee | 34S 24E 33CAC | 1,050 | Unknown | 20/11/81 – 16/03/82 | 2 |
| Cherokee | 34S 24E 36DB | 1,090 | Public supply | 01/03/56 – 13/05/65 | 24 |
| Cherokee | 34S 24E 36BBA | 1,175 | Public supply | 06/10/87 – 06/27/2003 | 36 |
| Cherokee | 34S 24E 17DCC | 1,050 | Unknown | 01/01/74 – 13/05/80 | 3 |
| Cherokee | 34S 25E 13BAC | 1,150 | Observation | 01/12/32 – 08/09/87 | 358 |
| Cherokee | 34S 25E 04ADB | 901 | Unknown | 01/02/42 – 27/09/79 | 2 |
| Cherokee | 34S 23E 02ABA | 26 | Domestic | 01/08/42 – 27/10/65 | 117 |
| Cherokee | 33S 25E 18ADD | 900 | Unknown | 01/04/64 – 13/05/81 | 4 |
| Cherokee | 33S 25E 09DAD | 1,020 | Domestic | 01/9/64 – 06/06/79 | 24 |
| Cherokee | 32S 24E 19CBD | 850 | Unused | 03/02/43 – 27/10/65 | 89 |
| Cherokee | 32S 25E 06DAD | 25 | Unused | 01/01/51 –09/09/64 | 81 |
| Cherokee | 32S 23E 06DAA | 1,280 | Unknown | 01/09/35 – 12/05/80 | 3 |
| Crawford | 31S 22E 08DCD | 1,310 | Public supply | 01/05/47 – 15/05/80 | 3 |
| Crawford | 31S 22E 08DC | 1,300 | Unknown | 01/08/63 – 09/06/64 | 3 |
| Crawford | 30S 25E 21CCD | 49 | Unknown | 27/09/79 – 16/05/80 | 2 |
| Crawford | 30S 24E 24DDD | 109 | Industrial | 02/03/87 – 08/09/87 | 3 |
| Crawford | 30S 24E 19ADD | 955 | Unused | 12/12/77 – 03/06/86 | 37 |
| Crawford | 29S 23E 24DBA | 1,210 | Unused | 12/12/77 – 05/12/97 | 80 |
| Crawford | 29S 23E 24ACD | 1,190 | Public supply | 01/01/45 – 14/05/80 | 4 |
| Crawford | 29S 23E 24ACC | 1,200 | Public supply | 01/01/52 – 09/06/64 | 4 |
| Crawford | 29S 24E 11ADD | 1,145 | Unused | 07/10/87 – 10/09/2003 | 30 |
| Crawford | 28S 22E 21CCD | 1,020 | Public supply | 01/06/59 – 14/05/80 | 3 |
| Bourbon | 25S 24E 36ADB | 700 | Unused | 13/12/77 – 05/12/97 | 74 |
| Bourbon | 25S 25E 29DDA | 1460 | Unused | 01/09/42 – 30/01/56 | 2 |

Table 4. Wells used to monitor water levels in ground-water systems in Cherokee, Crawford, and Bourbon counties, Kansas. Hydrographs of entries shaded in gray are presented in the Figure 11. Data taken from the KGS WIZARD well database.

In the early part of the record, the depth to water ranged from approximately 180 feet to 200 feet below surface (Figure 12). The well hydrograph shows that the water level declined rapidly from March 1985 when the depth to water was 186 feet below surface to June 1986 when the water level was 221 feet below surface. A slower rate of decline followed from June 1986 to the end of the monitoring period (May 1997). Pumping from nearby wells can largely be excluded as a cause for the water level declines. The city of Fort Scott used 2 Ozark Plateaus aquifer wells possibly until the late 1960s. These wells were abandoned and plugged by the city in 1987. No records are available that indicate significant pumping from the Ozark aquifer near Fort Scott or across the state line in Missouri during the mid 1980s.

The central Crawford County monitoring well located in 29S-23E-24DBA was used by the city of Girard for water supply until 1976 when a new city well was completed south of town in 30S-24E-21ADA. Construction data indicate that the well was 1,186 feet deep and was dual completed in both the Springfield Plateau and Ozark aquifers.

A trend line through water-level data on the hydrograph shows an average decline rate of approximately 0.96 feet per year over the whole period of record, which is consistent with the long-term average decline rate of 1.6 feet per year at Pittsburg (Figures 6 and 13). The early part of the hydrograph prior to 1990 is characterized by low amplitude fluctuations and a trend line through that segment of the data has a slope of 0.59 feet per year. From 1990 until the end of the period of monitoring in 1997, the record is dominated by higher amplitude fluctuations and the slope of the trend line through the data is 1.04 feet per year.

The monitoring well in 29S-24E-11ADD was a supply well that previously was owned and operated by Crawford County Rural Water District #2 supply well until it was abandoned by the District. The well is 1,145 feet deep and was dually completed in the Springfield Plateau and Ozark aquifer. KGS personnel became aware of the well's status during the May 2004 survey of water levels and attempted to measure the depth to water in the open bore hole during December survey. A high-quality measurement of the depth to water could not be obtained in the well because all but approximately 50 feet of the length of the tape was coated with orange-colored iron oxide slime. Discussions with the district operator indicated that oil had been dumped down the well by a vandal, forcing its abandonment as source of supply by the district. The residual oil in the well has been partially biodegraded by bacteria, leaving the inside of the casing coated with this slimy byproduct. Because of this problem, it is difficult to evaluate the quality of the data used to construct the well hydrograph.

Nevertheless, the hydrograph shows a steep decline of water level in the uppermost part of the Ozark aquifer from October 1987 to June 1989 (Figure 12). This was followed by a much slower rate of decline that has continued to the present. The overall trend of declining water levels in this hydrograph follows the declines observed in the Girard and the Fort Scott observation wells. Looked at in more detail, the pattern of decline seems to follow that observed in the Fort Scott well. In the Girard well the decline rate is low until 1990 followed by much higher after that date, which is contrary to the observed pattern in the former rural water district well.

The monitoring well located in southeastern Cherokee County (34S-25E-13BAC) was owned and used by the Eagle Picher Agricultural Chemicals Division plant at Galena for water supply beginning in 1953 (Figure 12). In correspondence between the KGS and Eagle Picher, this monitoring point was referred to as well #3. However, in correspondence between the Kansas Department of Health and Environment and Eagle Picher the well was referred to as well #5 and it was mentioned that the US Geological Survey and the Division of Water Resources used the well for monitoring. The well was drilled down to 870 feet with an open-hole completion below 340 feet, all within the Ozark aquifer. The well depth is given incorrectly in the WIZARD well database. The 1953 completion date indicates that two earlier depth-to-water measurements in the database taken in the 1930s must have come from the monitoring of a different well, perhaps

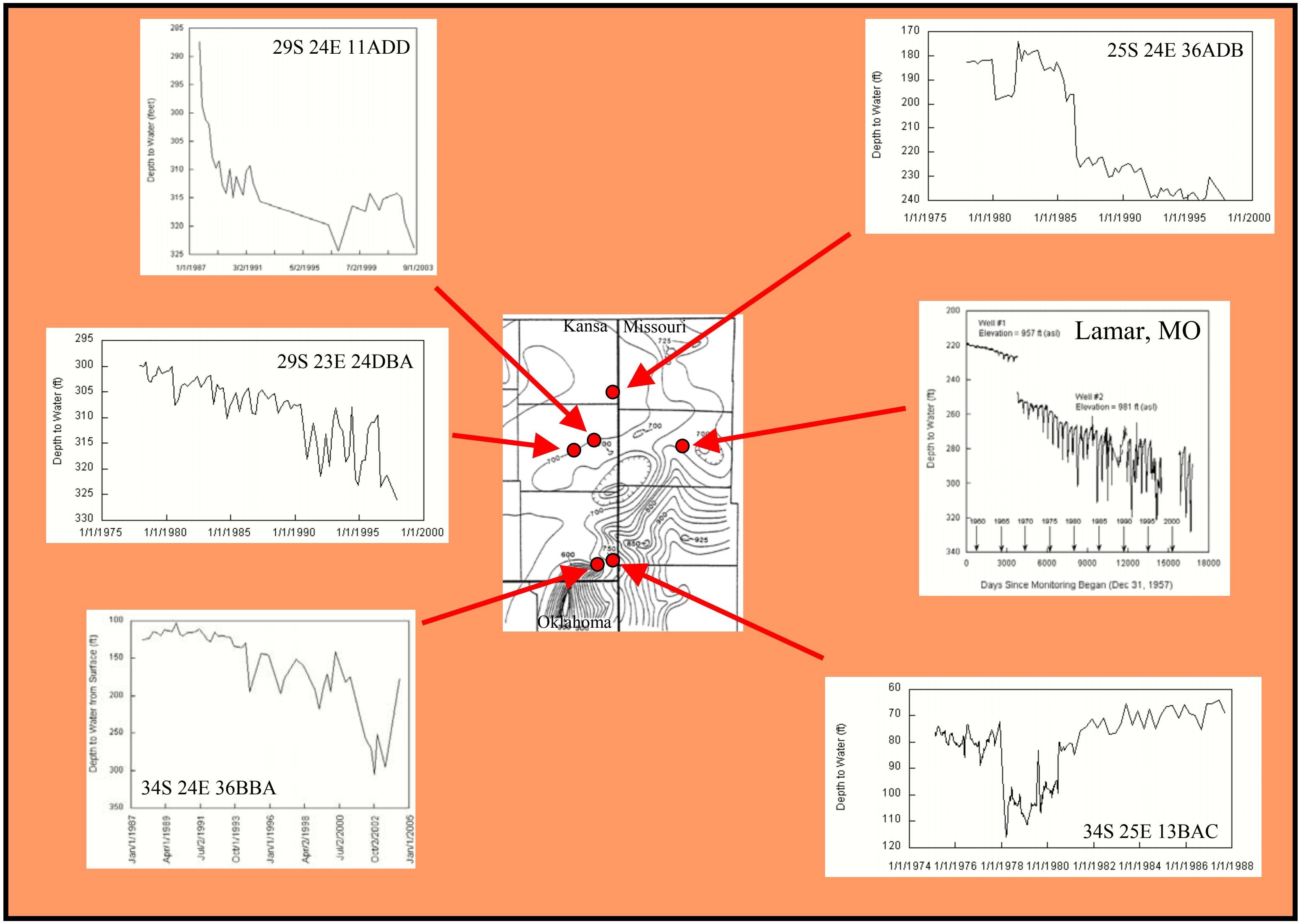



Figure 12. Selected hydrographs of monitoring wells open to the Ozark Plateaus aquifer system in southeast Kansas.

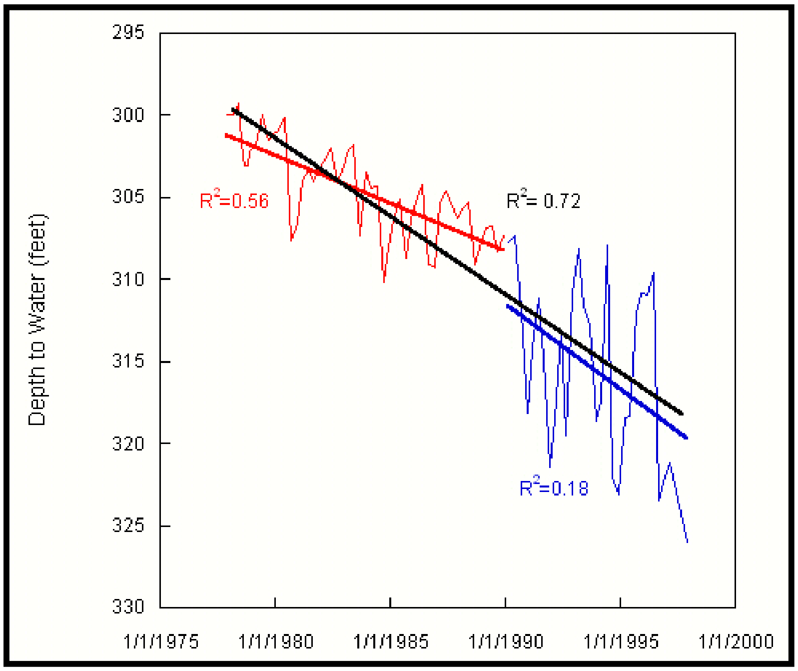



Figure 13. Short- and long-term water-level trends revealed in the hydrograph for the Ozark aquifer well at Girard.

at the plant site. The shallow depths to water from surface reported from monitoring are consistent with depths to water reported in other nearby unused wells, such as at the Jayhawk Fine Chemicals plant a few miles east of the Eagle Picher plant and at the Atlas Powder plant at Joplin, Missouri. The abrupt decline and slow recovery of the water level during the 1977-80 period are consistent with pumping from nearby plant supply wells and Galena's well 3 and the slow recovery of water levels in a low transmissivity aquifer (calculated specific capacity of approximately 1.3 gallons per minute per foot of drawdown).

The hydrograph for Baxter Springs well 6 shows a progressive downward trend in water levels from 1987 through 2004, even though the 1979-1981 and 2004 water-level surveys indicate a water-level rise (Figures 8, 14). Significant dips of the water level below the long-term trend occur late in 2001-2003, when annual ground-water withdrawals by the city were much higher than in the previous period.

Across the state line at Lamar, Missouri, well #2 has been used for observation since before 1970 (Figure 15). The well is 981 feet deep and bottoms in the Gasconade Dolomite. In the hydrograph water levels showing fluctuate with increasing amplitude over time due to seasonality effects from municipal use and the increasing use of water from the aquifer for irrigation (Figure 15). A trend line through the data from this well indicates a water-level decline rate of 1.23 feet per year.

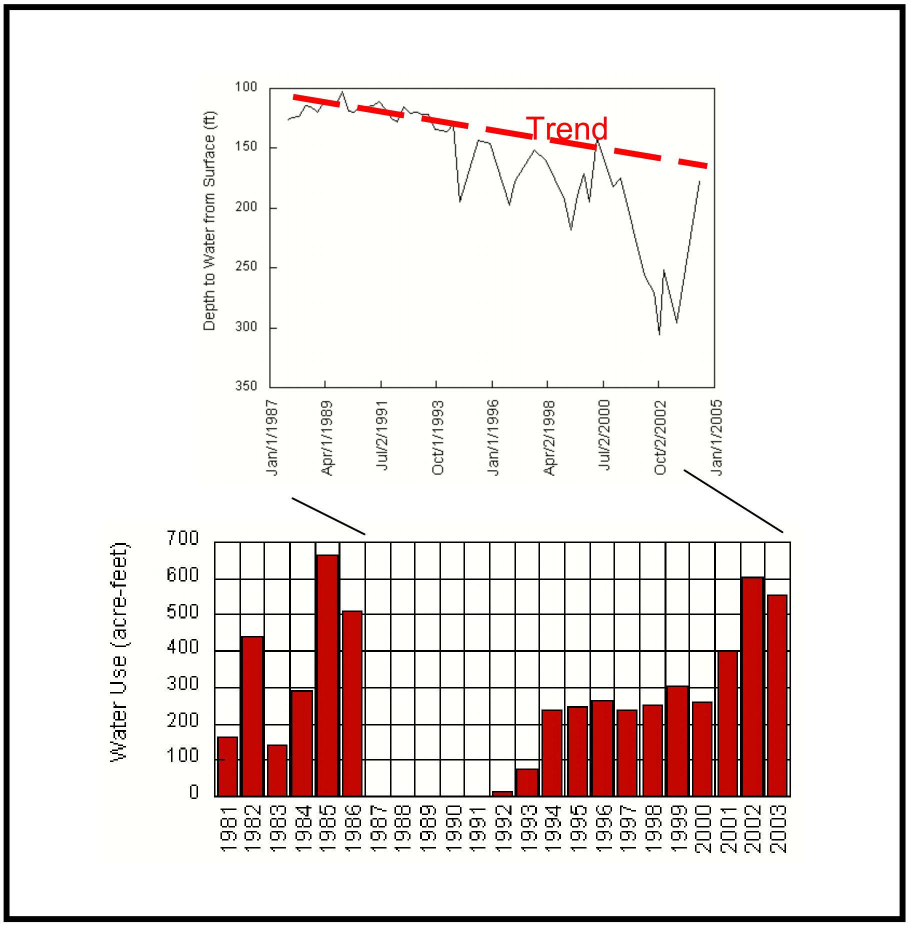



Figure 14. Hydrograph for Baxter Springs well 6 based on depth-to-water measurements made by the Division of Water Resources, Kansas Department of Agriculture (1987-2003) and the Kansas Geological Survey (2004). Annual ground-water use by the city of Baxter Springs, Kansas, is given in acre-feet.

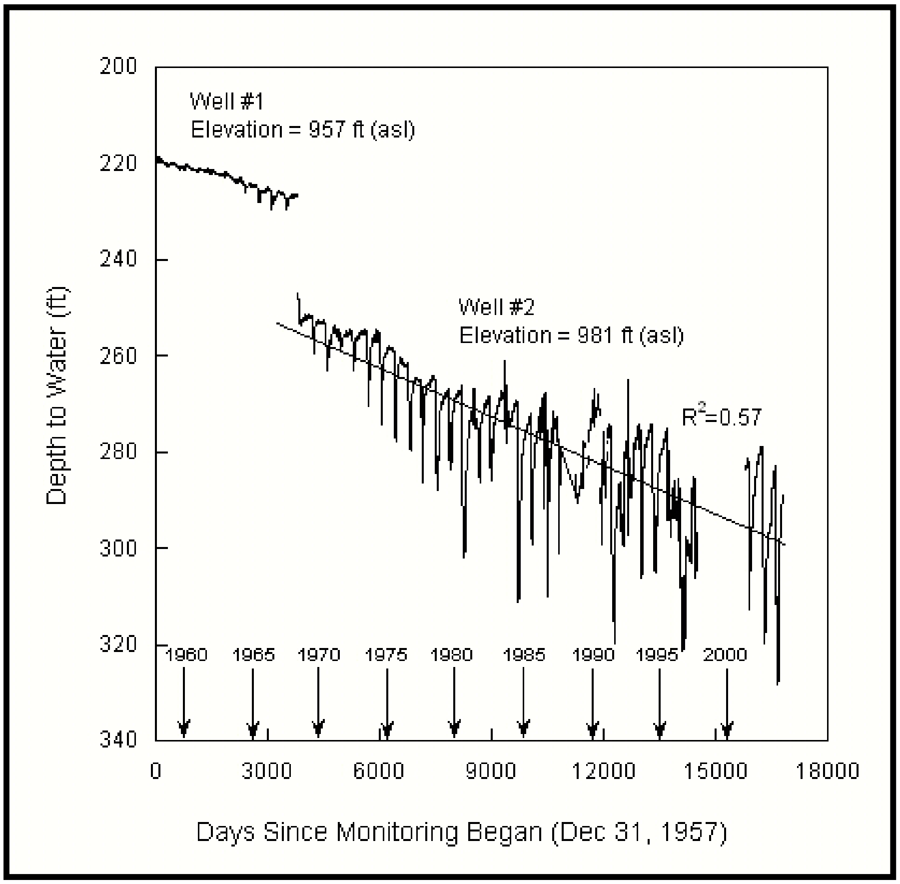



Figure 15. Hydrographs for Ozark aquifer wells at Lamar, Missouri.

**Status of the Existing Water-level Monitoring Network**

The Fort Scott and the Girard observation have been abandoned and plugged leaving only the wells in 29S-24E-11ADD in Crawford County and in 34S-25E-13BAC at the Eagle Picher plant in Cherokee County. Based on the WIZARD database, it appears that water level monitoring at the Crawford County well continued with quarterly measurements through June 2003 by Division of Water Resources, Department of Agriculture, personnel. However, September 2003 and later measurements are not in the KGS WIZARD database. The lack of water level data in the WIZARD database beyond 1987 for the Eagle Picher plant well indicates that monitoring has been discontinued. The status of water-level monitoring in the Baxter Springs 6 well is unknown at this time.

**Considerations in the Redesign of the Monitoring Well Network**

Past and Future Ground-water Use and Population Trends

The redesign of the existing water-level monitoring network for the Ozark Plateaus aquifer system will depend on where long-term water-level changes are expected to continue into the future. Water-level trends derived from periodic depth-to-water measurements in wells used for observation in addition to those being pumped provides information on the impacts of pumping on the aquifer system potentiometric surface up to the present. These have been discussed previously in the report. By an examination of population and water-use trends we can begin to predict changes in water use into the future and where the future impacts of pumping on water levels in wells tapping the Ozark aquifer will continue or will become significant. Water-use data are available for municipal and rural water districts in Crawford and Cherokee counties for the years 1981-2003 from the water-use reports filed with the Division of Water Resources, Kansas Department of Agriculture. Population data were gathered from the Kansas Policy Research Institute (KPRI; http://www.ku.edu/pri/). Most of the KPRI data used from the US Census (http://www.census.gov/).

The estimated total population of Crawford County was 38,130 in 1981, declined to 35,578 in 1990, and increased to an estimated 38,060 in 2004 (KPRI, http://www.ku.edu/pri/ksdata/ksdata.shtml; Figure 16). A somewhat similar pattern of population change took place in Cherokee County from 1981 to 2004 (Figure 17). Both the

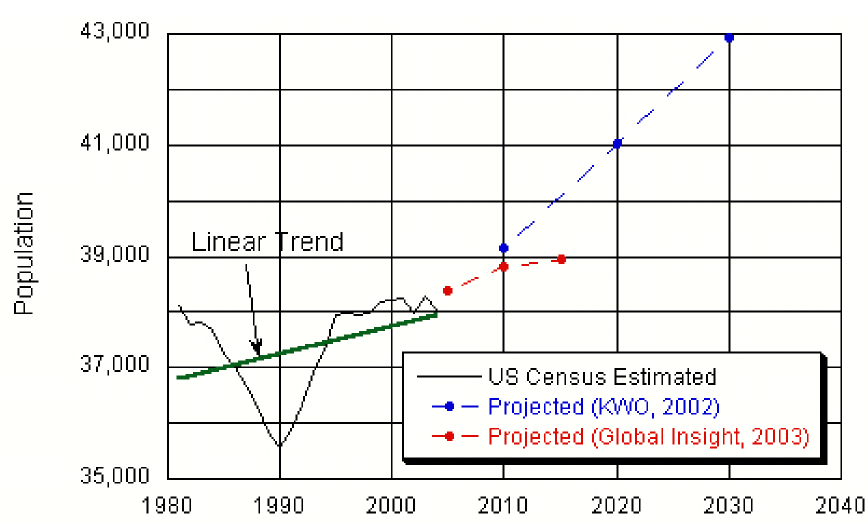



Figure 16. Estimated Crawford County population 1981-2004 with population projections from the Kansas Water Office (2002) and Global Insight (2003).

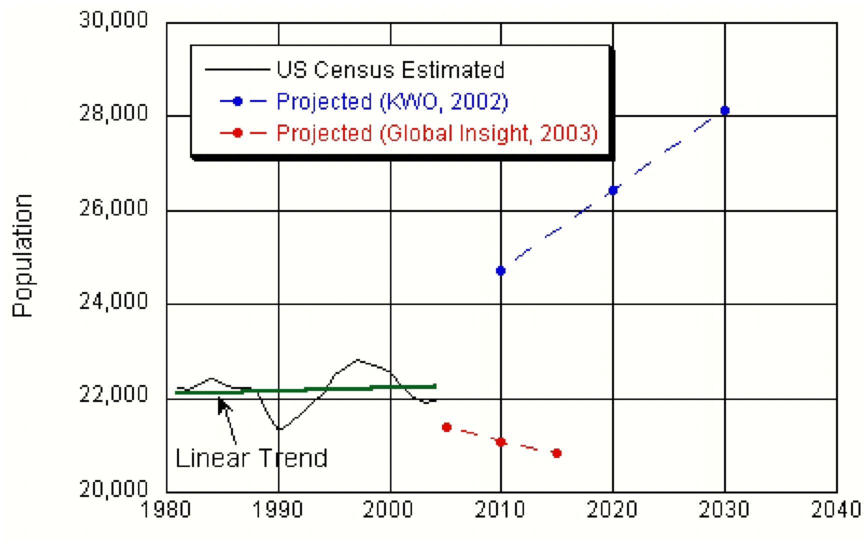



Figure 17. Estimated Cherokee County population 1981-2004 with population projections from the Kansas Water Office (2002) and Global Insight (2003).

Kansas Water Office (2002) and the Global Insight (2003) projections into the future show a rise of population in Crawford County up through 2015. The Kansas Water Office projects a continued rise in population up through 2030. However, the projected population trends predicted from these sources for Cherokee County are divergent up through 2015.

Total annual Ozark aquifer ground-water use in Crawford County appears to have increased through the decade of the 1980s and leveled off at approximately 5,000 acre-feet (Figure 18). Total annual Ozark aquifer ground-water use in eastern Cherokee County has fluctuated between 2,000 and 3,000 acre-feet since the early 1980s. Municipal users (city-owned utilities and rural water districts [RWDs]) account for more than 95% of the total use in both counties and industry, irrigation, and stock watering each account for approximately 1% or less of the total. In Crawford County the municipal supplies include: Pittsburg, Frontenac, Arma, Mulberry, Arcadia, Girard, Cherokee, Consolidated RWD #1, RWD #3, RWD #4, and RWD #5. In Cherokee County the municipal supplies include Columbus, Weir, Scammon, Galena, Baxter Springs, RWD #1, RWD #2, RWD, #3, RWD #8, and RWD #9. Industrial users in Cherokee County include Jayhawk Fine Chemicals and Empire District Electric, Riverton. From 1981 to 2003 RWD annual ground-water use from the Ozark aquifer was 7.5-38.5% and 1-20.8% of the total use in the eastern parts of Cherokee and Crawford counties, respectively (Figures 19-20).

The population and water-use trends suggest little change in Ozark Plateaus aquifer system ground-water use into the future. Witmann et al. (2003) report that Pittsburg, the most populous urban center in both counties, is not planning new wells to meet anticipated future water demands. Instead the city may supplement its supply with surface sources from the Spring River (Kerry Wedel, Kansas Water Office, personal communication, 2005). With the exception of the city of Galena, the number of municipal wells used to supply water to urban customers in both counties has remained stable with only a few replacement wells being drilled. The city of Galena has been purchasing water from the Missouri American Water Company since 2002, but would like to drill a new well (Kerry Wedel, Kansas Water Office, personal communication,

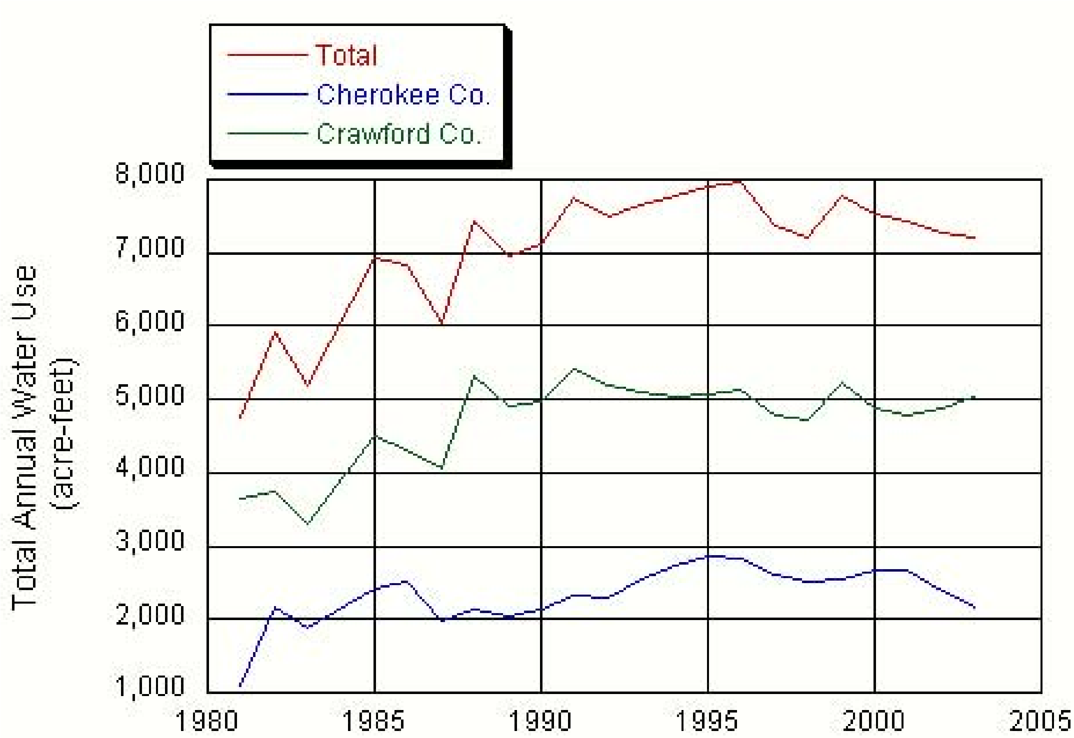



Figure 18. Reported ground-water use from the Ozark aquifer in central and eastern Cherokee and Crawford counties, Kansas.

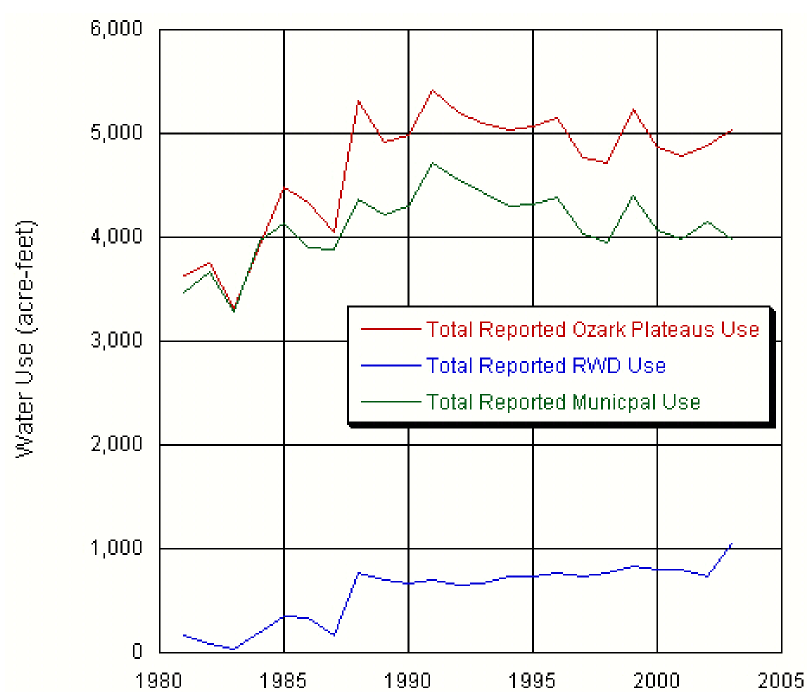



Figure 19. Reported municipal use of ground water from Ozark Plateaus aquifer system in central and eastern Crawford Co., Kansas.

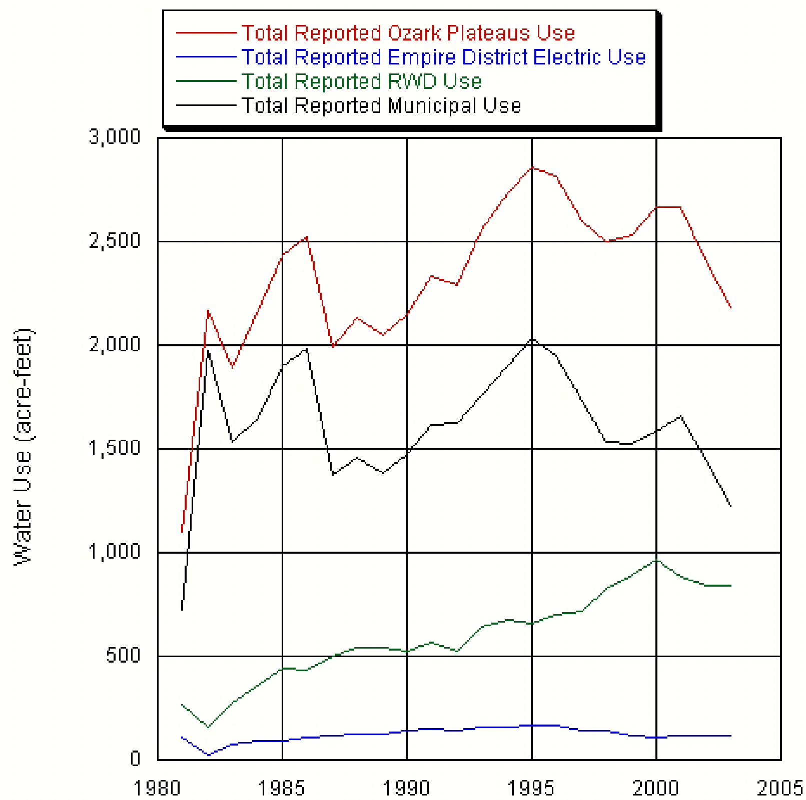



Figure 20. Reported municipal and industrial use of ground water from Ozark Plateaus aquifer system in central and eastern Cherokee Co., Kansas.

2005). This plan is on hold because of a moratorium on new applications for ground-water use from the Ozark aquifer in Bourbon, Crawford, and Cherokee counties (K.A.R. 5-3-29) put in place by the Division of Water Resources, Kansas Department of Agriculture. Wittman et al. (2003) reported that Columbus has expressed interest in using a surface-water source to supplement its ground-water sources. Baxter Springs will continue using both surface and Ozark aquifer ground-water to meet municipal demand. Weir and Scammon will be the only municipal water utilities relying entirely on the Ozark aquifer in Cherokee County.

Many of the municipal wells in Crawford and northern Cherokee counties tap sources in both the Springfield Plateau and the Ozark aquifers. The proportion of the well yield supplied by each aquifer unit most likely varies from well to well, but it is generally assumed that most of the produced water comes from the Ozark aquifer. Not accounted for in the water-use data are the withdrawals of water from the Springfield Plateau and uppermost Ozark aquifers for domestic and industrial users operating their own wells. There was a dramatic rise in the number of wells drilled for domestic use that peaked between 1991 and 1995 in Cherokee County (Figure 21). The frequency of well completions for industrial and irrigation use over time was more subdued but followed the domestic use completion trend. Many of the industrial use wells are for turkey farms in the Columbus area.

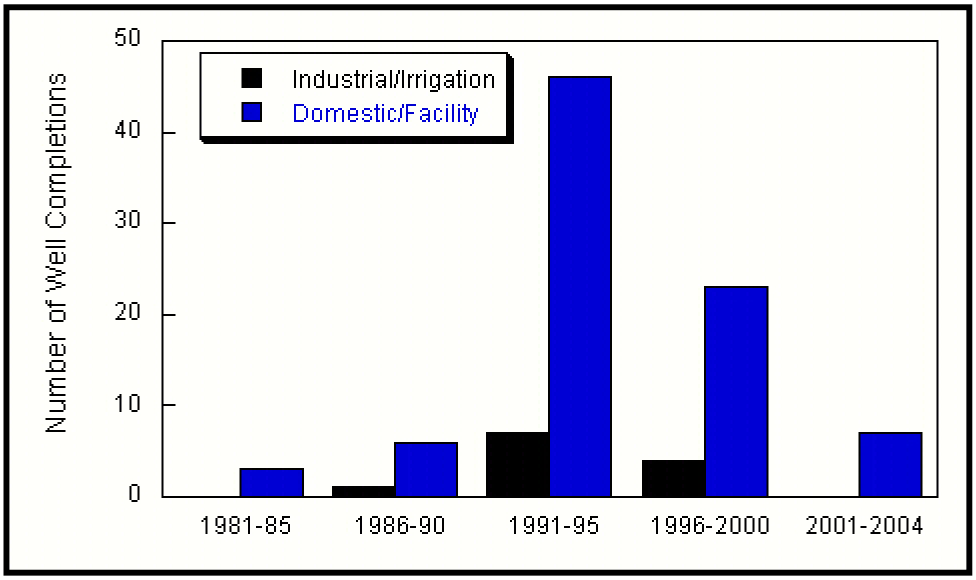



Figure 21. Well completions in the Springfield Plateau and uppermost Ozark aquifers in Cherokee County 1981 through 2004 based on records in the WWC-5 database.

## Ground-water Withdrawals in Missouri

Because of the proximity of most of the Ozark Plateaus aquifer system supply wells in southeast Kansas to the state border, some consideration of the location of existing supply wells in Missouri and the annual amounts of water withdrawn should be taken into account in the redesign of the monitoring network. The KGS received from the Missouri Department of Natural Resources a database of well locations and water-use data voluntarily supplied by well owners in Vernon, Barton, Jasper, and Newton counties for 2002. The data show significant concentrations of wells near the Kansas-Missouri border in western Jasper and Newton counties (Figure 22). Most of the wellfields produce water for public supply or electric power generation. Empire District Electric operates a field consisting of 5 wells in Sec. 17, T. 30 N., R. 33 W., all within approximately 1.5 miles east of the state line and 7.5 miles southeast of the Pittsburg town center (Table 5). In 2002 Empire District Electric was the largest user near the state line and pumped 1,905 acre-feet of water from the Ozark Plateaus aquifer system for power generation. Further south and east, Jasper County Public Water Supply District 2 pumped 342.7 acre-feet of water from a well in Sec. 4, T. 29 N., R. 33 W. Other large users include Missouri American Water Company (647.8 acre-feet of water used in 2002) with 3 wells within 9 miles, and the Empire District Electric Power Plant (567.8 acre-feet of water used in 2002) with 7 wells within 2 miles of the state line.

## The Impact of Well Pumping on Water Levels in the Surrounding Aquifer

The areal extent and the depth of the cone of depression from pumping a confined aquifer depend on the pumping rate and length of the pumping period and the aquifer transmissivity and

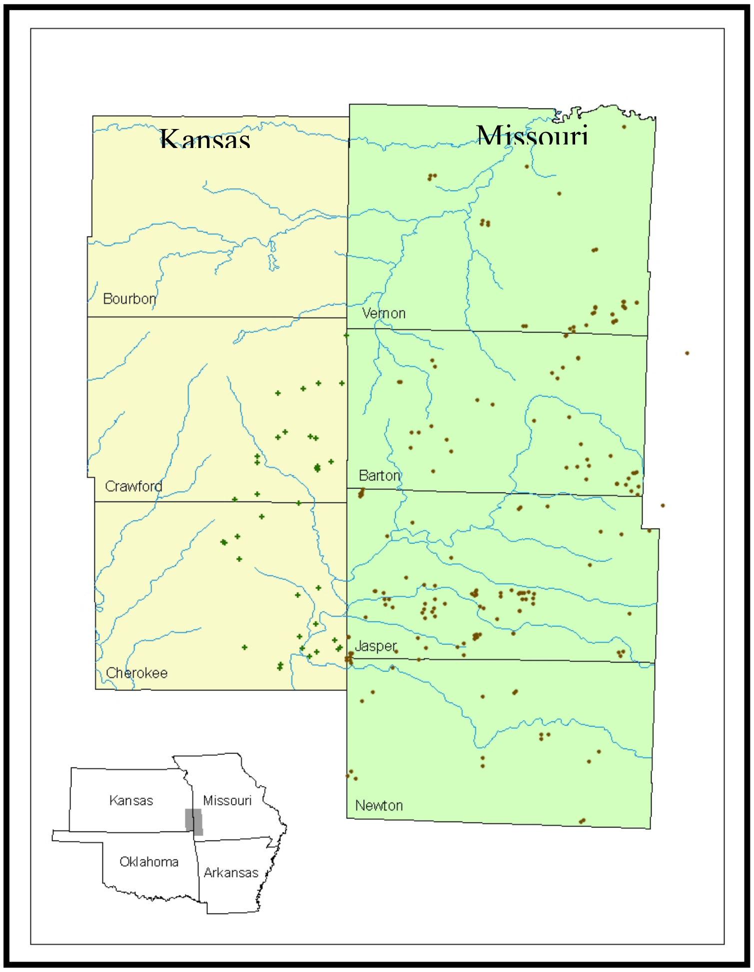



Figure 22. Distribution of production wells tapping water sources in the Ozark aquifer in southeast Kansas and southwest Missouri.

| County | Owner | Water Pumped (acre-feet) | Sec | Township North | Range East |
|---|---|---|---|---|---|
| JASPER | MISSOURI AMERICAN WATER COMPANY | 226.3 | 1 | T27N | R33W |
| | | 186.1 | 13 | T27N | R33W |
| | | 235.4 | 15 | T27N | R33W |
| | PCS PHOSPHATE COMPANY-KRAMER | 106.9 | 2 | T27N | R34W |
| | PCS PHOSPHATE COMPANY-WEST | 60.0 | 2 | T27N | R34W |
| | EMPIRE DIST ELEC-STATE LINE | 55.2 | 23 | T27N | R34W |
| | | 17.5 | 14 | T27N | R34W |
| | | 238.2 | 14 | T27N | R34W |
| | | 102.5 | 23 | T27N | R34W |
| | | 61.4 | 23 | T27N | R34W |
| | | 31.6 | 23 | T27N | R34W |
| | | 61.4 | 14 | T27N | R34W |
| | CITY OF CARL JUNCTION | 20.4 | 6 | T28N | R33W |
| | | 233.1 | 6 | T28N | R33W |
| | | 25.5 | 5 | T28N | R33W |
| | CITY OF WEBB CITY | 101.2 | 13 | T28N | R33W |
| | CARL JUNCTION\BRIARBROOK SUBD. | 47.0 | 16 | T28N | R33W |
| | CITY OF CARL JUNCTION | 142.6 | 16 | T28N | R33W |
| | CITY OF WEBB CITY | 147.3 | 13 | T28N | R33W |
| | | 209.5 | 24 | T28N | R33W |
| | CARL JUNCTION\BRIARBROOK SUBD. | 176.5 | 9 | T28N | R33W |
| | JASPER COUNTY PWSD #1 | 201.5 | 24 | T28N | R34W |
| | JASPER COUNTY P.W.S.D. #2 | 342.7 | 4 | T29N | R33W |
| | | 25.6 | 26 | T29N | R33W |
| | CITY OF ORONOGO | 82.6 | 36 | T29N | R33W |
| | . EMPIRE DISTRICT ELECTRIC CO. | 419.0 | 17 | T30N | R33W |
| | | 304.8 | 17 | T30N | R33W |
| | | 209.6 | 17 | T30N | R33W |
| | | 457.2 | 17 | T30N | R33W |
| | | 514.4 | 17 | T30N | R33W |
| NEWTON | LOMA LINDA ESTATES | 83.5 | 7 | T26N | R33W |
| | | 24.4 | 13 | T26N | R34W |

Table 5. Calendar year 2002 water use from the Ozark aquifer in Jasper and Newton counties within two ranges of the Kansas-Missouri state line reported to the Missouri Department of Natural Resources

storativity (Freeze and Cherry, 1979). As a general rule, the areal extent of the cone of depression is larger, but the amount of drawdown within the cone of depression is smaller in aquifers with higher transmissivity and storativity properties values. In this situation water levels in observation wells will be affected less by the drawdown-recovery cycles associated with the turning on and off of nearby pumping wells than they would be in a low transmissvity and low storativity aquifer. Table 3 provides a good example of the effect of pumping from a nearby well on water levels in an observation well in a low transmissvity-low storativity confined aquifer. The data show that the effects of pumping on water levels can be so great as to completely mask long-term water-level changes when only data from pumping wells are collected. Note the water-level difference between the old unused Jayhawk Ordnance Works well and, 300 feet away, the new Jayhawk Fine Chemicals well that has replaced the old well as the plant's source of water.

Proximity of the observation well to the pumping well is also an important factor for determining local trends in water levels, especially in low transmissivity/low storativity confined aquifers. To evaluate the effect of pumping well proximity on water levels in an observation well, hand calculations were made to estimate drawdown in the observation well located at distances up to one mile (5,280 feet) away from a well pumping 600 gallons per minute from a homogeneous, isotropic, low transmissivity, confined aquifer. In one case the drawdown was determined after 6 hours of pumping and in the other, after 12 hours of pumping. The aquifer transmissivity and storativity properties values used in this simulation come from the pumping tests that were conducted at Webb City, Missouri (Table 2). The relation used to calculate the drawdown at various distances from the pumping well is the Theis (1935) analytical solution to the flow equation for a homogeneous and isotropic confined aquifer expressed in radial coordinates as:

$$h_0 - h = (Q/4\pi T)W(u) \text{ and } u = r^2S/4Tt. \qquad \text{Eqns. 1 and 2}$$

$h_0 - h$ is the drawdown (L) in an observation well a radius r (L) away from the well in a confined aquifer with a transmissivity T ($L^2/T$) and a storativity S (dimensionless) caused pumping a well at the rate of Q ($L^3/T$) after time t (T). Table 8 shows the results of the simulations.

| Distance from the Pumping well (ft) | After 6 hours of Pumping | After 12 hours of Pumping |
|---|---|---|
| 1,320 (0.25 mile) | 6.93 feet | 17.67 feet |
| 2,640 (0.50 mile) | 0.48 feet | 2.89 feet |
| 3,960 (0.75 mile) | <0.01 feet | 0.28 feet |
| 5,280 (1.0 mile) | <0.01 feet | 0.02 feet |

Table 6. The drawdown from pumping a well at 600 gallons per minute at various distances from the pumping well after 6 and 12 hours in an aquifer with a transmissivity of 540 $ft^2$/day and a storativity of 0.0002.

The results generally show that the water level in an observation well located more than a mile away from a production well will not be noticeably affected by pumping at typical production well rates.

This hypothetical case is not meant to represent the hydrogeologic setting of the Ozark aquifer specifically, but is provided for illustrative purposes only. The hypothetical drawdowns developed from this analysis serve only to show order of magnitude impacts. Because of its karstic nature, the Ozark is best described as a heterogeneous and anisotropic aquifer. However, the parameter values that characterize these attributes are unavailable or are largely unknown (See Table 2, for example). One of the challenges in the selection of monitoring sites will be to develop a sense of these aquifer attributes over the Tri-state region. In terms of aquifer parameters, far less is known about them for the Ozark than for the High Plains aquifer.

**Recommendations**

The following recommendations are made based on (1) the water-level declines in wells tapping the Ozark aquifer, (2) the past and projected water-use and population trends for Crawford and Cherokee counties, (3) the location of pumping centers in southwest Missouri near the border with Kansas, and (4) the effect of aquifer properties and local pumping on the long- and short-term water-level trends:

- *Semi-annual water-level surveys are needed for Cherokee and Crawford counties to monitor short- and long-term water level changes in wells and should include most of the wells visited in the 2004 water-level surveys (see Appendix 2).*

  Although the May-December 2004 survey data show some differences, data presented in the Wittman et al. (2003) report clearly demonstrate that water levels are lower in the summer and higher in the winter months in Ozark aquifer wells. The seasonal difference in water levels is most likely greater in areas of the aquifer where the wells have a lower specific capacity. In these areas the Ozark aquifer transmits and releases less water to pumping wells. Elsewhere, seasonal changes in depth to water should be relatively small. The semi-annual surveys should be coordinated with similar surveys in southwest Missouri in order to discern local from regional scale trends in water levels. The results of these surveys should be examined along with monthly reports of the amounts of water pumped from each well producing from the Ozark aquifer to look for correlations between seasonal water level fluctuations and pumping.

- *Targeted data collection needs to be on-going in the Pittsburg area where a regional scale coalesced cone of depression has been forming for more than a century and in the Galena-Baxter Springs area where water-supply problems have more recently developed.*

  The potentiometric surface map for the Ozark aquifer in southeast Kansas and southwest Missouri clearly shows a widespread area depressed hydraulic heads that extends across the Kansas-Missouri border in the vicinity of Pittsburg. This depression is a coalesced cone of depression that has formed over time by the overlapping of cones of depression from local concentrations of pumping wells. The decline rate of 1.6 feet per year has remained fairly steady for more than a century at Pittsburg. At Girard, the water-level decline rate is approximately 0.96 feet per year for the period of record from 1977 to 1997. For more than the last 30 years the water-level decline rate at Lamar, Missouri, has been 1.23 feet per year.

  The projected trends in the population and water-use suggest that monitoring should be targeted in the Pittsburg area. Crawford County is projected to experience growth in population and the demand for additional water will put pressure on the Ozark aquifer or will initiate development of surface water sources.

  The data presented in this report indicate that the Ozark aquifer is very sensitive to pumping in an area that extends from Joplin westward into southeastern Cherokee County, Kansas, because the aquifer is less transmissive and yields less water to wells than elsewhere. Pumping at typical rates of production is capable of producing large drawdowns in the aquifer over a limited areal extent, as evidenced by the large differences in depth to water in the wells on the Jayhawk Fine Chemicals plant site.

Targeted data collection should have three components: (1) high-frequency static water-level data collection to monitor short- and long-term water level fluctuations due to the on-and-off cycling of pumping wells and regional declines; (2) water sampling of production wells during the summer (peak pumping) and winter (reduced pumping) months to monitor changes in water quality (changes in the concentrations of chloride and sulfate, primarily) due to upconing from sources deeper in the Ozark aquifer or the eastward lateral migration of poorer quality water from within the transition zone in the Ozark aquifer; and (3) monitoring of the timing and duration of pumping by each well within the developing coalesced cone of depression to more easily interpret the high-frequency water-level data. Water sampling should be coordinated with the Kansas Department of Health and Environment sampling schedule. If at all possible, similar activities should be conducted across the state line in Missouri east of Pittsburg. Downhole pressure transducers with a data logging and storage capacity can be used to conduct cost-effective, high frequency water-level data collection. The downhole devices are attached to a cable that can be plugged into a lap-top computer to manage data collection and periodically download the data.

- *Observation wells need to be installed for dedicated long-term monitoring of water levels in the Springfield Plateau and the Ozark aquifers in Crawford County and in the Springfield Plateau aquifer in southern Cherokee County (Figure 23). In Crawford County, one site should be located east of Pittsburg on the Kansas-Missouri border and another should be located west of Kansas Highway 7. In Cherokee County, a new monitoring well should be installed to monitor water levels in the Springfield Plateau aquifer between Riverton and Galena, Kansas. If the Eagle Picher Agricultural Chemical Division monitoring well has not been plugged, it should be reactivated to monitor water levels near the Kansas-Missouri border in southeastern Cherokee County.*

Historically, we have attempted to characterize the Ozark aquifer potentiometric surface using existing wells, primarily pumping wells or unused or abandoned wells located within a wellfield. Few if any opportunities are available to gather true static water-level data from a pumping well, especially if the water-level recovery time from pumping is long, such as in parts of southern Cherokee County. In the case where only an unused or abandoned well is available for observation, there may be uncertainties as to its construction or, because of the well's age, the integrity of the well casing. In many instances these wells are located in a wellfield that is being used for water supply. As a result, it is difficult to assess the significance of changes in the monitoring-well water level from one point in time to another.

With the installation of dedicated observation wells for water-level monitoring, these problems are avoided. Where the aquifer is believed to be less transmissive, the well can be placed sufficiently far away from nearby pumping wells that it will not be affected by periods of aquifer drawdown and recovery. This is not a critical factor in the Pittsburg area because even though the cones of depression from pumping are extensive, the drawdown at the pumping well is small because of the high transmissivity of the aquifer. As a result the expected water-level fluctuations from pumping should be small in amplitude.

In the design of the well, a specific interval of the aquifer can be targeted for monitoring. Water-level fluctuations and trends can be difficult to interpret because many of the production wells in Crawford and northern Cherokee county are open-hole completions through parts of the Springfield Plateau and Ozark aquifers. Abernathy (1943) monitored water levels in the borehole for the Jayhawk Ordnance Works well as it was being drilled by cable tool. He recorded water-level differences in the borehole of more than 100 feet between the Springfield Plateau aquifer and the underlying Ozark aquifer. Macfarlane et al. (1981) found a water-level difference of 9 feet between a well completed in the Springfield Plateau aquifer and one completed only in Ozark aquifer in the Pittsburg area in 1979. In this area, the thickness of the confining layer separating the two aquifers is approximately 40 feet but many wells in the area are completed in both aquifers.

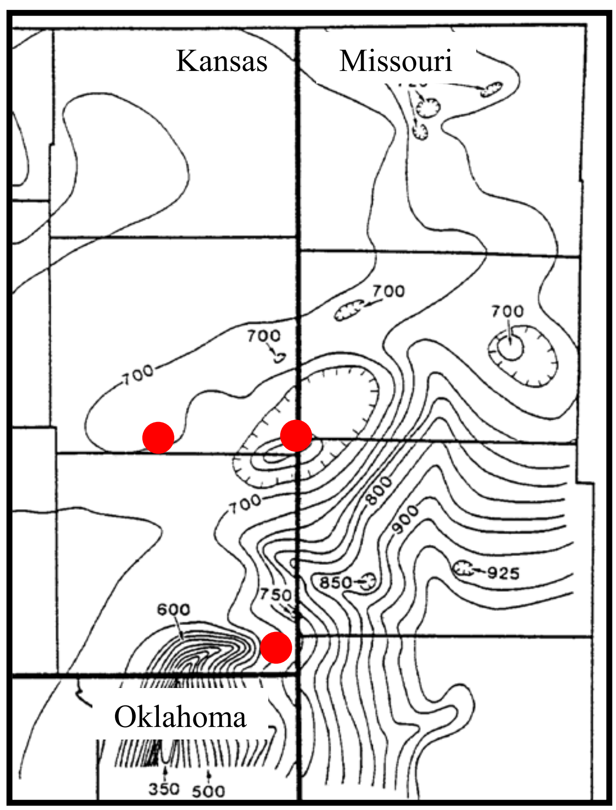



Figure 23. The recommended locations of sites for monitoring the Springfield Plateau and Ozark aquifers in Crawford and Cherokee counties, Kansas, are superimposed on the 1979-81 potentiometric surface of the Ozark aquifer in southeast Kansas, southwest Missouri, and northeastern Oklahoma.

Monitoring site placement east and west of the Pittsburg area will provide water-level data on both the Springfield Plateau and Ozark aquifers in the area where the effects of development appear to have been the most extensive and will likely continue. Many of the larger population centers have wells in the Pittsburg area as well as Crawford County Rural Water Districts #4 and #5. Because some of the older wells are dual completions, both aquifers should be monitored. Placement of one monitoring site along the border with Missouri will allow the agencies of both states to view the same data and situates an observation point between two of the biggest users of the aquifer in the region, the city of Pittsburg and the Empire District Electric power plant north of Asbury, Missouri (Figure 18). Placement of the other site west of Kansas Highway 7 will allow observation of water levels in the aquifer system deeper within the transition zone and near the presumed western edge of the coalesced cone of depression (Figures 23 and 24).

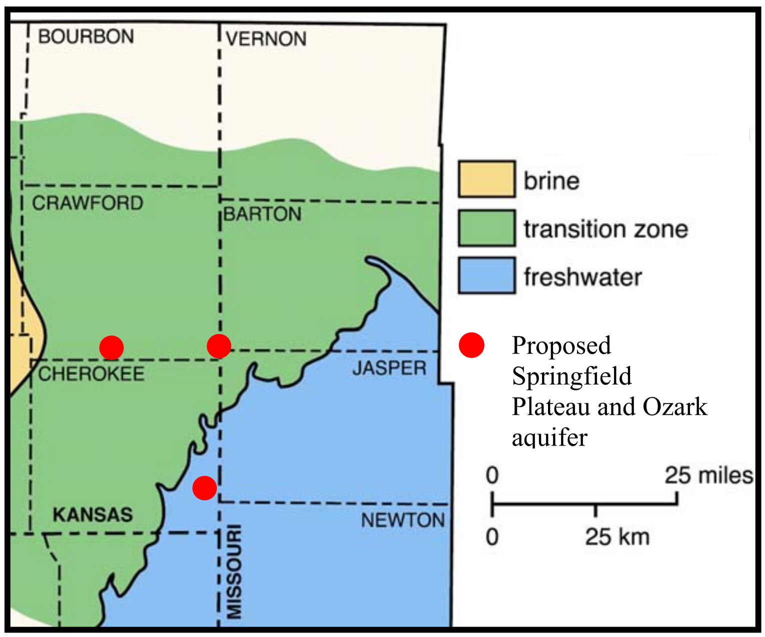



Figure 24. Locations of the proposed monitoring sites in the Ozark aquifer within the water-quality transition zone in southern Crawford County.

A dedicated monitoring site should also be acquired in southeastern Cherokee County because (1) water-level declines that have occurred in the past from pumping of water from the Ozark aquifer near the Kansas-Missouri border and (2) the large number of Springfield Plateau and uppermost Ozark aquifer water wells that were constructed in this part of Cherokee County in the 1990s (Figure 21). Existing wells in close proximity or newly constructed dedicated wells could be used for this purpose. The well that had been used for monitoring of water levels in the Ozark aquifer at the Eagle Picher Agricultural Chemicals Division plant was plugged and capped as part of the reclamation and remediation Superfund effort of the mining district in Kansas. As a replacement, Galena well 3 might be a good candidate because of its proximity to the previously monitored well, the well is currently not in use, and is easy to access.

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# APPENDIX 1:
# WELL DATA FOR CRAWFORD AND CHEROKEE COUNTIES

| Well Owner / Water Supply | Well ID | Aquifer | Township S | Range E | Sect. | Qualifier | Longitude | Latitude | Measuring Point Elevation (feet amsl) |
|---|---|---|---|---|---|---|---|---|---|
| Cherokee Co. RWD 2 | 1 | Ozark | 34 | 25 | 8 | SWNWSW | -94.70312 | 37.09409 | 848.75 |
| Cherokee Co. RWD 9 | 1 | Ozark | 34 | 25 | 20 | NWNENW | -94.69864 | 37.07394 | 825.25 |
| Cherokee Co. RWD 8 | 1 | Ozark | 34 | 25 | 21 | NWNESE | -94.67107 | 37.06670 | 917.71 |
| Cherokee Co. RWD 8 | 2 | Ozark | 34 | 25 | 28 | NWNWNW | -94.68488 | 37.05935 | 911.71 |
| Galena | 1 | Ozark | 34 | 25 | 23 | SENENE | -94.63237 | 37.07213 | 960.75 |
| Galena | 4 | Ozark | 34 | 25 | 13 | SWSWSW | -94.63013 | 37.07575 | 962.83 |
| Galena | 3 | Ozark | 34 | 25 | 14 | NWNWNE | -94.63930 | 37.08841 | 949 |
| Baxter Springs | 6 | Ozark | 34 | 24 | 36 | NENWNW | -94.73702 | 37.04490 | 822.3 |
| Baxter Springs | 5 | Ozark | 34 | 24 | 36 | NWNWSW | -94.73925 | 37.03751 | 826.25 |
| Cherokee RWD 3 | 1 | Ozark | 34 | 24 | 17 | SWSWSE | -94.80277 | 37.07608 | 856.17 |
| Jayhawk Fine Chemicals | PW1 | Ozark | 34 | 25 | 4 | NENWNE | -94.67332 | 37.11819 | 853 |
| Jayhawk Fine Chemicals | PW2 | Ozark | 34 | 25 | 4 | NENWNE | -94.67332 | 37.11819 | 855.25 |
| Cherokee RWD 1 | 1 | Ozark | 33 | 25 | 18 | NENESE | -94.70538 | 37.16952 | 870.9 |
| Cherokee RWD 1 | 2 | Ozark | 33 | 25 | 9 | SENESE | -94.66908 | 37.18244 | |
| Columbus | 4 | Ozark | 32 | 23 | 13 | NENENW | -94.84204 | 37.26561 | 894.13 |
| Columbus | 5 | Ozark | 32 | 23 | 13 | NENENW | -94.84204 | 37.26561 | 892.55 |
| Columbus | 6 | Ozark | 32 | 23 | 13 | NWNE | -94.83862 | 37.26467 | 913.5 |
| Cherokee Co. RWD 4 | 1 | Ozark Plateaus | 32 | 24 | 29 | NWNWNW | -94.81252 | 37.23606 | 912 |
| Cherokee Co. RWD 4 | 2 | Ozark Plateaus | 32 | 24 | 29 | NWNWNW | -94.81252 | 37.23606 | 912.71 |
| Scammon | 2 | Ozark Plateaus | 32 | 24 | 7 | NESENE | -94.81502 | 37.27653 | 930.5 |
| Scammon | 1 | Ozark Plateaus | 32 | 24 | 7 | NESENE | -94.81502 | 37.27653 | 930.5 |
| Weir | 1 | Ozark Plateaus | 31 | 24 | 27 | NWSESW | -94.77203 | 37.31271 | 924.08 |
| Arma | 1 | Ozark Plateaus | 29 | 25 | 5 | SESESW | -94.69661 | 37.54398 | 1020.5 |
| Arma | 2 | Ozark Plateaus | 29 | 25 | 5 | SESESW | -94.69661 | 37.54398 | 1020.5 |
| Frontenac | North | Ozark Plateaus | 30 | 25 | 9 | NENWNE | -94.67357 | 37.45391 | 954.9 |
| Frontenac | South | Ozark Plateaus | 30 | 25 | 9 | NENWNE | -94.67357 | 37.45391 | 954.9 |
| Frontenac | 1 | Ozark Plateaus | 30 | 25 | 4 | NESWSW | -94.68285 | 37.45766 | 954.27 |

| Well Owner / Water Supply | Well ID | Aquifer | Township S | Range E | Sect. | Qualifier | Longitude | Latitude | Measuring Point Elevation (feet amsl) |
|---|---|---|---|---|---|---|---|---|---|
| Pittsburg | 8 | Ozark | 30 | 25 | 28 | NENESE | -94.66949 | 37.40276 | 905 |
| Pittsburg | 9 | Ozark | 30 | 25 | 28 | SWNESE | -94.67178 | 37.40092 | 905 |
| Pittsburg | 10 | Ozark | 30 | 25 | 28 | NESESE | -94.66950 | 37.39909 | 898.3 |
| Pittsburg | 11 | Ozark | 30 | 25 | 28 | SESESE | -94.66951 | 37.39726 | 899.7 |
| Cherokee | 1 | Ozark Plateaus | 31 | 24 | 18 | SENWSE | -94.81966 | 37.34378 | 929.8 |
| Cherokee | 2 | Ozark Plateaus | 31 | 24 | 18 | SENWSE | -94.81966 | 37.34378 | 929.8 |
| Girard | 3 | Ozark | 30 | 24 | 21 | NESENE | -94.77904 | 37.42122 | 922 |
| Girard | 4 | Ozark | 30 | 24 | 21 | NESENE | -94.77904 | 37.42122 | 925 |
| Arcadia | 2 | Ozark | 28 | 25 | 1 | NESWNE | -94.61774 | 37.63937 | 836.45 |
| Crawford Co. RWD 1C | North | Ozark | 30 | 24 | 2 | SESESE | -94.74251 | 37.45587 | 948.3 |
| Crawford Co. RWD 1C | South | Ozark | 30 | 24 | 2 | SESESE | -94.74251 | 37.45587 | 948.3 |
| Crawford Co. RWD 3 | 1 | Ozark Plateaus | 29 | 25 | 4 | NESENE | -94.66880 | 37.55304 | 910.3 |
| Crawford Co. RWD 4 | 1 | Ozark Plateaus | 30 | 24 | 28 | NENENE | -94.77900 | 37.41038 | 928.3 |
| Crawford Co. RWD 4 | 3 | Ozark Plateaus | 31 | 24 | 16 | NENENE | -94.77881 | 37.35262 | 909.4 |
| Crawford Co. RWD 5 | 1 | Ozark Plateaus | 30 | 25 | 23 | SESWSW | -94.64613 | 37.41193 | 926.4 |
| Crawford Co. RWD 5 | 3 | Ozark Plateaus | 31 | 25 | 20 | SWNWNW | -94.70406 | 37.33595 | 914.25 |
| Crawford Co. RWD 2 | 2 | Ozark Plateaus | 29 | 24 | 11 | NENESE | -94.74269 | 37.53483 | 994 |

| Well Owner/ Water Supply | Well Number | Measurement Date | Depth to Water from MP (feet) | Water-level Elevation (feet amsl) | Remarks |
|---|---|---|---|---|---|
| Cherokee Co. RWD 2 | 1 | 5/24/04 | 118.38 | 730.37 | Pump off 1 hour |
| Cherokee Co. RWD 9 | 1 | 5/25/04 | 143.6 | 681.65 | Appears to be recovering |
| Cherokee Co. RWD 8 | 1 | 5/25/04 | 149.49 | 768.22 | Pump off long time |
| Cherokee Co. RWD 8 | 2 | 5/25/04 | 124.99 | 786.72 | Pump off 3 hours |
| Galena | 1 | 5/24/04 | 199.83 | 760.92 | Pump off 2 years |
| Galena | 4 | 5/25/04 | 222.58 | 740.25 | Pump off about 1 hour |
| Galena | 3 | 5/25/04 | 138.69 | 810.31 | Pump off about 1.5 years |
| Baxter Springs | 6 | 5/24/04 | 180.58 | 641.72 | Pump off several hours |
| Baxter Springs | 5 | 5/24/04 | 125.29 | 700.96 | Pump off for several days |
| Cherokee RWD 3 | 1 | 5/25/04 | 173.29 | 682.88 | Well 2 recovering from pumping Well 1 off for a week |
| Jayhawk Fine Chemicals | PW 1 | 5/26/04 | 107.7 | 745.3 | No pump in well |
| Jayhawk Fine Chemicals | PW2 | 5/26/04 | 209.66 | 645.59 | Pump off 1 hour |
| Cherokee RWD 1 | 1 | | | | |
| Cherokee RWD 1 | | | | | |
| Columbus | 4 | 5/26/05 | 203.5 | 690.63 | pump off for more than 1 hour |
| Columbus | 5 | 5/26/04 | 208.9 | 683.65 | pump off for more than 1 hour |
| Columbus | 6 | 5/25/04 | 203.63 | 709.87 | pump off 2 months |
| Cherokee Co. RWD 4 | 1 | 5/25/04 | 235.12 | 676.88 | Pump off 1 hour |
| Cherokee Co. RWD 4 | 2 | 5/25/04 | 236.53 | 676.18 | Pump off 5 hours |
| Scammon | 2 | 5/25/04 | 68 | | Took readings with the airline |
| Scammon | 1 | 5/26/04 | 52 | | Took readings with the airline |
| Weir | 1 | 5/25/04 | 242.4 | 681.68 | Dirty tape; hard to pick a water level |
| Arma | 1 | 5/24/04 | | | Could not determine the cut; too much gunk on the tape |
| Arma | 2 | 5/24/04 | 336.5 | 684 | |
| Frontenac | North | 5/25/04 | | | Did not measure; Shallowest of two wells |
| Frontenac | South | 5/26/04 | 283.15 | 671.75 | Pump off for some time; another older well located a block or so north was pumping |
| Frontenac | 1 | | | | |
| Pittsburg | 8 | 5/27/04 | | | Could not get below 200 ft; tape covered in rust colored gunk |

| Well Owner/ Water Supply | Well Number | Measurement Date | Depth to Water from MP (feet) | Water-level Elevation (feet amsl) | Remarks |
|---|---|---|---|---|---|
| Pittsburg | 9 | 5/28/04 | | | Could not get below 230 ft; tape covered in rust colored gunk |
| Pittsburg | 10 | 5/29/04 | 249.90 | 648.4 | Well 11 turned off less than 30 min before measurement |
| Pittsburg | 11 | 5/30/04 | 257.75 | 641.95 | Pump off for less than 1 hr |
| Cherokee | 1 | 5/24/04 | | | Maximum depth indicated on the airline gauge dial to shallow |
| Cherokee | 2 | 5/24/04 | | | Maximum depth indicated on the airline gauge dial to shallow |
| Girard | 3 | 5/24/04 | | | Could get tape below 105 ft. |
| Girard | 4 | 5/24/04 | 278.00 | 647 | Pump motor warm to the touch; pump off probably less than a few hours |
| Arcadia | 2 | 5/24/04 | 152.80 | 683.65 | Pump off for 15 minutes |
| Crawford Co. RWD 1C | North | 5/24/04 | 289.90 | 658.4 | Well had not been in use for some time |
| Crawford Co. RWD 1C | South | 5/24/04 | 290.00 | 658.3 | Well had not been in use for some time |
| Crawford Co. RWD 3 | 1 | 5/24/04 | 227.08 | 683.22 | Pump off for an unknown time period |
| Crawford Co. RWD 4 | 1 | 5/24/04 | 258.13 | 670.17 | Pump off for an unknown time period |
| Crawford Co. RWD 4 | 3 | 5/24/04 | 242.53 | 666.87 | Pump off for an unknown time period |
| Crawford Co. RWD 5 | 1 | 5/24/04 | 280.5 | 645.9 | Pump off for approximately 15 min; WL at 284.65 during pumping |
| Crawford Co. RWD 5 | 3 | 5/24/04 | 271. | 643.25 | Well pumps continuously |
| Crawford Co. RWD 2 | 2 | 5/30/04 | 257.75 | 641.95 | No access to the observation well |

| Well Owner/ Water Supply | Well Number | Water Level Elevation change Since 1979-81 (feet) |
|---|---|---|
| Cherokee Co. RWD 2 | 1 | -0.87 |
| Cherokee Co. RWD 9 | 1 | |
| Cherokee Co. RWD 8 | 1 | |
| Cherokee Co. RWD 8 | 2 | |
| Galena | 1 | -19.62 |
| Galena | 4 | -6.65 |
| Galena | 3 | -180.91 |
| Baxter Springs | 6 | -63.42 |
| Baxter Springs | 5 | -61.71 |
| Cherokee RWD 3 | 1 | -9.38 |
| Jayhawk Fine Chemicals | PW 1 | -124.75 |
| Jayhawk Fine Chemicals | PW2 | |
| Cherokee RWD 1 | 1 | |
| Cherokee RWD 1 | | |
| Columbus | 4 | |
| Columbus | 5 | |
| Columbus | 6 | -21.77 |
| Cherokee Co. RWD 4 | 1 | 14.62 |
| Cherokee Co. RWD 4 | 2 | |
| Scammon | 2 | |
| Scammon | 1 | |
| Weir | 1 | 2.32 |
| Arma | 1 | |
| Arma | 2 | 6.5 |
| Frontenac | North | |
| Frontenac | South | 29.35 |
| Frontenac | 1 | |
| Pittsburg | 8 | |
| Pittsburg | 9 | |
| Pittsburg | 10 | |

| Well Owner/ Water Supply | Well Number | Water Level Elevation change Since 1979-81 (feet) |
|---|---|---|
| Pittsburg | 11 | *21.05 |
| Cherokee | 1 | |
| Cherokee | 2 | |
| Girard | 3 | |
| Girard | 4 | |
| Arcadia | 2 | |
| Crawford Co. RWD 1C | North | 11.8 |
| Crawford Co. RWD 1C | South | |
| Crawford Co. RWD 3 | 1 | 8.28 |
| Crawford Co. RWD 4 | 1 | 17.73 |
| Crawford Co. RWD 4 | 3 | |
| Crawford Co. RWD 5 | 1 | 26.4 |
| Crawford Co. RWD 5 | 3 | |
| Crawford Co. RWD 2 | 2 | |

| Well Owner/ Water Supply | Well Number | Date | Depth to Water From Measurement Point (feet) | Water Level Elevation (feet amsl) | Remarks |
|---|---|---|---|---|---|
| Cherokee Co. RWD 2 | 1 | 12/6/04 | 123.29 | 725.46 | Pump off less than 1 hour, WL recovering |
| Cherokee Co. RWD 9 | 1 | 12/6/04 | 135.72 | 689.53 | Pump off 45 minutes |
| Cherokee Co. RWD 8 | 1 | 12/6/04 | 150.69 | 767.02 | Pump off for several days at least |
| Cherokee Co. RWD 8 | 2 | 12/6/04 | 126.15 | 785.56 | Pump off since 5 AM |
| Galena | 1 | 12/7/04 | 193.44 | 767.31 | Pump off several months |
| Galena | 4 | 12/7/04 | 214.15 | 748.68 | Pump off 8 hours |
| Galena | 3 | 12/7/04 | 139.13 | 809.87 | Pump off permanently |
| Baxter Springs | 6 | 12/7/04 | | | Could not measure |
| Baxter Springs | 5 | 12/7/04 | 118.39 | 707.86 | Pump off days to months |
| Cherokee RWD 3 | 1 | 12/6/04 | 195.13 | 661.04 | Pump off about 45 minutes |
| Jayhawk Fine Chemicals | PW 1 | 12/8/04 | 99.43 | 753.57 | Pump off for an unknown period of time |
| Jayhawk Fine Chemicals | PW2 | 12/8/04 | 230.07 | 625.18 | No pump |
| Cherokee RWD 1 | 1 | 12/6/04 | | | Could not make an acceptable measurement |
| Cherokee RWD 1 | 2 | | | | |
| Columbus | 4 | 12/7/04 | 201.58 | 692.55 | Pump off 4-5 hours; few hangs |
| Columbus | 5 | 12/7/04 | 203.94 | 688.61 | Pump off 3-4 hrs |
| Columbus | 6 | 12/7/04 | 200.79 | 712.71 | Pump off 2-3 weeks |
| Cherokee Co. RWD 4 | 1 | 12/7/04 | 240.71 | 671.29 | Pump off 35 min. |
| Cherokee Co. RWD 4 | 2 | 12/7/04 | 237.3 | 675.41 | Pump off 2 hrs 45 min. |
| Scammon | 2 | 12/8/04 | | | Used the airline; well 1 pumping and shutdown after arrival |
| Scammon | 1 | 12/8/04 | | | Used the airline |
| Weir | 1 | 12/8/04 | 244.61 | 679.47 | Tape dirty cut fair; pump off approx 26 minutes |
| Arma | 1 | 12/6/04 | | | Could not determine the cut; too much gunk on the tape |
| Arma | 2 | 12/6/04 | 338.63 | 681.87 | Pump off less than 24 hours |
| Frontenac | North | 12/7/04 | | | Could not reach the water level too many hangs |
| Frontenac | South | 12/7/04 | | | Could not reach the water level too many hangs |
| Frontenac | 1 | 12/7/04 | 284.6 | 669.67 | Good cut |

| Well Owner/ Water Supply | Well Number | Date | Depth to Water From Measurement Point (feet) | Water Level Elevation (feet amsl) | Remarks |
|---|---|---|---|---|---|
| Pittsburg | 8 | | | | |
| Pittsburg | 9 | | | | |
| Pittsburg | 10 | | | | |
| Pittsburg | 11 | 12/7/04 | 255.27 | 644.43 | Cut fair second trial |
| Cherokee | 1 | 12/7/04 | | | Airline not functional |
| Cherokee | 2 | 12/7/04 | | | Airline not functional |
| Girard | 3 | 12/6/04 | 247 | 675 | Poor cut; tape partially wet above the cut. Well off a few hours; Thunderstorm on the way |
| Girard | 4 | | | | |
| Arcadia | 2 | 12/6/04 | 155.59 | 680.86 | |
| Crawford Co. RWD 1C | North | 12/6/04 | 286.71 | 661.59 | |
| Crawford Co. RWD 1C | South | 12/6/04 | | | Could not measure |
| Crawford Co. RWD 3 | 1 | 12/6/04 | 237.91 | 672.39 | Tape very dirty and slimy; difficult to determine true water level; pump off less than 2 hours |
| Crawford Co. RWD 4 | 1 | 12/6/04 | 251.88 | 676.42 | |
| Crawford Co. RWD 4 | 3 | 12/6/04 | 239.29 | 670.11 | Pump off an unknown period of time |
| Crawford Co. RWD 5 | 1 | 12/7/04 | 277.19 | 649.21 | Well 2 pump off 45 minutes |
| Crawford Co. RWD 5 | 3 | 12/7/04 | 222 | 692.25 | Airline length unknown |
| Crawford Co. RWD 2 | 2 | 12/7/04 | 240.3 | 753.7 | Very poor cut; tape covered with orange slime from 50 ft downward. |

| Well Owner/ Water Supply | Well Number | Water-level Elevation Change Spring -Fall 2004 (feet) |
|---|---|---|
| Cherokee Co. RWD 2 | 1 | 4.91 |
| Cherokee Co. RWD 9 | 1 | -7.88 |
| Cherokee Co. RWD 8 | 1 | 1.2 |
| Cherokee Co. RWD 8 | 2 | 1.16 |
| Galena | 1 | -6.39 |
| Galena | 4 | -8.43 |
| Galena | 3 | 0.44 |
| Baxter Springs | 6 | |
| Baxter Springs | 5 | -6.9 |
| Cherokee RWD 3 | 1 | 21.84 |
| Jayhawk Fine Chemicals | PW 1 | -8.27 |
| Jayhawk Fine Chemicals | PW2 | 20.41 |
| Cherokee RWD 1 | 1 | |
| Cherokee RWD 1 | | |
| Columbus | 4 | -1.92 |
| Columbus | 5 | -4.96 |
| Columbus | 6 | -2.84 |
| Cherokee Co. RWD 4 | 1 | 5.59 |
| Cherokee Co. RWD 4 | 2 | 0.77 |
| Scammon | 2 | |
| Scammon | 1 | |
| Weir | 1 | 2.21 |
| Arma | 1 | |
| Arma | 2 | 2.13 |
| Frontenac | North | |
| Frontenac | South | |
| Frontenac | 1 | |
| Pittsburg | 8 | |
| Pittsburg | 9 | |
| Pittsburg | 10 | |

| Well Owner/ Water Supply | Well Number | Water-level Elevation Change Spring -Fall 2004 (feet) |
|---|---|---|
| Pittsburg | 11 | -2.48 |
| Cherokee | 1 | |
| Cherokee | 2 | |
| Girard | 3 | |
| Girard | 4 | |
| Arcadia | 2 | 2.79 |
| Crawford Co. RWD 1C | North | -3.19 |
| Crawford Co. RWD 1C | South | |
| Crawford Co. RWD 3 | 1 | 10.83 |
| Crawford Co. RWD 4 | 1 | -6.25 |
| Crawford Co. RWD 4 | 3 | -3.24 |
| Crawford Co. RWD 5 | 1 | -3.31 |
| Crawford Co. RWD 5 | 3 | |
| Crawford Co. RWD 2 | 2 | |

APPENDIX 2:
WELLS FOR INCLUSION IN THE NEW OZARK PLATEAUS AQUIFER WATER-LEVEL MONITORING NETWORK

| Well Owner/ Water Supply | Well Number | Aquifer | Township S | Range E | Section | Qualifier | Latitude | Longitude | Measurement Point Elevation (feet amsl) |
|---|---|---|---|---|---|---|---|---|---|
| Cherokee Co. RWD 2 | 1 | Ozark | 34 | 25 | 8 | SWNWSW | 37.09409 | -94.70312 | 848.75 |
| Cherokee Co. RWD 9 | 1 | Ozark | 34 | 25 | 20 | NWNENW | 37.07394 | -94.69864 | 825.25 |
| Cherokee Co. RWD 8 | 1 | Ozark | 34 | 25 | 21 | NWNESE | 37.06670 | -94.67107 | 917.71 |
| Cherokee Co. RWD 8 | 2 | Ozark | 34 | 25 | 28 | NWNWNW | 37.05935 | -94.68488 | 911.71 |
| Galena | 1 | Ozark | 34 | 25 | 23 | SENENE | 37.07213 | -94.63237 | 960.75 |
| Galena | 3 | Ozark | 34 | 25 | 14 | NWNWNE | 37.08841 | -94.63930 | 949 |
| Baxter Springs | 6 | Ozark | 34 | 24 | 36 | NENWNW | 37.04490 | -94.73702 | 822.3 |
| Cherokee RWD 3 | 1 | Ozark | 34 | 24 | 17 | SWSWSE | 37.07608 | -94.80277 | 856.17 |
| Jayhawk Fine Chemicals | PW 1 | Ozark | 34 | 25 | 4 | NENWNE | 37.11819 | -94.67332 | 853 |
| Cherokee RWD 1 | 1 | Ozark | 33 | 25 | 18 | NENESE | 37.16952 | -94.70538 | 870.9 |
| Cherokee RWD 1 | 2 | Ozark | 33 | 25 | 9 | SENESE | 37.18244 | -94.66908 | |
| Columbus | 4 | Ozark | 32 | 23 | 13 | NENENW | 37.26561 | -94.84204 | 894.13 |
| Cherokee Co. RWD 4 | 1 | Ozark Plateaus | 32 | 24 | 29 | NWNWNW | 37.23606 | -94.81252 | 912 |
| Cherokee Co. RWD 4 | 2 | Ozark Plateaus | 32 | 24 | 29 | NWNWNW | 37.23606 | -94.81252 | 912.71 |
| Weir | 1 | Ozark Plateaus | 31 | 24 | 27 | NWSESW | 37.31271 | -94.77203 | 924.08 |
| Arma | 1 | Ozark Plateaus | 29 | 25 | 5 | SESESW | 37.54398 | -94.69661 | 1020.5 |
| Frontenac | 1 | Ozark Plateaus | 30 | 25 | 4 | NESWSW | 37.45766 | -94.68285 | 954.27 |
| Pittsburg | 11 | Ozark | 30 | 25 | 28 | SESESE | 37.39726 | -94.66951 | 899.7 |
| Girard | 3 | Ozark | 30 | 24 | 21 | NESENE | 37.42122 | -94.77904 | 922 |
| Arcadia | 2 | Ozark | 28 | 25 | 1 | NESWNE | 37.63937 | -94.61774 | 836.45 |
| Crawford Co. RWD 1C | South | Ozark | 30 | 24 | 2 | SESESE | 37.45587 | -94.74251 | 948.3 |
| Crawford Co. RWD 3 | 1 | Ozark Plateaus | 29 | 25 | 4 | NESENE | 37.55304 | -94.66880 | 910.3 |
| Crawford Co. RWD 4 | 1 | Ozark Plateaus | 30 | 24 | 28 | NENENE | 37.41038 | -94.77900 | 928.3 |
| Crawford Co. RWD 4 | 3 | Ozark Plateaus | 31 | 24 | 16 | NENENE | 37.35262 | -94.77881 | 909.4 |
| Crawford Co. RWD 5 | 1 | Ozark Plateaus | 30 | 25 | 23 | SESWSW | 37.41193 | -94.64613 | 926.4 |