Final Report
Source of Supply Investigation
for Joplin, Missouri

Jack Wittman, Ph.D. CGWP       Vic Kelson, Ph.D. CGWP
Theresa Wilson

11th February 2003
Executive summary

Missouri–American Water Company (Missouri American) has hired Wittman Hydro Planning Associates of Bloomington, IN (WHPA) to conduct a regional groundwater study of Jasper and Newton counties in southwestern Missouri. The purpose of the study is to investigate a number of issues related to water supply, in particular the ability of the Ozark aquifer to sustain long-term population growth in the Joplin area and the potential for water-quality risks in the Ozark aquifer due to the contamination of the overlying Springfield Plateau aquifer.

Issues

As the population of southwestern Missouri has grown, the demand for water has increased. Between 1990 and 2000 the population of Jasper and Newton counties grew from 135,082 to 157,322 (16 percent increase) while personal income in the region increased from $1,969,000 to $3,272,500 between 1990 and 1999 (65 percent increase). Per capita personal income grew in the region more than 50 percent as a result of business development and expansion [MERIC, 2002]. As demand for water increases, the local drinking water suppliers need to add to their system capacity. Given the economics of drinking water development, the most common approach to increasing the capacity of any growing municipal system is to drill new deep wells into the Ozark aquifer as additional water is needed. The following problems have been identified:

Increasing reliance on the Ozark aquifer

As the demand for water increases in southwestern Missouri, more wells are being drilled into the Ozark aquifer, leading to problems with well field operation and production. All of the high capacity wells located in Jasper and Newton counties are drilled into the Ozark aquifer. Unfortunately, water enters the aquifer through a low-permeability confining layer that separates it from the overlying Springfield Plateau aquifer and locally increases drawdowns due to pumping. To further com-
plicate the situation, there have been well-reported episodes of high capacity well fields pumping from the Ozark aquifer that were unable to meet their production goals.

**Risk of contamination from the Springfield Plateau aquifer**

In Southwestern Missouri the Springfield Plateau aquifer is locally contaminated by high concentrations of lead and cadmium from mining that occurred over the past century. Other problems have been caused by more recent industrial activity where there have been unintended releases of solvents. These groundwater quality problems led to an effort by the state Department of Natural Resources to regulate well construction in areas where contamination was documented. The state requires that wells drilled into the deeper Ozark aquifer in areas where the Springfield Plateau aquifer is known to be contaminated must be cased and grouted through the confining layer. As more water is pumped from the deeper aquifer, the potential for migration of contaminated water into the drinking water supply increases.

**Well interference in the Ozark aquifer**

As wells continue to be drilled in the Ozark aquifer, it becomes increasingly likely that pumping at one well will lower water levels and pumping rates in neighboring wells. Because recharge (or leakage) into the deep aquifer is limited by the confining units and because there is no way to induce additional natural recharge or leakage into the system, local well interference could easily become a problem during peak demand periods.

**Investigation objectives**

The objectives of this investigation are to

1. characterize growth in demand and estimate future water use from the Ozark aquifer,
2. describe local and regional effects of groundwater withdrawal in the area,
3. evaluate the risk of contamination from the upper aquifer,
4. evaluate local yield under current and future conditions,
5. systematically evaluate water supply options, including groundwater, surface water, and springs.

Investigation approach

This investigation was conducted in six phases:

1. review the published literature and data for the area,
2. model groundwater flow using the hydrogeologic analysis presented in the Regional Aquifer System Analysis reports (Imes and Emmit, 1994),
3. conduct a site visit to interview water utility representatives in the area to collect data on water levels and pumping rates,
4. model groundwater flow to simulate flow patterns near the drinking water wells,
5. model aquifer yield to determine the long-term maximum production of the Ozark aquifer near Joplin,
6. evaluate stream and spring flows to consider their potential as sources of supply.

The final component of this project is a set of recommendations based on the findings of each of the phases of our work.

Summary of findings

A complete discussion of our findings and conclusions are provided within the report; however, a summary is provided below:
Additional data are required for reliable management of the groundwater resource

The pumping water levels of future drinking water wells are expected to decline (relative to current levels) as withdrawals from the aquifer increase. The information needed to manage the resource includes water levels in the aquifer at wells that have been shut down for a period of several weeks. Unfortunately, our experience in the area suggests that there are few communities that have the resources or personnel to collect data in a manner consistent with accurate predictions and resource management.

The Missouri DNR has one observation well in each of Jasper county. Because the predicted cone of depression is expected to develop in and around Joplin, it is important for the state and the local communities to establish a targeted data collection effort. The developing cone of depression near Joplin, along with the expanding cone of depression near Carthage, suggest that the limited groundwater supply will need to be closely monitored.

The data currently indicate that Ozark aquifer groundwater withdrawals are increasing rapidly, and that potentiometric heads are falling. This results in increasing "induced leakage" from the Springfield Plateau aquifer into the Ozark aquifer. Since the Springfield Plateau aquifer has large areas of known groundwater contamination, future risks may be present.

A cooperative effort will be needed to protect the Ozark aquifer from contamination

All of the water in the Ozark aquifer in the study region enters as leakage from the Springfield Plateau aquifer. Since the 1960s the state and the federal government have shown concern about the possibility of contaminated water from the Springfield Plateau aquifer reaching the Ozark aquifer. The first discussion of this risk was presented in the 1969 report, *Water Resources of the Joplin Area, Missouri* [Feder et al., 1969]. Feder reported that old mine works, chat piles, and mine waste that are distributed in the vicinity of Joplin are the primary source of groundwa-
ter contaminants in the area. Extensive mined areas exist along a line between Oronogo and Duenweg on the northeast side of Joplin. In addition, many mined areas are present between Carl Junction and Galena, Kansas on the west side of Joplin. Adding to the risk of these mined areas is breccia that acts as drains, introducing additional recharge in the previously mined areas. Recently, we have heard reports that metals contamination of the Ozark aquifer has been observed in northeastern Oklahoma; we are currently investigating these reports.

One possible source of support for data collection and analysis efforts related to the protection of the Ozark aquifer is the Center for Agricultural, Resource and Environmental Systems (CARES) at the University of Missouri–Columbia. This group has been primarily responsible for source water protection in the state for the past four years [Callison et al, 2002]. Their assistance in monitoring groundwater quality in the area, and their familiarity with the largest public databases, puts them in a position to effectively support this community effort. It may be beneficial for a cooperative water-supply organization in southwestern Missouri to partially fund a staff position at CARES to coordinate data management efforts.

Only a cooperative regional response will create new water supply options

Since the middle of the last century it has been understood that the aquifers near Joplin have limited capacity [Feder et al., 1969]. Creative pumping strategies and other mitigation techniques will not change the fact that the aquifer can produce only a limited supply of water. Without any state action, the best way for development to be coordinated and water levels restored in the Ozark aquifer is for all the involved parties to work together to manage the resource.

A cooperative effort will require more complete information about pumping rates and observed water levels. In addition, it might be desirable for a Regional Groundwater Consortium to be formed to help oversee the development of new supplies in the Newton-Jasper county area. The consortium might be responsible for analysis of all of the data that is collected by its members for distribution and consideration, and may become involved in advocacy for the development of
additional surface water supplies and surface storage facilities.

**The state DNR should collect additional data and encourage cooperation**

The role of the state in regional water supply planning is unclear. Between 1995 and 2000 the Missouri DNR Division of Geology and Land Survey produced a State Water Plan series that covered topics that include water use, water management and water quality protection. These documents, while representing the current status of water law and water resources at a state-wide scale, do not indicate how problems like regional water shortage problems should be addressed. Volume II of the Plan, *Groundwater Resources of Missouri* [Vandike, 1997] states:

> Missouri statutes and regulations generally provide for adequate protection of water quality. However, there are few if any laws that regulate the volume of water that is used for a particular purpose... If groundwater use exceeds recharge, water-level declines will occur, and disputes will likely arise. Currently these types of disputes, though uncommon, must be addressed in the courts through civil suits. As population and water use increases, there will be even greater demands placed on groundwater resources, and the incidence of conflict will probably increase. *Further legislation may be needed to prevent overuse of groundwater resources, or to define which uses should receive priority, especially during periods of drought or where groundwater demands greatly exceed resource capacity* (emphasis added).

Our investigation suggests that increasing demand for water, combined with the limited capacity of the aquifer, make it likely that these conflicts will occur in and around Joplin. It is apparent that drinking water is the most important use of groundwater in Missouri. While agriculture and industry (the other major players in water resource development) have well established strategies and voices to promote their rights to water, there is a far more diffuse voice for public water supply that should be heard.
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1 Introduction

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The final component of this project is a set of recommendations based on the findings of each of the phases of our work.
2 Review of previous work

An important part of our analysis was the collection and review of previously–published data and the results of earlier water resource investigations. This section describes the overall findings that resulted from that effort.

2.1 Literature and data review

The first step in this investigation was to review the published reports describing previous work done in the Joplin area. The results of that effort, outlining the most important findings of a selection of the hydrogeologic investigations done in the area, were contained in the data and literature review that was the initial product of our contract. The final report was delivered to Missouri American in May of 2002. The following are primary findings related to the hydrology of the system and other general information learned during the past decades of investigation:

**Historic mining affects the hydrology of the Springfield Plateau aquifer**

The Springfield Plateau aquifer, which overlies the Ozark aquifer in the Joplin area, was extensively mined during the 20th century. The mining required extensive underground works that opened up the formation to groundwater inflows and changed the storage capacity of the aquifer. The mines have increased the storage capacity of the system and have produced more complex conditions for flow in the upper zone. The changes in the aquifer properties and the increases in regional transmissivity have resulted in changes in groundwater flow in the area. In some areas, the now–flooded mines are used as underground reservoirs for drinking water. In other areas, heavy metal concentrations are so high that the water in the mine is not safe as drinking water.
Seepage through the mines and the mine wastes affects groundwater quality in the Springfield Plateau aquifer

The mine wastes, the mines, and the mineralized deposits within the upper 400 feet of rock all increase the likelihood that groundwater in the deep aquifer could become contaminated by heavy metals. It was pointed out by several investigators that the downward gradients in the system make it possible for any contamination in the upper zone to move into the Ozark aquifer. As more pumping is added to the system, the vertical gradient across the confining layer (and thus the local rate of leakage into the Ozark aquifer) will increase, raising the risk of contamination.

Viruses do not appear to be a major groundwater quality problem

In the 1990s, the USGS National Water Quality Assessment project evaluated the possibility that drinking water supplies in this area could be compromised by water-borne pathogen contamination. Of the public water systems sampled, only 14 percent detected water-borne viruses in their raw water.

During the 1990s, the population of Jasper and Newton counties increased 16 percent and personal income grew by 65 percent

During the 1990s, groundwater use has more than doubled, increasing by 120 percent. Because surface water treatment capacity is more capital-intensive, all new drinking water capacity has been added by sinking wells into the Ozark aquifer.

Well interference is more likely where transmissivity is low and leakage is limited

A pumping well develops a “cone of depression”: a roughly-circular region surrounding the well where the potentiometric head is lower than in the surrounding region. If two or more wells are pumped in close proximity, their cones of depression may coincide, resulting in even lower head drawdowns near the wells. This phenomenon is commonly called “well interference.”
For a given pumping rate, the spatial size of the cone of depression is larger in areas of low aquifer transmissivity or low recharge (in this case, low leakage rates from the Springfield Plateau aquifer). Published maps suggest that the Ozark aquifer transmissivity is lower in the near vicinity of Joplin than elsewhere in the study area.

The spring and wells at ICI (Atlas) may be a reliable source of water except during extended drought periods

The spring and wells at ICI may be one option for expanding the water supply east of Joplin. Based on the investigations and reports that have been written about Scotland Spring and the analysis of the wells during the early 1980’s, the area could supply between 3 and 5 MGD of raw water. Because the source of the spring was been determined by dye trace experiments, this additional water would require surface water treatment.

2.2 Summary of published data

The data used in this work take three forms: (1) spatial data presented as rasters, e.g. digital elevation models; (2) spatial data in the form of vectors, here delivered as shapefiles; and (3) point data, e.g. the locations of public water supply wells and well logs. In addition, we have located and downloaded the USGS Digital Raster Graphic images of all 1:24,000—scale topographic maps for the region. We have obtained data sets related to the geography, hydrology, and hydrogeology of the study area in southwestern Missouri. Table 1 is a summary of the contents of the files, and presents what we believe is the most relevant information for the analysis.

2.3 Regional modeling

The Ozark aquifer was modeled as part of a very large scale regional aquifer systems investigation done by the USGS in the 1980s and 1990s. This work was done with the purpose of understanding the extent of the groundwater resources in the
area and to consider the degree to which the system has been altered by human activity. As a part of this analysis, a regional model was used to evaluate recharge into the system and to estimate a total water budget for the groundwater flow system. The USGS modeling was supported by a thorough data collection effort in the project area. As the first step of the aquifer yield analysis near Joplin we re-opened the original USGS modeling files and rebuilt the files to run with current modeling software. This re-activated model was used to define a study area, to estimate aquifer properties and groundwater recharge, and to determine perimeter conditions for a regional flow model. The most important findings of that work follow:

The source of water in the Ozark is leakage from the Springfield Plateau aquifer

Examination of the head contours indicates that groundwater flow in the Ozark aquifer near Joplin is from the southeast to the northwest. There is a groundwater high 30 – 40 mi southeast of Joplin. The groundwater mound defines the southeast-
ern edge of a regional groundwatershed and can be treated as a no–flow boundary for purposes of the model.

There is not much water moving through the Ozark aquifer

The regional USGS model suggests that the total flow in the aquifer across Jasper and Newton counties is in the range of 50 – 60 MGD. The modeled leakage rate through the Ozark confining unit is less than 0.5 in/year. Our more detailed modeling (see Section 4) indicates that the regional model may overstate the total amount of water flowing through the Ozark aquifer.

Contamination may threaten drinking water supplies

Given the gradients in the two aquifers it is clear that known and potential sources of groundwater contamination in the upper can move into the lower. The locations of contaminated water in the Springfield aquifer should be a consideration for well siting and design in the underlying Ozark aquifer.

The model predicts regional drawdowns consistent with observations

When reported pumping rates for the most recent year (2000) are used in the regional model, predicted water levels drop by about 200 ft in the study area, based on the assumption that steady–state conditions are achieved. Based on the available literature and data, this is consistent with what has been observed in the area.

2.4 Site visit

During the first week of August 2002, WHPA staff visited southwestern Missouri to talk to local municipal water utility personnel and collect pumping and water level information. While the interviews were informal, our team asked the same basic questions in each community. In each community the local water utility managers were asked how many wells they operated, the pumping capacity of their system, how pumping rates changed during the year, whether they collected water level
Table 2: Summary of well information for cities and towns in Jasper and Newton counties, Missouri. Many of the existing wells have only been pumping for the past 4—5 years. There are 11 wells that are expected to be on—line within the next few years, and most communities reported an overall reduction in groundwater levels. Jasper County PWSD #2 was not interviewed, and is omitted from this table.

data in the wells (either pumping levels or static), and whether there were plans for additional wells. The responses are described below:

**Groundwater levels are falling throughout the region**

In most of the communities we visited, the water utility workers reported that they had recently lowered their well intakes or their pumps to keep pace with falling heads (see Table 2). In some communities the decline in water levels had forced community operations personnel to alter their pumping strategy and plan for new facilities. It was reported that 11 wells are planned and expected to be on—line within the next few years.
Demand is increasing

Since 1990 the Joplin wells have increased total annual withdrawal from 20 $MG/\text{y}$ to 348 $MG/\text{y}$ in 2000 (Figure 1). Because the surface water treatment plant in Joplin is already operating at capacity during periods of peak demand, total system capacity has been increased by adding new wells. In the last ten years MAWC has added five wells to their system. The Jasper County / Newton County study region shows a similar trend (Figure 2). If both industrial and public water supplies are considered together, the increase is even larger. The total groundwater withdrawal has increased in the two counties from a total of 2.9 billion gallons in 1990 to over 6.5 billion gallons in 2000 (Table 3).
Figure 2: Total groundwater use in Jasper and Newton Counties, Missouri from 1990 to 2000. Total use is categorized to show the fraction of groundwater pumping that is for public water supply and that fraction associated with other uses, such as industry or agriculture. All pumping data is based on the DNR water use database maintained in Rolla, Missouri.

Data from the local cities also exposed evidence of seasonal variations in the water levels (see Figures 3 and 4). During the growing season more water is consumed. Each community, except Neosho, stated that they increase pumping in the summer months, particularly in August. Most increase pumping by 25–50% in the summer, but some, such as Carl Junction, pump as much as three times more in summer than in winter. Neosho has an increased demand in the summer, but uses surface water to meet the peak demands instead of groundwater.
Pumping has been affected by well interference from neighboring wells

Some of the public water supply well fields in the area experience interference from other nearby wells. During periods of peak demand, all of the wells are being pumped at capacity. This means that if well interference can develop, it will first become apparent when there is the least flexibility in sources of supply. Since interference is already happening in and around Joplin, Neosho and Carthage, it is clear that new wells in the area will need to be placed strategically to at least minimize the effect on regional groundwater levels. Further, this means that under the right set of conditions (e.g., high pumping rates in the lower, high leakage through the aquitard, and low water levels in the upper) localized high capacity pumping in the deep aquifer may affect water levels in the shallow aquifer.

There is a risk of contamination of the Ozark aquifer

The additional pumping in the Ozark has lowered water levels in the deep aquifer, thus increasing the gradient between it and the overlying Springfield aquifer. In one case, a municipal supply well has been shut down because of problems with water quality usually associated with mining activity. It is clear that the potential for groundwater contamination is serious and real. If the deep aquifer becomes regionally contaminated, there are few other options for public water supplies near Joplin. West of Joplin, it has been reported that TDS in water supply wells

Table 3: Groundwater pumping rates in 1990 and 2000 for public water supplies and other major water user wells in Jasper and Newton Counties. Additional details are available that specify the annual pumping information for each well field.

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2 REVIEW OF PREVIOUS WORK

Figure 3: Seasonal variation in groundwater pumping in Missouri American Water Company’s Joplin wells in year 2001.

is increasing over time. This suggests that the increases in pumping have led to eastward movement of high TDS water in Kansas. So, not only is there a risk of contamination moving from the overlying aquifer through improperly abandoned wells, thin spots in the aquitard, or fractures, but there is also a risk that high withdrawals from the Ozark aquifer in Missouri could affect groundwater quality by moving higher TDS water into the aquifer from the west.

**Surface water could be further developed as a source of supply**

Currently, Shoal Creek is the primary source of drinking water supply for the City of Joplin. The karst aquifer that feeds Shoal Creek alters the flow duration characteristics of the stream, buffering high flow and supplementing low flow. North of
Figure 4: Seasonal variation in static water levels in Carl Junction’s well #1 in 2000–2001.

Shoal Creek, Center Creek empties into Spring River. When comparing the flow–duration curves of the three streams, it appears that Center Creek is a hybrid of the flashy Spring River at Waco and Shoal Creek near Joplin (see Figure 5). Because part of the basin is in the shale bedrock areas to the north, Center Creek has a rapid rainfall response and relatively high flood flows. The western half of the basin is in karst areas similar to Shoal Creek basin. Consequently, available gaging data shows that low flow during drought conditions remains relatively high.

As a source of supply, the most important problem with surface water in this area is that the lowest flows happen to coincide with the highest water demand. The average peak flows for the Spring River occur earlier than the high flow on Shoal Creek. The highest average peak flows on the Spring River occurs in March while the highest flow on Shoal Creek is does not happen until May (see Figure
Figure 5: Average monthly flows recorded for stream gages on Shoal Creek and Spring River. The average monthly flows for Shoal Creek are based on 59 years of record and the average flows on Spring River are based on 16 years’ record.
Figure 6: Average monthly flows recorded for stream gages on Shoal Creek and Spring River. The average monthly flows for Shoal Creek are based on 59 years of record and the average flows on Spring River are based on 16 years record.

6). While average flows do not peak during the same month on these two streams, low flows do coincide. The lowest average flow on either stream occurs each year in August. It is clear that the design condition for community water supplies in Southwestern Missouri is to satisfy the (peak) demand during periods of seasonal drought.

Other than groundwater, there are three ways to enhance the current water supply:

1. Develop springs in the vicinity

2. Develop additional surface water treatment capacity on another stream; or

3. Build a reservoir that can effectively create enough storage to supply the sys-
Aside from water quality issues associated with streams in the area, the only drawback to any of these options is that surface waters would be available in all but the driest conditions. Traditionally, the design of the system accounts for the peak demand period and in this scenario, there may always be a need for substantial groundwater withdrawal capability.

The spring at the ICI facility east of Joplin has been used as a source of industrial water supply for the past 75 years. Based on memoranda written by Atlas Powder personnel and their engineering consultants over the past 50 years, during average years the spring seems to reliably produce 2500 gpm (over 3.5 MGD). In 1979 the United States Geological Survey investigated the source area for the spring by performing a dye tracing analysis. A dye pulse was added to a losing reach of Grove Creek between county highway FF and 20th street near Duenweg. The dye emerged at Scotland Spring (2.2 miles downstream) just 22 hours later. Based on this data the estimated velocity of the dye in the karst formations that connect the headwaters to the Spring is 2.4 miles/d.
3 High-capacity pumping data collection

Our investigation (and particularly the modeling analysis) required the collection of groundwater extraction data for the time period 1990–2000, and for projected 2015 water use. This section describes our data collection efforts and results. An overall summary of the groundwater use data is provided in Appendix B.

Missouri DNR water use records

The primary source of data for Ozark Aquifer groundwater extraction is the Missouri Department of Natural Resources (DNR) water well database. The database contains well details on major groundwater users in each county of Missouri, including both municipal and industrial wells (see Figure 7). We made use of the information regarding well ownership, pumping capacity, reported annual pumpage, ground elevation, and location. For some wells, the location was given only according to the Public Land Survey System, so we digitized well locations and ground elevations for modeling use from USGS 1:24,000-scale topographic maps.

Interviews with public water supply operators

During interviews with municipalities within the study region, it became apparent that the Missouri DNR database was missing information for three major groundwater users in Jasper County: Webb City, Carterville, and Jasper County Rural Water District #1. For example, Webb City has six wells that are omitted from the DNR database. For these wells, we obtained detailed information directly from the public water utility employees, and added it to our records.

Unaccounted–for industrial pumping estimates

Many industrial wells were included in the DNR database; however, it is apparent that a substantial number of industrial wells are missing. This was confirmed through interviews with city employees in the study region who have knowledge of industrial wells that are not found in the database. To account for missing
Figure 7: Locations of wells near Joplin in the year 2000. The violet and blue areas are those quarter-sections in which groundwater contamination in the Springfield Plateau aquifer has been identified.
industrial wells, we compared the total pumpage at the "missing" public water supply wells found in interviews to the total pumpage reported in the Missouri DNR database. We estimate that in the Joplin area, 18% of the public water supply pumpage is not accounted for by Missouri DNR. We assume that this is an appropriate estimate for the fraction of omitted industrial well pumpage. This estimate yields a total "missing" industrial pumpage for 1995 of 1.7 MGD. The "missing" industrial pumping was distributed equally among ten hypothetical wells in the model region (see wells labeled "additional industrial wells" in Figure 21).

3.1 Selection of pumping data for model runs

Our modeling analyses were all based on estimated summer pumping conditions, as this is conservative given the study objectives. For each well in the model, a summer pumping rate was calculated. The municipalities described their seasonal pumping rates in interviews. All cities said they increased their pumping in the summer to account for increased demand. The increased pumping ranged from 25% more in summer to three times more water pumped in summer than in winter. Using this information, and the annual pumping rates, we were able to estimate how much of the water was pumped in the summer. For the industrial wells, we assumed that the seasonal variations in pumping rates were negligible.

In order to model the year 2015, pumping rates for that year were estimated for each of the wells in the region. Based on the amount of water pumped from 1990 to 2000, we used a linear extrapolation for both industrial and municipal wells and calculated how much water would be pumped in 2010 if the trend from 1990 continued. In order to be conservative in our estimation, we used the linear extrapolation of 2010 for our 2015 projected pumping. We distributed the projected amount of water among all the wells in the region. The amount pumped for each individual well was prorated according to the fraction of the total pumpage that calculated based on the percentage of cities water that well produced in 2000. Also in the 2015 scenario are "proposed wells." In discussions with cities in the region, we were informed of locations and expected pumping rates of wells that will be
drilled by the year 2015. For individual well pumping rates for cities with proposed wells, we distributed the projected amount of water pumped based on the capacity of individual wells. The cities with proposed wells are Joplin, Carl Junction, Carthage, and Jasper County Rural Water District #1.
4 Model development and results

This section describes the modeling analysis and its interpretation. This section is divided into the following topical discussions:

- A description of the model, including the boundary conditions in the model and properties, and calibration to field observations;
- Model results showing trends (i.e. drawdowns) in the regional aquifer, including proposed wells near Joplin;
- Potential aquifer yield calculations from the regional model, both regionally and locally, including a description of the methodology used to compute aquifer yield.

4.1 Model description

Due to the complexity of the flow system, we have chosen to use the USGS MODFLOW [McDonald and Harbaugh, 1988] model code for the final modeling effort. We performed scoping calculations with analytic element models in order to better represent flow (particularly leakage distributions) near wells, but the results of those analyses indicate that a properly-constructed MODFLOW model will give appropriate leakage distributions for this problem. We can account for the error in heads at individual wells by use of an approximation, as shown below.

Grid design

The model grid is shown in Figures 8 and 9. Figure 8 shows layer 1, which represents the Springfield Plateau aquifer, while Figure 9 shows layer 2, the Ozark aquifer. We have omitted all flow systems below the Ozark aquifer, because the flow rates there are much smaller than those in the Ozark aquifer. The model consists of 25,150 active cells per layer, in a regular grid with both row and column spacing of 2000 feet. It has been demonstrated [H. M. Haitjema, 2001] that MODFLOW will give an appropriate distribution of leakage if the cell size is smaller
Figure 8: Location of the model grid and boundary conditions for the Springfield Plateau aquifer (layer 1).
Figure 9: Location of the model grid and boundary conditions for the Ozark aquifer (layer 2)
than the representative leakage length,

\[ \lambda = \sqrt{T/L} \]  \hspace{1cm} (1)

where \(T\) is the transmissivity of the Ozark aquifer and \(L\) is the "leakance" of the confining unit. Using representative values from our previous modeling, we determined a value of

\[ \lambda = 7000 \text{ ft} \]

as the smallest value in the Joplin area. We chose a cell size of 2000 ft, in order to ensure that each cell will contain a maximum of one well, providing appropriately accurate flow patterns near wells. It should be noted that the initial estimate for \(\lambda\) is much smaller than that obtained during model calibration; our selected cell size is still appropriate, since it is smaller than \(\lambda\).

It should be noted that in the physical system, leakage through the Ozark confining unit is believed to take place through discrete fracture networks that connect the Springfield Plateau and Ozark aquifers. It is of course impossible to understand the nature of these networks, in particular the potential for contaminants to move laterally through the confining unit due to the arrangement of fractures. However, at the regional scale, and from a water–balance perspective, we make the assumption that the confining unit may be represented as a porous medium of low vertical hydraulic conductivity and negligible horizontal hydraulic conductivity. This assumption is consistent with the study of groundwater flow at the regional scale, with little local detail. As a result, the model should not be used to predict, e.g. contaminant pathways for water entering the Ozark aquifer.

After consultation with USGS (Rolla, MO) and Missouri DNR (Rolla, MO), it was apparent that the model domain must extend far to the west of Joplin. We have chosen to use a combination of boundary conditions derived from previous modeling and geohydrological studies of the Missouri–Kansas–Oklahoma three–state region.
4.2 Aquifer geometry

In the interest of simplicity, we have adopted the strategy used by others when modeling this region [Imes and Emmett, 1994], assuming confined conditions exist everywhere in the model, and specifying horizontal aquifers of constant thickness. We have assumed a thickness of 500 ft for the Springfield Plateau aquifer and a thickness of 1000 ft for the Ozark aquifer. However, since we have assumed confined flow it is convenient to describe the model in terms of the aquifer transmissivity. All references in the remainder of the report are provided in these terms. All aquifer transmissivity values and the leakance of the confining units were determined during the model calibration effort.

Layer 1 (Springfield Plateau aquifer) boundary conditions

In the Springfield Plateau aquifer, the perimeter boundary conditions are specified as follows (see Figure 8):

1. At the south edge of the model, a no–flow condition follows the water divide between Buffalo Creek and Indian Creek, and at the regional groundwater divide described by Imes and Emmett [1994].

2. At the east edge of the model, a no–flow condition follows along an inferred streamline oriented roughly north–south.

3. At the north edge of the model, a no–flow condition follows the water divide between the Spring River and Osage River basins.

4. At the northwest, a no–flow condition follows the boundary used by Imes and Emmett [1994].

5. At the west and southwest, a head–specified flux condition (MODFLOW RIV package) represents the Neosho River.

In addition to the perimeter boundary conditions described above, internal head–dependent flux (RIV) boundary conditions were included, representing surface
waters in the model region. River elevations were determined from the USGS 1:100,000–scale and 1:24,000–scale maps of the region. A conductance value of 50,000 was used for each cell; however, during model calibration, the choice of the river cell conductance had no noticeable effect on modeling results.

**Layer 2 (Ozark aquifer) boundary conditions**

In the Ozark aquifer, the perimeter boundary conditions are specified as follows (see Figure 9):

1. The south edge of the model corresponds to the no–flow condition in layer 1 (based on the contour plots of Imes and Emmett [1994]).
2. The east edge of the model corresponds to the no–flow condition in layer 1 (based on the contour plots of Imes and Emmett [1994]).
3. The north edge of the model has a general–head boundary representing the far–field Osage River. The cell conductances are computed based on a far–field transmissivity of 1000 \( ft^2/d \), and a distance of 40 \( mi \) to the Osage River. The elevation is selected as a value 20 \( ft \) higher than the average elevation of the Osage River and its major tributaries due north of the study region; this accounts for vertical resistance to upward flow beneath the Osage River.
4. At the northwest, a no–flow condition follows the boundary used by Imes and Emmett [1994].
5. At the west, a no–flow condition follows the Neosho River. This assumes that the Neosho River is the regional "drain" for groundwater in the Ozark aquifer, with groundwater "upwelling" toward the river. McFarlane and Hathaway [1987] suggest that the dividing line between the brines of the Western High Plains aquifer and the freshwater of the Ozark aquifer is in this vicinity. We therefore assume that any errors arising from the omission of "underflow" in the Ozark aquifer beneath the Neosho River are negligible.
The Ozark aquifer (layer 2) has no internal boundary conditions except extraction wells, which are discussed elsewhere in this report.

### 4.3 Recharge rate

Because nearly all of the model is bounded by no-flow conditions, the only source of water to the Springfield Plateau / Ozark aquifer system in the model region is recharge to the Springfield Plateau aquifer due to precipitation. Imes and Emmett [1994] performed a very detailed study of rainfall and runoff, resulting in a regional value for net recharge to the water table of $1.5 \times 10^{-4}$ ft/d. We have adopted those values for the duration of this study. This is defensible because the most important recharge rate in our model is the leakage to the Ozark aquifer, which is determined by the heads in the Springfield Plateau aquifer and the leakance of the confining units. Thus, calibration of layer 1 to heads measured in the field using the given recharge rate should be sufficient, assuming that pumpage in the Ozark aquifer has a small effect on the heads in the Springfield Plateau aquifer, as has been observed nearly everywhere in the Joplin area. All of our model results support this assumption.

### 4.4 Model calibration and validation

We have performed one calibration simulation and two verification simulations to ensure that the model is consistent with prior observations for regional potentiometric heads. No flux calibrations based on surface water flow were performed because a previously reported recharge estimate was used, as described above.

All modeling was based on an assumption of steady-state flow. This choice was made due to the observed rapid responses of the aquifer to local pumping and the 1–2 month recovery time observed in SCADA data for Missouri American well #4. These observations support the use of steady-state models based on seasonally–adjusted average pumping rates for all wells. Furthermore, there are nearly no high-quality data for use in calibrating a fully–transient model; collection of such a data set over the many–year time period required was impossible given the scope
of this study. Finally, the steady–state model represents the "worst case" for heads in the aquifer, given a set of pumping rates that might vary seasonally. Also, the steady–state model is the appropriate model for use in the "aquifer yield" analysis (see below).

**Calibration simulation**

The model was calibrated to match the approximate contour plots for the Springfield Plateau aquifer and Ozark aquifer in the Joplin–Webb City region (1994). This data set provided us with a potentiometric head field near Joplin that included the regional effects of pumping. Also, the data set was spacially concentrated in our area of interest. We used adjusted regional pumping rates for 1995, scaled down 2% to account for growth for all wells in the model during the calibration run.

The resulting transmissivity distribution is shown in Figures 10 and 11; a constant value of the leakance of the confining unit was also determined during model calibration. Figure 10 shows the distribution of transmissivity in the Springfield Plateau aquifer. The region of higher transmissivity in the southeastern portion of the model was derived from distributions shown in previous studies, and was necessary to keep the potentiometric heads in that portion of the model from exceeding the land surface. Figure 11 shows the distribution of transmissivity in the Ozark aquifer. The general distribution was derived from the Missouri DNR publication, *Water Resources of the Joplin Area, Missouri*, page 13. The transmissivity values result from head matching with the contours determined during the U.S. EPA investigation of contamination in the Springfield Plateau aquifer [Dames and Moore, 1993].

Observed heads in the Springfield Plateau aquifer are shown in Figure 12 while results of the calibration are shown in Figure 13. Observed heads in the Ozark aquifer are shown in Figure 14 while results of the calibration are shown in Figure 15. It was not possible to find a synoptic set of reliable observations for heads in both aquifers, other than the published Dames and Moore contour plots. Because records of pumping rates on a daily or even seasonal basis are unavailable and well interference effects are so pronounced, it is not possible to calibrate precisely
Figure 10: Model distribution of transmissivity in the Springfield Plateau aquifer (layer 1).
Figure 11: Model distribution of transmissivity in the Ozark aquifer (layer 2).
Figure 12: Observed water levels in the Springfield Plateau aquifer (model layer 1) near Joplin, MO. Source: [Dames and Moore, 1993].
Figure 13: Modeled 1995 heads in the Springfield Plateau aquifer (layer 1).
Figure 14: Observed water levels in the Ozark aquifer (model layer 2) near Joplin, MO. Source: [Dames and Moore, 1993].
Figure 15: Modeled 1995 heads in the Ozark aquifer (layer 2).
to a set of observations. We therefore cannot provide a statistical analysis of model calibration. Future studies in this region should attempt to improve the availability of consistent pumping records and well pumping rates.

It should be noted that the MODFLOW model cannot precisely simulate the water level in a pumping well, due to the grid cell size in the model. In the region near Joplin, all head calibration data are associated with wells that may have been active shortly before measurements were taken (this may explain the 100 ft or more differences between nearby wells in the data set). We have not attempted to calibrate to water levels in the near vicinity of wells, but to the ground levels in the area (e.g. the 800 ft contour line near Webb City).

Verification simulations

After the calibration was complete, we compared the model to two other conditions in an attempt to verify the model as a predictive tool:

1. Comparison to the predevelopment heads of Imes and Emmett [1994]. We removed all pumping wells and re–solved the model to ensure that the regional heads agree generally with the previously reported values for Springfield Plateau aquifer heads near Joplin (which differ only slightly) and the head at the up–gradient water divide southeast of Joplin (which differs by 50 ft or less). These results are appropriate, given the differences in the representations of aquifer transmissivity (Figures 10 and 11).

2. Comparison to reported drawdowns in Carthage, MO. It is reported that water levels in Carthage have fallen by about 50 ft in 5 years between 1995 and 2000. We re–solved the calibrated model using seasonally–adjusted summer pumping rates for all wells in 2000 (see Figure 16 ), and compared the heads to the 1994 calibrated result. The 1995–2000 head difference in Carthage is about 50 ft, which is consistent with the anecdotal information.
Figure 16: Modeled 2000 heads in the Ozark aquifer (layer 2).
Discrepancies in parameters from the previous study of Imes and Emmett [1994]

Imes and Emmett [1994] used transmissivity values much higher than those we have determined during this study. In the Springfield Plateau aquifer, this is because their model had large grid cells (14 mi on a side) that could not properly represent surface waters. As a result, calibration of the regional model resulted in high transmissivity values, particularly in the Springfield Plateau aquifer. In their regional model, heads in the Ozark aquifer were nearly equal to those in the Springfield Plateau aquifer. This was a result of the value of the representative leakage distance in that model, which was much smaller than the cell size (see Strack [1989] for a discussion).

The discrepancies between our estimates of aquifer properties are mostly due to the difference in the objectives of the two studies. The previous study determined "predevelopment" conditions only. Since there were no "stressed" conditions for model calibration available, the model was nonunique (that is, an infinite number of combinations of recharge rate and transmissivity could result in the same potentiometric head. We were able to make use of a set of observations from 1994 that include approximate contours for the Springfield Plateau aquifer and Ozark aquifer near Joplin. The heads in this "stressed" data set allow us to determine a more unique leakance and transmissivity for the Ozark aquifer. A complete explanation is not included here; see [Anderson et al., 1991] for details.

4.5 Predictions of regional head changes with time

The first set of model predictions was designed to evaluate the effects of increased pumping by wells in the regional system over time, due to population growth. We provide three model simulations:

1. Predicted heads for summer 2000, based on seasonally–adjusted pumping rates. The year 2000 was a dry year, in which many public water supplies near Joplin set records for groundwater usage. Results are shown in Figure 16 (above).
2. Predicted heads for summer 2015, based on seasonally–adjusted pumping rates determined from projected water demands. It should be noted that the projected demand for 2015 is only slightly larger than the actual demand for 2000, a dry year. The 2015 model distributes this slightly larger groundwater demand over existing and proposed wells in the study region, and adds additional pumping at proposed wells. Results are shown in Figure 17.

3. Predicted heads for a drought in 2015, with a similar intensity to the 2000 drought. The 2000 groundwater demand exceeded the 1990–1999 trend line by nearly 50%, so the 2015 predictive simulation has been repeated using total pumpage of 150% of the projected 2015 pumpage. Results are shown in Figure 18.

These models were used only to predict likely drawdowns in the regional aquifer over time. The results may be used to illustrate areas where well pumps may need to be lowered and regions of increased leakage from the Springfield Plateau aquifer (which may increase the risk of groundwater contamination in the Ozark aquifer).

4.6 Changes in leakage distributions

As pumpage in the Joplin area increases, the decline in heads in the Ozark aquifer increases the hydraulic gradient across the confining layer, resulting in higher leakage rates from the Springfield Plateau aquifer. Although this means that more water enters the Ozark aquifer, it also increases the risk that contaminants that are known to exist in Springfield Plateau aquifer will migrate into water supply wells. In this section, we present a description of the modeled changes in the leakage distribution near Joplin.

Figure 19 shows the modeled “pre–development” distribution of leakage into the Ozark aquifer. In areas colored green, yellow and red, vertical flow is downward into the Ozark aquifer; in areas colored blue, vertical flow is upward into the Springfield Plateau aquifer. As shown in the figure, during pre–development times, some water moved upwards from the Ozark aquifer into Spring River, Shoal Creek, and other major surface waters near Joplin.
Figure 17: Modeled 2015 heads in the Ozark aquifer (layer 2).
Figure 18: Modeled 2015 heads during drought conditions in the Ozark aquifer (layer 2).
Figure 19: Modeled pre–development leakage distribution for water entering the Ozark aquifer. Values presented are areally-averaged recharge rates, in $[ft/d]$. 
Figure 20: Modeled 2000 leakage distribution for water entering the Ozark aquifer. Values presented are areally-averaged recharge rates, in $[ft/d]$.

Figure 20 shows the modeled vertical flow patterns for 2000. Note that nearly all of the areas near Joplin where water was moving upward in pre-development times now show water moving downward into the Ozark aquifer. This means that some of the water that once arrived at the surface in springs or other surface waters now is extracted by wells. Some of the induced leakage from the Springfield Plateau aquifer infiltrates from areas known to be contaminated in the Springfield Plateau aquifer. This suggests that there is a slight risk of contamination for some wells in the Ozark aquifer near Joplin (it is reported that one Ozark aquifer well in Webb City has been contaminated; see Appendix B).

A prediction of the leakage distribution given the increased pumpage anticipated by 2015 is shown in Figure 21. The infiltration rates from potential sites of contaminated water are expected to increase during the period 2000–2015.
Figure 21: Modeled 2015 leakage distribution for water entering the Ozark aquifer. Values presented are areally-averaged recharge rates, in \([ft/d]\).
4.7 Aquifer yield analysis

Deriving a number for "aquifer yield" is a challenging task, because it is necessary to understand what factors affect the yield over a regional extent. This section is divided into a discussion of how we have defined aquifer yield, methodology we have used to predict it, and the results.

Defining aquifer yield

Groundwater yield values are often defined in terms of a quantity of water withdrawn per unit of drawdown in the aquifer (e.g. the specific yield of a well determined during a pumping test). For a regional aquifer with many competing users of groundwater, the definition of aquifer yield is more difficult: Quantity of water withdrawn by whom, and drawdown where?

In the Joplin area, nearly all of the groundwater users interviewed during this study have indicated in one way or another that heads in the regional aquifer are falling, and many of them have lowered pumps or deepened wells in recent years. In Carthage, records indicate a 50 ft decline in water levels over the five-year period from 1995–2000. When a new well is drilled, or when an existing well is pumped more frequently, neighboring wells often experience interference effects even a half-mile or more away. Over the entire regional aquifer, well interference adds up, and the regional heads continue to fall. It is clear that we will need to come up with a definition of "yield" that describes the entire Joplin region, taking into account the possibility of lowering wells and the operational cost of lowered pump elevations.

We have used an operating definition of aquifer yield based on the assumption that all users in the Joplin area will experience drawdowns with time, and will continue to respond by lowering pumps or deepening wells. We base the yield calculations on the average operating water level for each well, relative to the ground elevation. This is based on the idea that a withdrawal facility will lower the pumping elevation only when necessary, in an effort to control operating costs. In our model, therefore, we place MODFLOW "drain cells" in place of all wells, with the
drain elevation for each well at the same distance below the ground surface. We compute the drain resistance values based upon an approximation of the difference between the water level in a well and the water level in a model cell given by Trescott et al. [1976].

4.8 Modeling Ozark aquifer yield near Joplin

We have developed a strategy for computing the maximum amount of water that may be abstracted from the Ozark aquifer, given a distribution of wells and the distance between the ground surface and the average operating water level in all of the wells. The technique is to place "drains" (MODFLOW DRN package) in place of all pumping wells, with the water level in the drain set to the value

\[ h_{\text{drain}} = h_{\text{ground}} - z \]  

(2)

where \( h_{\text{drain}} \) [ft] is the water level in the drain, \( h_{\text{ground}} \) [ft] is the ground elevation at the well, and \( z \) [ft] is the desired distance between the ground surface and the operating water level in the well. The drain conductance values are computed according to the analysis below.

Computing the drain conductance

A finite–difference model cannot accurately simulate the potentiometric surface near a well; we need a reliable way to take the difference between the heads in the MODFLOW model and the actual head in each well. Trescott et al. [1976] presented the following approximation for the head in a well contained within a cell of a finite–difference model:

\[ h_w = h_{ij} - \frac{Q_w}{2\pi T} \ln \frac{r_e}{r_w} \]  

(3)

where \( h_w \) [ft] is the head in the well, \( h_{ij} \) is the head in cell \((i, j)\), which contains the well, \( r_w \) [ft] is the radius of the well, \( r_e \) [ft] is the effective radius of the cell.
(for regular grids, \( r_e = 0.208a \) where \( a [f t] \) is the row and column spacing), and \( Q_w [f t^3/d] \) is the pumping rate of the well.

For the yield analysis, we chose to represent the wells using “drain” cells in MODFLOW (using the DRN package). In MODFLOW, the extraction rate of a drain in row \( i \), column \( j \), layer \( m \) is given by

\[
Q_{\text{drain}} = C_{\text{drain}} \times (h_{\text{drain}} - h_{ijk})
\]

\[ (4) \]

where \( Q_{\text{drain}} [f t^3/d] \) is the extraction rate of the drain, \( C_{\text{drain}} \) is the drain conductance, \( h_{\text{drain}} [f t] \) is the specified head in the drain, and \( h_{ijk} [f t] \) is the head in the cell containing the drain. By combining Equation 4 with Equation 3 and then rearranging terms, we obtain

\[
C_{\text{drain}} = \frac{1}{\alpha} [f t^2/d]
\]

\[ (5) \]

where

\[
\alpha = \frac{1}{2\pi T} \ln \frac{r_e}{r_w}
\]

\[ (6) \]

which is the conductance of a drain that represents a well where the operating water level is known.

In our model, it is necessary only to assume an “effective radius” for each wells, then compute the drain conductance based on the local transmissivity from the calibrated model and the effective radius. We assume an effective well radius \( r_w = 1 \) \( f t \) for all wells. For the calibrated model, Table 4 contains the drain conductance for each transmissivity region in the Ozark aquifer (layer 2).

**Yield simulations**

The yield simulations were performed using the drain conductance derived above, then performing several runs, each with a different distance from the ground surface to the operating water level in all wells, \( z \). We then determined the total amount of water abstracted by drains in the Joplin–Carthage area. This region
4  MODEL DEVELOPMENT AND RESULTS

<table>
<thead>
<tr>
<th>Region</th>
<th>$T \text{ [ft}^2/\text{d} \text{]}$</th>
<th>$C_{\text{drain}} \text{ [ft}^2/\text{d} \text{]}$</th>
</tr>
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<td>1</td>
<td>200</td>
<td>208</td>
</tr>
<tr>
<td>2</td>
<td>350</td>
<td>364</td>
</tr>
<tr>
<td>3</td>
<td>1000</td>
<td>1041</td>
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</table>

Table 4: Drain conductance for each transmissivity region in the Ozark aquifer (layer 2).

<table>
<thead>
<tr>
<th>$z \text{ [ft]}$</th>
<th>$Q_{\text{total}} \text{ [MGD]}$</th>
<th>low</th>
<th>best-fit</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.91</td>
<td>1.01</td>
<td>1.31</td>
<td></td>
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<tr>
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<td>3.29</td>
<td></td>
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</tr>
</tbody>
</table>

Table 5: Results of the aquifer yield analysis.

includes the cities of Joplin, Carl Junction, Webb City, Duenweg, Carthage, and Carterville.

In Table 5 we present values for aquifer yield as a function of the parameter $z$, for values in the range of $100 < z < 800$. Yield estimates were computed based on parameters from the "best-fit" calibration run, and for runs in which the Ozark aquifer hydraulic conductivity and the leakance of the Ozark aquifer confining unit were increased and decreased 20%.
5 Conclusions and recommendations

Additional data are required for reliable management of the groundwater resource

For all of the growth scenarios, the operating levels at the well will be lower than the modeled water level predicted from our MODFLOW analysis. Depending on the location and pumping rate of each well, the difference will be on the order of 50–200 feet. This difference is a reflection of the averaging that takes place when the sharp cone of depression that surrounds each well is represented by a smoother lowering of the water level by a grid cell much larger than the actual pumping well.

The pumping water levels of future drinking water wells are expected to decline (relative to current levels) as withdrawals from the aquifer increase. The information needed to manage the resource includes water levels in the aquifer at wells that have been shut down for a period of several weeks. Unfortunately, our experience in the area suggests that there are few communities that have the resources or personnel to collect data in a manner that supports accurate predictions and resource management.

The Missouri DNR has one observation well in each of Jasper and Newton counties. Because the predicted cone of depression is expected to develop in and around Joplin, it is important for the state and the local communities to establish a targeted data collection effort. The developing cone of depression near Joplin, along with the expanding cone of depression near Carthage, suggest that the limited groundwater supply will need to be closely monitored.

The data currently indicate that Ozark aquifer groundwater withdrawals are increasing rapidly, and that potentiometric heads are falling. This results in increasing "induced leakage" from the Springfield Plateau aquifer into the Ozark aquifer. Since the Springfield Plateau aquifer has large areas of known groundwater contamination, future risks may be present.

The ability to alter pumping rates within the area to manage the groundwater supply will determine whether or not public water supply producers will be able to meet peak demands. In addition to monitoring water levels, it is crucial that
all of the water users who pump from the Ozark Aquifer report their water levels and pumping data on a regular (at least monthly) basis and make this information publicly available. Our analysis suggests that $15 - 20\%$ of all of the high capacity groundwater users are not reporting their withdrawals to the state. In the area near Joplin, this "hidden" pumping can dramatically alter availability of water to public water supply systems. It is in the interest of public water suppliers to make sure that water use is reported.

**A cooperative effort will be needed to protect the Ozark aquifer from contamination**

As pointed out elsewhere in this report, all of the water in the deep aquifer comes from the upper aquifer. Since the 1960s the state and federal government have been concerned about the possibility of contaminated water from the upper aquifer reaching the Ozark aquifer. The first discussion of this risk was presented in the 1969 report, *Water Resources of the Joplin Area, Missouri* [Feder et al., 1969]. Feder reported that old mine works, chat piles, and mine waste that are distributed in the vicinity of Joplin are the primary source of groundwater contaminants in the area. Extensive mined areas exist along a line between Oronogo and Duenweg on the northeast side of Joplin. In addition, many mined areas between Carl Junction and Galena, Kansas on the west side of town. Adding to the risk of these mined areas is breccia that acts as drains, introducing additional recharge in the previously mined areas. USEPA and the Missouri DNR Public Drinking Water Section have launched several investigations to determine the magnitude and extent of mine-related risks to groundwater.

Based on investigations funded by the USEPA, the Missouri DNR passed a set of regulations that require pressure grouting of all public supply wells in particular areas in the Springfield Plateau aquifer near Joplin (known as impacted areas). The impacted areas include locations where there are elevated lead and cadmium concentrations as well as areas where there is documented TCE or PCE contamination. It is in the interest of public drinking water suppliers in the area to be vigilant
guardians of groundwater and surface water quality. New wells should be located east and south of town for two reasons: 1) to take advantage of the generally higher transmissivity of the aquifer; and 2) to avoid the risks of known contamination moving from the upper aquifer to the Ozark. In particular, there should be some coordinated effort to track water quality for Pb, Cd, and VOCs. Such an effort would be the best way to detect the presence of upper aquifer contaminants of concern in the deeper Ozark.

One possible source of support for data collection and analysis efforts related to the protection of the Ozark aquifer is the Center for Agricultural, Resource and Environmental Systems (CARES) at the University of Missouri–Columbia. This group has been primarily responsible for source water protection in the state for the past four years [Callison et al, 2002]. Their assistance in monitoring groundwater quality in the area, and their familiarity with the largest public databases, puts them in a position to effectively support this community effort. It may be beneficial for a cooperative water-supply organization in southwestern Missouri to partially fund a staff position at CARES to coordinate data management efforts.

Only a cooperative regional response will create new water supply options

Since the middle of the last century it has been understood that the aquifers near Joplin have limited capacity. Creative pumping strategies and other mitigation techniques will not change the fact that the aquifer can produce a limited supply of water. Without any state action, the best way for development to be coordinated and water levels restored in the Ozark Aquifer is for all communities to work together to manage the resource. As suggested above, any cooperative effort requires more complete information about pumping rates and observed water levels. In addition, it might be desirable for a Regional Groundwater Consortium to be formed to help oversee the development of new supplies in the Newton County / Jasper County area. The consortium could be responsible for analysis of all of the data that is collected by its members for distribution and consideration. In addition, such a
The state DNR should collect additional data and encourage cooperation

The role of the state in regional water supply planning is unclear. Between 1995 and 2000 the Missouri DNR Division of Geology and Land Survey produced a State Water Plan series that covered topics that include water use, water management and water quality protection. These documents, while representing the current status of water law and water resources at a state-wide scale, do not indicate how problems like regional water shortage problems should be addressed. Volume II of the Plan, Groundwater Resources of Missouri [1997] states the following:

Missouri statutes and regulations generally provide for adequate protection of water quality. However, there are few if any laws that regulate the volume of water that is used for a particular purpose... If groundwater use exceeds recharge, water-level declines will occur, and disputes will likely arise. Currently these types of disputes, though uncommon, must be addressed in the courts through civil suits. As population and water use increases, there will be even greater demands placed on groundwater resources, and the incidence of conflict will probably increase. Further legislation may be needed to prevent overuse of groundwater resources, or to define which uses should receive priority, especially during periods of drought or where groundwater demands greatly exceed resource capacity (emphasis added).

Our investigation suggests that increasing demand for water, combined with the limited capacity of the aquifer in southwestern Missouri, make it likely that these conflicts will occur in and around Joplin. In the public interest, the case should be made that drinking water is the most important use of groundwater in Missouri. While agriculture and industry (the other major players in water resource development) have well established strategies and voices to promote their rights to water, there is a far more diffuse voice for public water supply that needs to be heard.
References


REFERENCES


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A City Information

During the first week of August, 2002, WHPA staff visited southwestern Missouri to talk to local municipal water utility personnel and collect pumping and water level information. While the interviews were informal, our team asked the same basic questions in each community. In each community the local water utility managers were asked how many wells they operated, the pumping capacity of their system, how pumping rates changed during the year, whether they collected water level data in the wells (either pumping levels or static), and whether there were plans for additional wells. The following summarizes the information received in these interviews as well as data from the Missouri Department of Natural Resources (DNR) major water users database. Data from the city contact persons and from the database have been provided in graphical format when possible.

A.1 Carl Junction

Location Carl Junction is located in Township 28 North, Range 33 West, approximately seven miles northwest of Joplin in Jasper County, Missouri.


Water Demand The city pumped 201.5 million gallons in 2000. The water demand has increased 37% since 1987 (see Figure 22).

Number of Wells Carl Junction has seven wells. Six are currently in use.

Drill Date Wells 1, 2, 3, 5, 6, and 7 were drilled in 1916, 1968, 1973, 1983, 1985, 1996, respectively. The drill date for well 4, which is not in use, was not reported.

Capacity The capacity of the groundwater system is 2.8 MGD. The capacities of the individual wells range from 185 – 315 gpm, with the exception of well 5 which pumps 650 gpm.
A CITY INFORMATION

Seasonal Pumping Variation  The city estimates that summer water use is 3–5 times the amount consumed in the winter.

Reported Water Level Decline  Carl Junction notices seasonal variation in the static water levels (see Figures 23 and 24). The summer water levels drop by approximately $25 - 50 \, ft$. The city has not seen evidence of a regional decline in groundwater levels.

Proposed Wells  The city voted on August 6, 2002 in favor of a bond that will fund the drilling of two more wells.

Interview Comments  The city is divided by Center Creek. Currently, approximately 40% of the population lives on the north side of the creek and the
Figure 23: Static and pumping water levels in Carl Junction well 1 from 2001–2002. Note: no data were reported for June, 2001 or February, 2002.
Figure 24: Static and pumping water levels in Carl Junction well 5 from 2001–2002. No data were reported for June 2001 or February 2002.
rest on the south side. In the future, however, the population distribution is expected to reverse, with 60% on the north side and 40% on the south.

A.2 Carterville

Location  Carterville is located in Township 28 North, Range 32 West, Section 7 and 18, approximately eight miles northeast of Joplin in Jasper County, Missouri.

Population  According to the 2000 census, 1,850 people live in Carterville. The population has decreased 8.8% from 1990–2000.

Water Demand  Water use has increased 16% from 62 million gallons in 1994 to 74 million gallons in 2001 (see Figure 25.)
Number of Wells  Carterville has one well in the northeast corner of town.

Drill Date  The drill date of the well is unknown.

Capacity  The capacity of the groundwater system is \( 0.65 \text{ MGD} \). The well is pumped at \( 350 - 450 \text{ gpm} \).

Seasonal Pumping Variation  The city estimates a 40% increase in water usage in the summer.

Reported Water Level Decline  No declines were reported.

Proposed Wells  No new wells have been proposed.

Interview Comments  Webb City supplied the city with water when Carterville’s well was out of service.

A.3 Carthage

Location  Carthage is located approximately 15 \text{ mi} northeast of Joplin. It is the county seat of Jasper County.

Population  The city has a population of 12,688, according to the 2000 census. The population increased 15% from 1990–2000.

Water Demand  The city pumped 1,126 million gallons in 2000. The water demand has increased 39% since 1987 (see Figure 26).

Number of Wells  The Carthage groundwater supply system contains 17 wells. All of the wells, except well 9, are currently producing. Well 9 has not been in use since 1997.

Drill Date  The drill dates for the Carthage wells are shown in Table 6. Drill dates for wells 3 and 4 were not reported.

Capacity  The total capacity of the well system is \( 8.5 \text{ MGD} \). However, the 17 wells are not pumped simultaneously. Instead, a subset of the wells is pumped
Figure 26: Annual groundwater pumping in Carthage from 1987–2000.
Table 6: Drill Dates for wells in Carthage, MO.

<table>
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<td>16</td>
<td>1999</td>
</tr>
<tr>
<td>17</td>
<td>1999</td>
</tr>
</tbody>
</table>
each week. Wells 16 and 17 are the best producers at 800 \( gpm \) and 900 \( gpm \), respectively.

**Seasonal Pumping Variation** Carthage pumps 2.5 \( MGD \) in the spring and approximately 3 – 3.5 \( MGD \) during the summertime.

**Reported Water Level Decline** Well 9 has not been in use since 1997 and since this time the static water level has dropped 40 \( ft \). In addition, five years ago the pumps had to be lowered from 705 \( ft \) to 805 \( ft \) because of dropping water levels.

**Proposed Wells** Carthage has proposed the addition of two more wells. Each of the new wells is expected to pump 700 \( gpm \).

**Interview Comments** Carthage created a 20 year water plan in 1996 that expects five new wells within the next twenty years. As of 2002, three of the five wells have already been installed.

### A.4 Duenweg

**Location** Duenweg is located approximately five miles east of Joplin in Jasper County, Missouri.

**Population** According to the 2000 census, Duenweg has a population of 1,034. This is an increase of 7.3% from 1990–2000.

**Water Demand** The city pumped 41 million gallons in 2000. The water demand has increased 18% since 1987 (see Figure 27).

**Number of Wells** Duenweg has two wells. Both wells are producing.

**Drill Date** Well 1 was drilled in 1957. Well 2 was drilled in 1985.

**Capacity** The two Duenweg wells have a combined capacity of 1.4 MGD. Well 1 is 1,275 \( ft \) deep and pumps 300 \( gpm \). In 2001, this well pumped 6,724,500 gallons of water. Well 2 is 1,675 \( ft \) deep and pumps 750 \( gpm \).
Figure 27: Annual groundwater pumping in Duenweg wells from 1987–2000.
Seasonal Pumping Variation  Duenweg observes seasonal variation in water usage. In July, 2001, the city used 3,675,000 gal, whereas in December, 2001 only 2,910,000 gal were pumped.

Reported Water Level Decline  No groundwater level declines were reported.

Proposed Wells  No new wells have been proposed.

Interview Comments  The static water level was 125 ft above the pump on August 5, 2002. When Missouri American Water Company drilled its well 5, Duenweg watched closely to see if there was any effect on their wells. They did not notice any change.

A.5 Jasper County Rural District No. 1

Location  Jasper County Rural Water District #1 (PWSD #1) serves the rural areas of the northeast part of Jasper County. They are responsible for areas outside of city limits. The public works office for RWD #1 is in Carl Junction.

Population  No estimate of the population served is available.

Water Demand  Approximately 60 million gallons were used in the year 2001 (see Figure 28).

Number of Wells  RWD #1 has one well which pumps 335 gpm.

Drill Date  The well was drilled in 1997.

Capacity  The capacity of the RWD #1 well system is 0.4 MGD.

Seasonal Pumping Variation  In 2001–2002 the RWD #1 pumped approximately 1 MGD more in the summer months.

Reported Water Level Declines  No groundwater level declines have been reported, although the RWD #1 observes seasonal water level declines (see Figure 29).

Proposed Wells  Two additional wells have been proposed.
Figure 28: Monthly groundwater pumping in Jasper County Rural Water District #1 well from 2001–2002.
Figure 29: Static and pumping water levels in the Jasper County Rural Water District #1 well from 2001–2002.
A CITY INFORMATION

Figure 30: Annual groundwater pumping in Neosho wells from 1997–2000.

Interview Comments  No further comments were given.

A.6 Neosho

Location  Neosho, Missouri is located approximately 25 miles southeast of Joplin in Newton County. It is the county seat of Newton County.

Population  According to the 2000 census, the city has a population of 10,505. Neosho grew 12% from 1990–2000.

Water Demand  Neosho uses approximately 45% groundwater. In 2000, groundwater use was 429 million gallons. This is a 28% decrease from the initial year of pumping, 1997.


**A CITY INFORMATION**

**Number of Wells** The city has five wells that were drilled between 1930–1950. In 1997, the city began using three of these wells to supplement its primary supply of surface water from Shoal Creek.

**Drill Date** The Dewey/Finney well (well 2) was drilled in 1937. The Wheeler well (well 1) and the Pet well (well 5) were both drilled in 1944. Wells 3 and 4 are not in use.

**Capacity** They pump the wells at the same level throughout the year; about 1.5 MGD total for all three wells. The Wheeler well pumps 480 gpm. Pet and Dewey/Finney wells pump 275 gpm and 300 gpm, respectively.

**Seasonal Pumping Variation** The city may observe an increase in demand in the summer months, but because the wells just supplement the surface water, they are pumped at the same level throughout the year.

**Reported Water Level Declines** The Wheeler and Pet wells, prior to pumping, were both artesian wells flowing at 100 gpm. When pumping began, the static water level dropped and has continued to drop. It is now currently at 10 ft above the pump. The pump is 500 ft below the surface elevation.

**Proposed Wells** No new wells have been proposed.

**Interview Comments** An industry in town (Lindy) has a well that pumps 100,000–120,000 gpd at 83 gpm. They began pumping 3 or 4 years ago. In August, 2002 the well was temporarily out of service due to necessary pump lowering. They lowered the pump from 483 ft to 713 ft. The well is 1500 ft deep with the ground elevation at Lindy about 200 ft higher than the water plant. A few years ago, a man southwest of town pumped pure product TCE from his private well drilled in the upper aquifer. This began an EPA investigation into groundwater contamination in the area. It is now known that the upper aquifer is contaminated from Hickory Creek south to the old rocket plant, and west to the other side of the city. They have also report that they have found TCE in the lower aquifer.
A.7 Oronogo

Location  Oronogo is located approximately 10 miles north of Joplin in Jasper County, Missouri.

Population  According to the 2000 census, Oronogo has a population of 976. The city has grown 64% in the past ten years and currently there are 790 additional homes being built.

Water Demand  Oronogo uses an estimated 45 $MG/year$, an increase of 81% from 1990–2000 (see Figure 31). The Missouri Rural Water Association has estimated that Oronogo will need to increase water production by 250,000 $gal/d$.

Number of Wells  The town has two wells that each produce 500 $gpm$. 

Figure 31: Annual groundwater pumping in Oronogo wells from 1987–2000.
Drill Date  Well 2 was drilled in 1956 and well 3 was drilled in 1989.

Capacity  The combined capacity of the wells is 1.5 MGD.

Seasonal Pumping Variation  It is unknown whether demand increases in the summer months.

Reported Water Level Declines  In the past few years, Oronogo had to lower the pumps in both wells from 500 ft to 700 ft because the water level dropped below the pumps.

Proposed Wells  No new wells have been proposed.

Interview Comments  No additional comments were made.

A.8  Pittsburg, KS

Location  Pittsburg is located at 37°25′N 94°42′W, approximately 32 miles north and west of Joplin, just over the Kansas/Missouri state border.

Population  Pittsburg has a population of 19,243 according to the 2000 census. It has grown 8% from 1990–2000.

Water Demand  The city uses approximately one billion gallons per year. Demand has remained relatively constant from 1991–2001 (see Figure 32).

Number of Wells  Pittsburg has four wells in use.

Drill date  The drill dates are unknown.

Capacity  The capacity of the groundwater system is 11 MGD.

Seasonal Pumping Variation  Pittsburg observes an increase in demand in the summer months (see Figure 33).

Reported Water Level Declines  No water level declines have been reported.

Proposed Wells  No new wells have been proposed.
Figure 32: Annual groundwater pumping in Pittsburg wells from 1991–2001.
Figure 33: Monthly groundwater pumping in Pittsburg wells in 2001.
Figure 34: Comparison of pumping in Webb City wells in all 1990 and 2000–2002.

Interview Comments No additional comments were made.

A.9 Webb City

Location Webb City is located approximately seven miles north of Joplin in Jasper County.

Population The city has a population of 9,812 and has grown 24% from 1990–2000.

Water Demand The city uses approximately 400 million gallons per year (see Figures 34, 35, 36, and 37).

Number of Wells Webb City has 13 wells, but only seven are currently pumping. Wells 1–5 stopped pumping in the early 1970’s. Well 10 is not pumping be-
Figure 35: Monthly groundwater pumping in Webb City wells from 2001–2002.
Figure 36: Monthly groundwater pumping in Webb City wells in 2000.
Figure 37: Monthly groundwater pumping in Webb City wells in 1990.
cause it produces water that is high in sulfur.

**Drill Date** The drill dates of the wells are unknown, except for well 13 which was drilled in 2002.

**Capacity** The estimated capacity of the well system is $4 \ MGD$.

**Seasonal Pumping Variation** Webb City observes very little seasonal variation (see Figure 37). In 2000, the Webb City wells pumped approximately $1 \ MGD$ in the winter and $1.15 \ MGD$ in the summer.

**Reported Water Level Declines** When Joplin pumps its Hill Street well (well 3), the water levels in Webb City’s well 11 and 12 drop below the pump. The pumps for these wells are 650 ft and 700 ft below the surface, respectively. The water level returns six hours after the Hill Street well is turned off. The city also observes seasonal fluctuations (see Figure 38).

**Proposed Wells** No new wells have been proposed.

**Interview Comments** Webb City would like to improve its water supply system.
Figure 38: Static and pumping water levels in Webb City’s well 7 in 2001–2002.
B  Data Tables

The following pages contain tables of detailed well data used in the Joplin Source of Supply analysis.