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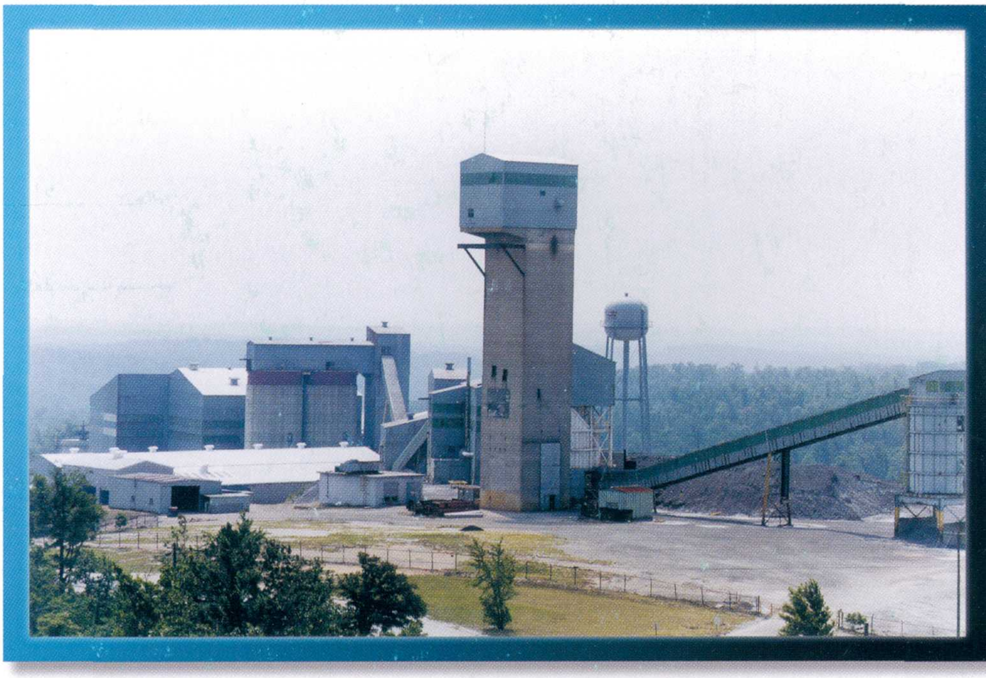
Water-Resources Investigations Report 00–4293



Prepared in cooperation with the
U.S. Department of Agriculture, Forest Service,
U.S. Department of the Interior, Bureau of Land Management, and
Missouri Department of Conservation

U.S. Department of the Interior
U.S. Geological Survey

Cover Photograph: Buick Mine, Iron County, Missouri.

U.S. Department of the Interior
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Rolla, Missouri
2001

U.S. Department of the Interior

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CONTENTS

FIGURES

TABLES

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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Abstract

Lead-zinc mines in the Viburnum Trend of southeastern Missouri are dewatered during mining operations. Although the mines are located in the Bonneterre Formation of the St. Francois aquifer, and this aquifer is separated from the surficial Ozark aquifer by the St. Francois confining unit, there is concern that pumpage for mine dewatering may have or possibly could lower water levels in the Ozark aquifer regionally. Also, a reduction in the flow of water to area springs and streams and lower water levels in area wells could result. Pumpage for mine dewatering is estimated to have been 26 million gallons per day in 1971 and was reported to be 27 million gallons per day in 1999.

The lowermost geohydrologic unit in the 600-square mile study area (parts of Crawford, Iron, Washington, Dent, Reynolds, and Shannon Counties of southeastern Missouri) is the Precambrian Basement confining unit, which is nearly impermeable. The Precambrian surface is irregular with buried knobs. Formations overlying these knobs may be thin or missing. The St. Francois aquifer overlies the Basement confining unit and consists of the Lamotte Sandstone and the Bonneterre Formation (host formation for lead-zinc deposits). The thickness of the aquifer in the study area varies from less than 100 feet over Precambrian knobs to about 800 feet, but typically the aquifer is from 300 to 600 feet thick. The St. Francois confining unit overlies the St. Francois aquifer and consists of the Davis Formation and the Derby-Doerun Dolomite. The typical thickness of the confining unit in the study area is 200 to 300 feet. The confining unit effectively impedes the flow of ground water between the Ozark aquifer and the St. Francois aquifer except where preferred path secondary permeability has developed along faults and fractures and appreciably increased the vertical hydraulic conductivity in the confining unit. The Ozark aquifer is the uppermost geohydrologic unit, is primarily unconfined, and is the primary source of water for water supplies in much of southern Missouri. This predominantly carbonate aquifer consists of rocks from the base of the Potosi Dolomite through the Roubidoux Formation and typically ranges from 200 to 900 feet thick in the study area.

The pre-mining potentiometric surface for the Ozark aquifer (prepared using 115 static water-level measurements taken before 1960 and 3 post-1960 historic water-level measurements) and the 1999 potentiometric surface (prepared from water levels measured in 7 observation wells and 59 domestic- and public-water-supply wells) were mapped for the Ozark aquifer and compared to assess the affect of mine dewatering.

A digital analysis was accomplished by computer interpolation of the pre-mining (prior to 1960) and 1999 data sets on a regular grid with 0.5-mile centers. The results of this analysis indicate that the differences in the two data sets are small and are within the accuracy of the determined potentiometric altitudes, which are limited by the accuracy of the water-level measurements

and topographic maps (plus or minus 15 feet). The isolated areas of calculated water-level declines appear to be related to the distribution of the pre-mining and 1999 data, the accuracy of the water-level data, and inherent error in interpolating the water-level data and not to actual water-level declines. The general conclusion is that no large cones of depression are apparent in the potentiometric surface of the Ozark aquifer in the Viburnum Trend as a consequence of mining activity. Leakage of water from the Ozark aquifer into the St. Francois aquifer probably is occurring at shafts, ventholes, and inadequately plugged exploration drill holes. Therefore, there may be localized areas of small drawdowns.

INTRODUCTION

The initial discovery of lead-zinc deposits near Viburnum, Missouri (fig. 1) was made in 1955 and initial ore production began in the mid-1960s (Wharton, 1975). Between 1960 and 1973, eight operating underground mines were opened (Warner and others, 1974) along a 45-mile north-south trending band that ranges from less than 500 feet wide to, in rare cases, about 1 mile wide (Wharton, 1975). This mining area is locally referred to as the Viburnum Trend. Currently (2000), there are nine active mines in the Viburnum Trend. One of the original eight mines (Viburnum Mine No. 27) was allowed to fill with water and is used by the City of Viburnum as a drinking water source. In the early 1980's, two other mines, West Fork and Casteel Mines, opened (fig. 1).

Predominantly carbonate rock sequences of the Lower Ordovician and Upper Cambrian Series (Roubidoux Formation to the base of the Lamotte Sandstone) overlie igneous granites and rhyolites of the Precambrian basement rock. These rocks form the surficial Ozark aquifer, the St. Francois confining unit, and the underlying St. Francois aquifer (fig. 2). Locally, the Roubidoux Formation is present and exposed on some of the highest ridge tops, but predominantly the formations from the Gasconade Dolomite to the Potosi Dolomite crop out (Anderson and others, 1979). The Bonneterre Formation, which forms part of the St. Francois aquifer, is the host formation for the largest and most important lead-zinc deposits in southeastern Missouri (Wharton, 1975).

Before lead-zinc ore can be extracted, the mine area must be dewatered. Pumpage from the St. Francois aquifer for mine dewatering in the Viburnum Trend was estimated to be 26 million gallons per day in 1971 (Warner and others, 1974). In 1999, the total pumpage for mine dewatering was slightly larger, reported to be 27 million gallons per day (Denis N. Murphy, The Doe Run Company, written commun., 2000). This continued pumpage possibly could lower water levels in the Ozark aquifer regionally and cause a reduction in the flow of water to area springs and streams and lower water levels in area wells.

In 1999, a study was begun to determine if water-level declines were occurring in the Ozark aquifer in the Viburnum Trend as a result of lead-zinc mining. This study was performed by the U.S. Geological Survey (USGS) in cooperation with the U.S. Department of Agriculture, Forest Service (hereafter referred to as Forest Service); U.S. Department of the Interior, Bureau of Land Management; and the Missouri Department of Conservation.

Purpose and Scope

This report presents the results of a geohydrologic study to determine if water levels in the surficial Ozark aquifer have declined in the Viburnum Trend as a result of mine dewatering in the deeper St. Francois aquifer. The study area consists of about 600 square miles in an area that includes parts of Crawford, Iron, Washington, Dent, Reynolds, and Shannon Counties of southeastern Missouri (fig. 1). However, pre-mining water-level data were collected for an expanded area (2,200 square miles) to ensure that the full extent of water-level declines, if present, could be identified.

The data analysis was accomplished by comparing potentiometric surfaces of the Ozark aquifer for two different times. The pre-mining potentiometric surface was mapped from static water-level measurements on file at the Missouri Department of Natural Resources, Division of Geology and Land Survey (DGLS) in Rolla, Missouri, that were reported by well drillers upon completion of wells. The second potentiometric surface was mapped from water-level measurements made during the summer and fall of 1999. The two surfaces were compared, and water-level changes were quantified.

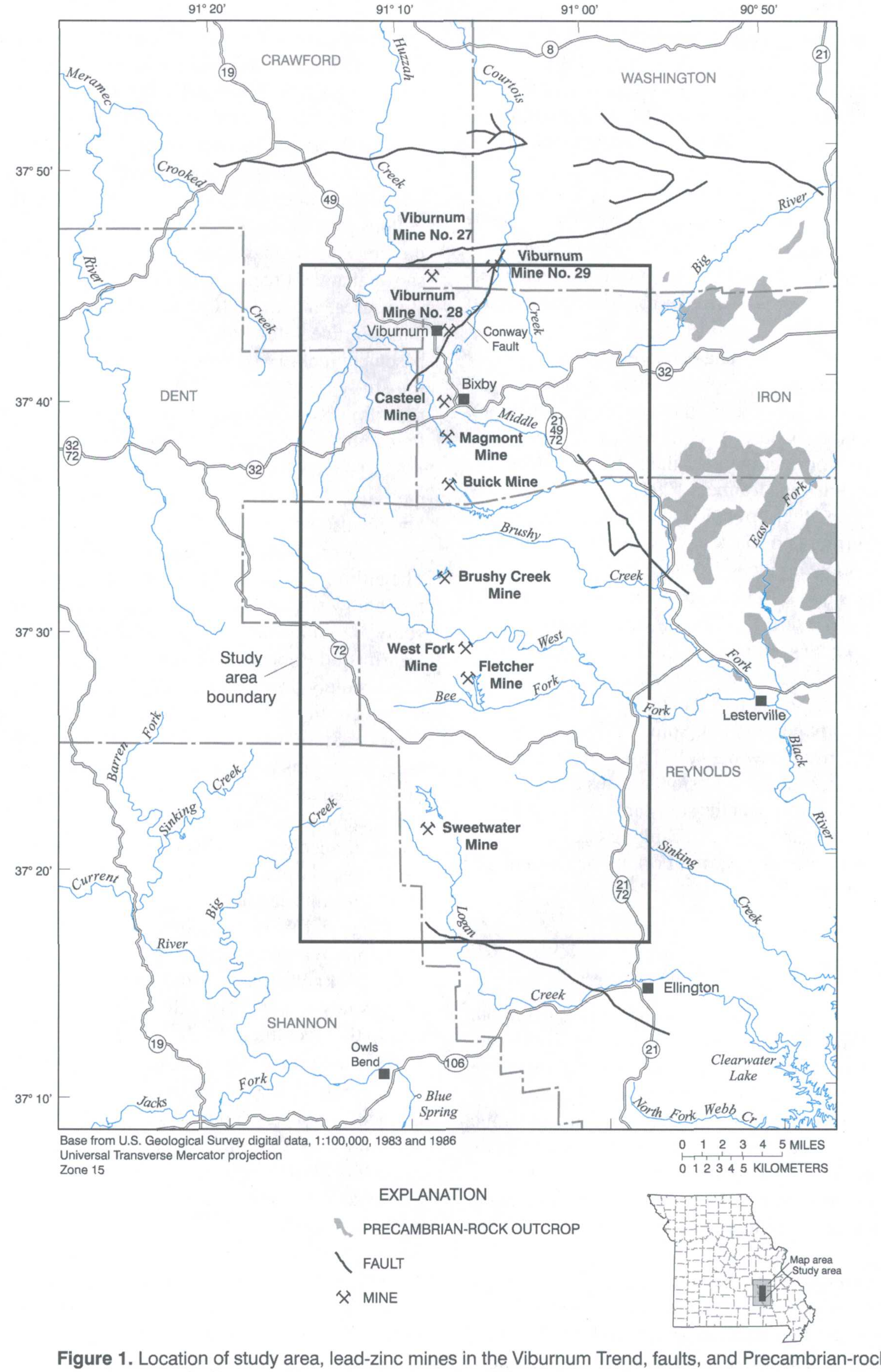


Figure 1. Location of study area, lead-zinc mines in the Viburnum Trend, faults, and Precambrian-rock outcrops in the St. Francois Mountains, southeastern Missouri.

Description of Study Area

The study area is on the western flank of the St. Francois Mountains and much of the area is within the boundaries of the Mark Twain National Forest and managed by the Forest Service. Much of the area within the National Forest boundaries is uninhabited, hickory-oak forest. The area includes scattered parcels of private property that contain either isolated homesteads or small communities. Most of the private property is concentrated along major roads or along stream valleys.

The study area is characterized by deep, narrow valleys, and narrow, steep-sided ridges. It is common to have more than 300 feet of relief between the ridge top and the adjacent valley. A regional surface-water divide trends northeast across the northern part of the study area (Imes and Emmett, 1994). The Meramec and Big Rivers and their tributaries are north of this divide and the Current and Black Rivers and their tributaries are south of the divide.

The study area lies within a large region of well-developed karst terrain that is characterized by the presence of caves, springs, sinkholes, and gaining and losing streams. Most of the springs in the study area are small, discharging 0.1 to 1.0 cubic feet per second (Vineyard and Feder, 1974). Some of these small springs and many flowing wells in the area are used as domestic water supplies. Losing streams also have been identified in or near the study area (Harvey, 1980), and include Logan Creek and Sinking Creek in the Black River Basin and Barren Fork in the Current River Basin (fig. 1).

Geohydrologic Units

Delineation of geohydrologic units is based on hydraulic properties and the hydrologic relation of each unit to adjacent geohydrologic units at a regional scale. The terms aquifer and confining unit, as defined regionally, may not adequately describe the hydraulic properties of a sequence of rocks locally because of the variation in water-yielding capability of the same sequence from one area to another. The geologic names used in this report follow the nomenclature used by the DGLS.

The lowermost geohydrologic unit underlying the study area is the Basement confining unit, which is predominantly Precambrian granite and rhyolite porphyry (fig. 2). The altitude of the top of the basement confining unit ranges from 600 feet below sea level to 600 feet above sea level in the study area (Fletcher, 1974). Imes (1989) states that this confining unit is nearly impermeable, but in areas where extensive faulting and fracturing has occurred, the Basement confining unit can yield small quantities of water. In areas where the unit crops out, well yields are less than 10 gallons per minute. A map of the altitude of the top of the Precambrian basement rock in Fletcher (1974) shows that the Precambrian surface is irregular in the study area, and about 10 scattered, buried knobs exist that protrude 400 to 600 feet above the surrounding basement rock. Two knobs in the southeastern part of the study area extend 1,200 feet above the surrounding basement rock. Formations overlying these Precambrian knobs may be thin or missing.

The St. Francois aquifer (Imes, 1990a) overlies the Basement confining unit and consists of the Lamotte Sandstone and the Bonneterre Formation, which is the host formation for lead-zinc deposits (fig. 2). The altitude of the top of the aquifer ranges from 200 feet below sea level to 900 feet above sea level in the study area (Fletcher, 1974). Because the surficial Ozark aquifer meets the stock, domestic, and public-water-supply needs in the study area, the deeper, primarily confined, St. Francois aquifer rarely is used. Near the St. Francois Mountains just east of the study area, where this aquifer is close to land surface, it yields adequate supplies of water for domestic and small-capacity public-supply wells. The thickness of the St. Francois aquifer can vary considerably in the study area because of the rugged surface of the underlying Precambrian basement rocks. Based on DGLS well logs and Warner and others (1974), the thickness of the aquifer varies from less than 100 feet over Precambrian knobs to about 800 feet in the western part of the study area, but typically the aquifer ranges from 300 to 600 feet thick.

The St. Francois confining unit (Imes, 1990b) overlies the St. Francois aquifer and consists of fine-grained carbonates and shales of the Davis Formation and the Derby-Doerun Dolomite (fig. 2). Common indicators of the effectiveness of a confining unit are the thickness and the shale content (usually a minimally permeable material) of the unit. Whereas these normally are good measures of the confining capability of a unit, other physical properties may alter the confining ability, including the degree of cementation of the rock and secondary permeability features such as solution channels, fractures, and faults that develop in the

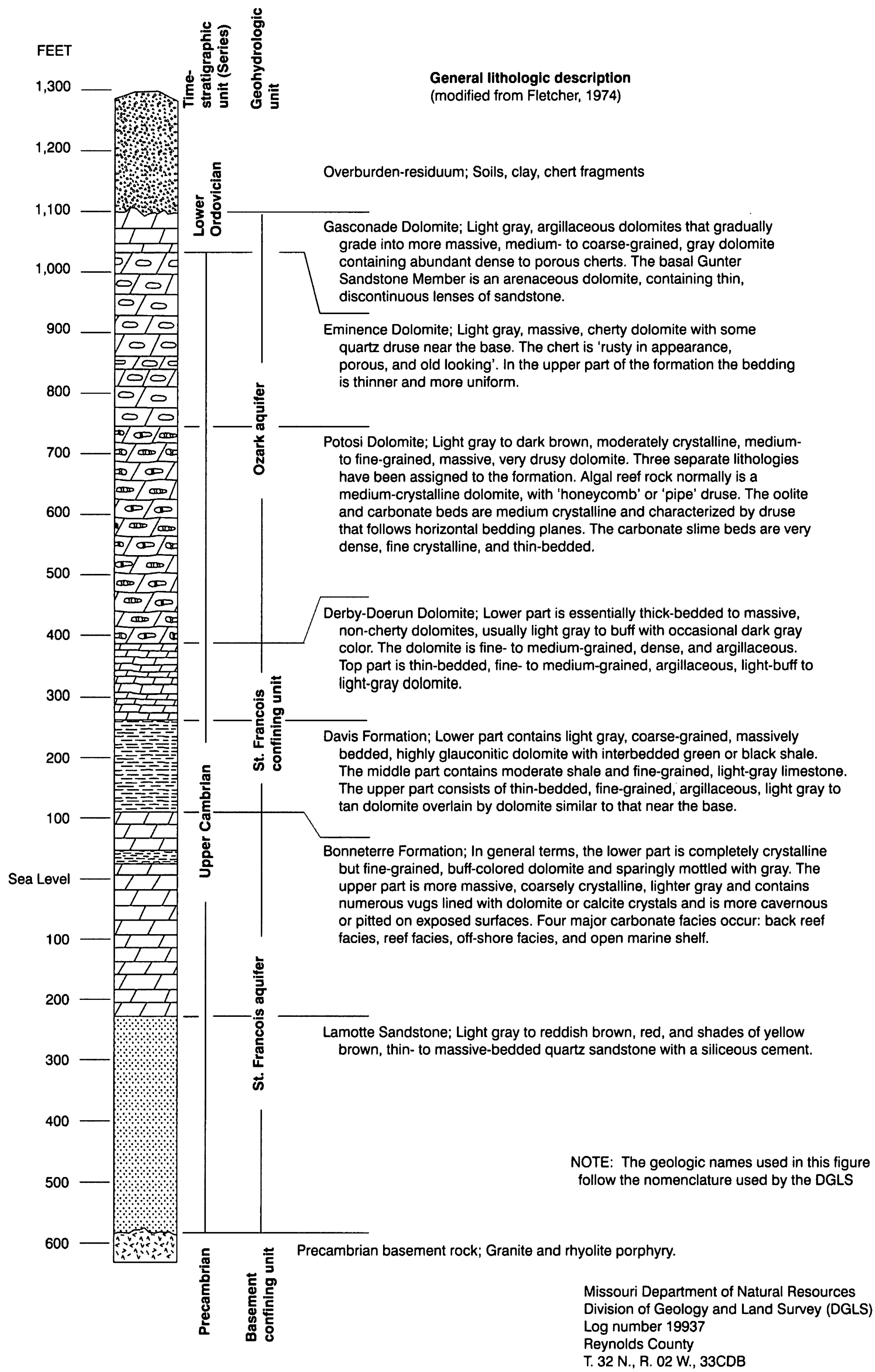


Figure 2. Stratigraphic column for an exploration hole in Reynolds County, Missouri, and a general lithologic description of formations in the Viburnum Trend.

rock (Imes, 1990b). Imes and Emmett (1994) state that substantial secondary porosity and permeability have not developed regionally in the St. Francois confining unit. The clastic to carbonate ratio (shale content) in the Davis Formation increases westward from the St. Francois Mountains (Warner and others, 1974). Based on DGLS well logs, the typical thickness of the confining unit in the study area is 200 to 300 feet.

Laboratory vertical hydraulic conductivity values for the St. Francois confining unit were determined for 24 rock core samples from 5 exploration holes drilled in the southern part of the Viburnum Trend (Kleeschulte and Seeger, 2000). The vertical hydraulic conductivity of the core samples ranged from 2×10^{-12} foot per second to less than 3×10^{-14} foot per second (the minimum reporting limit). These vertical hydraulic conductivities are small; therefore, the confining unit effectively impedes the flow of ground water between the Ozark aquifer and the St. Francois aquifer except where preferred path secondary permeability (not present in the rock core samples) has developed along faults and fractures and appreciably increased the vertical hydraulic conductivity in the confining unit.

The Ozark aquifer (Imes, 1990c) is the uppermost geohydrologic unit, is primarily unconfined, and is the primary source of water for water supplies in much of southern Missouri. Based on DGLS well logs, the thickness of the aquifer typically ranges from 200 to 900 feet in the study area. This predominantly carbonate aquifer consists of rocks from the base of the Potosi Dolomite through the Roubidoux Formation and, in the study area, is composed of dolomite and limestone with some sandstone. Several of the wells used to define the potentiometric surface of the Ozark aquifer were also open to the overlying residuum.

Well-Numbering System

In this report, well locations are described using the local well number (table 1, at the back of the report) and follow the General Land Office coordinate system (fig. 3). According to this system, the first three sets of numbers of a well location designate township, range, and section. The letters that follow indicate quarter section, quarter-quarter section, and quarter-quarter-quarter section. The quarter sections are represented by the letters A, B, C, and D, in counterclockwise order, starting in the northeastern quadrant. Two or more wells in the same quarter-quarter-quarter section are numbered serially in the order they were inventoried.

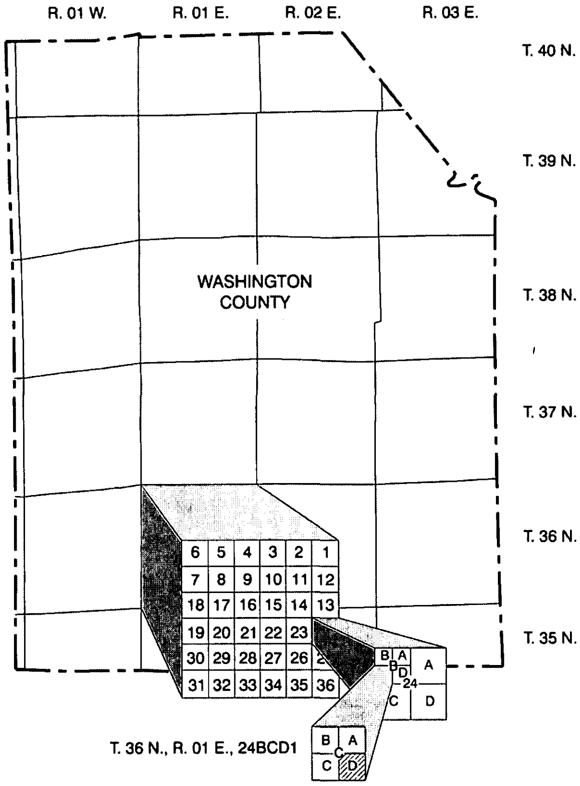


Figure 3. Well-numbering system used for this study.

Previous Investigations

In 1974, the University of Missouri-Rolla completed a geohydrologic study in the Viburnum Trend area (Warner and others, 1974). The report discusses the geohydrology of the area and the effects of mine dewatering on water levels in the Ozark and St. Francois aquifers. Pre-mining (pre-1960) potentiometric-surface maps were drawn for the Ozark and St. Francois aquifers in the Viburnum Trend area. The report also describes the geologic framework in the Viburnum Trend and includes maps of the altitude of the tops of the Precambrian rocks, the Lamotte Sandstone, Bonneterre Formation, and the Davis Formation, and thickness maps for the St. Francois aquifer and the Davis Formation. The stratigraphy of the formations from the uppermost Roubidoux Formation to the Precambrian basement rock also is described.

Warner and others (1974) state that depending on the mine location, the potentiometric surface of the St. Francois aquifer was lowered 600 to 1,200 feet in dewatering the mines. Even though the aquifer thickness typically ranges from 300 to 600 feet, the potentiometric surface can extend much higher than the top of the aquifer. Because ground water in the St. Francois aquifer is under substantial pressure, water levels in tightly cased wells that are open only to the confined St. Francois aquifer typically will rise hundreds of feet above the top of the aquifer until the pressure of the water column in the well equals the pressure in the aquifer. This would be analogous to water escaping through a puncture in a pressurized garden hose. During the process of dewatering the mines, the pressure head is lowered first. After water levels have declined below the top of the aquifer, the aquifer will begin to be dewatered. Because of the effective confining capability of the St. Francois confining unit, water levels in the overlying Ozark aquifer will not necessarily decline. The St. Francois confining unit essentially may hold water in the Ozark aquifer even though the St. Francois aquifer is being dewatered.

Water-level data collected from 20 observation wells in the St. Francois aquifer in the vicinity of 5 active mines, and ground-water discharge data from these mines, were used to calculate the transmissivity and storage coefficient of the St. Francois aquifer at the mine sites (Warner and others, 1974). Transmissivities ranged from 195 to 4,075 gallons per day per foot of drawdown (the median value was 1,174 gallons per day per foot). Storage coefficients ranged from 0.0026 to 0.0085.

Water-level declines were estimated for the deep St. Francois aquifer using the transmissivities, storage coefficients, and ground-water discharge data that were determined for each of the five mine sites. The report concluded that the effect of pumping in the St. Francois aquifer probably is not great beyond a distance of about 5 miles from any of the mines, and the areas of major effect are more restricted than the stated 5 mile distance. Further conclusions state that as mining continues and the mines become interconnected, the affected area is not expected to widen much from east to west, but is expected to form a continuous narrow dewatered zone throughout the length of the Viburnum Trend in the St. Francois aquifer (Warner and others, 1974). Currently (2000), several of the individual mines are connected in the subsurface to essentially form one larger mine; these include Casteel, Magmont, Buick, and Brushy Creek. The West Fork and Fletcher Mines are also connected (John T. Scheumbauer, Bureau of Land Management, oral commun., 2000).

An analysis of the surficial Ozark aquifer in Warner and others (1974) concluded that water-level changes that resulted in the aquifer were not large. This conclusion was based primarily on data from nine observation wells that were constructed around the Sweetwater Mine. One of the wells was at the mine and others were located at distances ranging from 0.5 to 9 miles south and southwest of the mine. The highest recorded water-level altitude in the observation well at the mine was 1,020 feet above sea level in April 1965 when it was first measured. This measurement was made about 6 years after pumping from the mine began at a rate of about 800 gallons per minute (1.15 million gallons per day). The lowest recorded water-level altitude in the well was 904 feet above sea level in March 1968, and the final recorded water-level altitude was 949 feet above sea level in October 1971 (pumping for mine dewatering was still occurring). A maximum water-level fluctuation of 116 feet was observed in this well with the final water-level measurement showing 71 feet of decline. The authors stated that data from the observation well 0.5 mile from the mine showed a maximum decline of about 32 feet from 1962 to 1971, and that data from the other seven wells were difficult to interpret because water levels in some wells increased, some decreased, and others remained the same. They also noted that no obvious declines in spring flow or stream base flow have been reported in the Viburnum Trend, nor have any widespread problems with water-level declines in the Ozark aquifer been reported.

One incident occurring in the study area involving isolated mining-related water-level declines in the Ozark aquifer was described by Miller and Vandike (1997). About May 1987 most domestic- and public-water-supply wells in and near Bixby, Missouri (fig. 1) were affected by declining water levels and well yields. Many of the affected wells were less than 200 feet deep. The problems were related to the opening of vent shaft number 50 at the Casteel mine (fig. 1). This shaft was constructed about 1,000 feet northwest of Bixby. The shaft encountered well-developed, solution-enlarged openings in the Potosi Dolomite and the initial flow from that formation into the mine via the shaft was estimated at 400 to 500 gallons per minute. The additional inflow of water into the mine did not hamper mining operations, but it did cause appreciable water-level declines in Bixby.

The findings of a study of the ground-water problem reported at Bixby state that ground water in that area historically has been pumped from a highly permeable zone ranging from 145 to 200 feet below land surface (Steffen Robertson and Kirsten, Inc., 1988). This permeable zone corresponds with the contact of the residuum and the Eminence Dolomite. Water levels had declined by as much as an additional 70 feet in the area, and this shallow permeable ground-water zone underlying Bixby had essentially been dewatered. Because water levels had dropped below this permeable zone and the Eminence Dolomite has a low permeability, well yields also decreased. It was recommended that leakage from the shallow aquifer to the mine via shafts, ventholes, and exploration drill holes be minimized; this included grouting the vent shaft (Steffen Robertson and Kirsten, Inc., 1988).

A water-level recorder was installed by the DGLS on a well near the vent shaft in late 1987 (Miller and Vandike, 1997). This well is 640 feet deep with 120 feet of casing and based on nearby well logs on file at the DGLS the well is open to the Ozark aquifer and probably part of the St. Francois confining unit. The vent shaft was plugged on September 5, 1991, and water levels in the observation well began recovering (fig. 4). The 71 to 116 feet of water-level decline reported by Warner and others (1974) in the Ozark aquifer observation well at the Sweetwater Mine may have resulted from water flowing from the Ozark aquifer down into the mine via the mine shaft. The distance the well was from the mine shaft was not stated but presumably was close, based on the fact that the well was described as 'at the mine'.

Acknowledgments

The author acknowledges James E. Vandike of the DGLS for supplying ground-water information from the Viburnum Trend area. The information included 1998–2000 hydrograph data from the observation well near Bixby, so the hydrograph in figure 4 could be extended into 2000, results of five unpublished aquifer tests conducted near Bixby, and copies of reports. The author also acknowledges the assistance of Denis Murphy of the Doe Run Company and Kelly Ray of Environmental Analysis, Inc. for supplying the water-level data from observation wells in the vicinity of the mines. The cooperation of the many land owners in the study area by allowing access to their wells for water-level measurements also is appreciated.

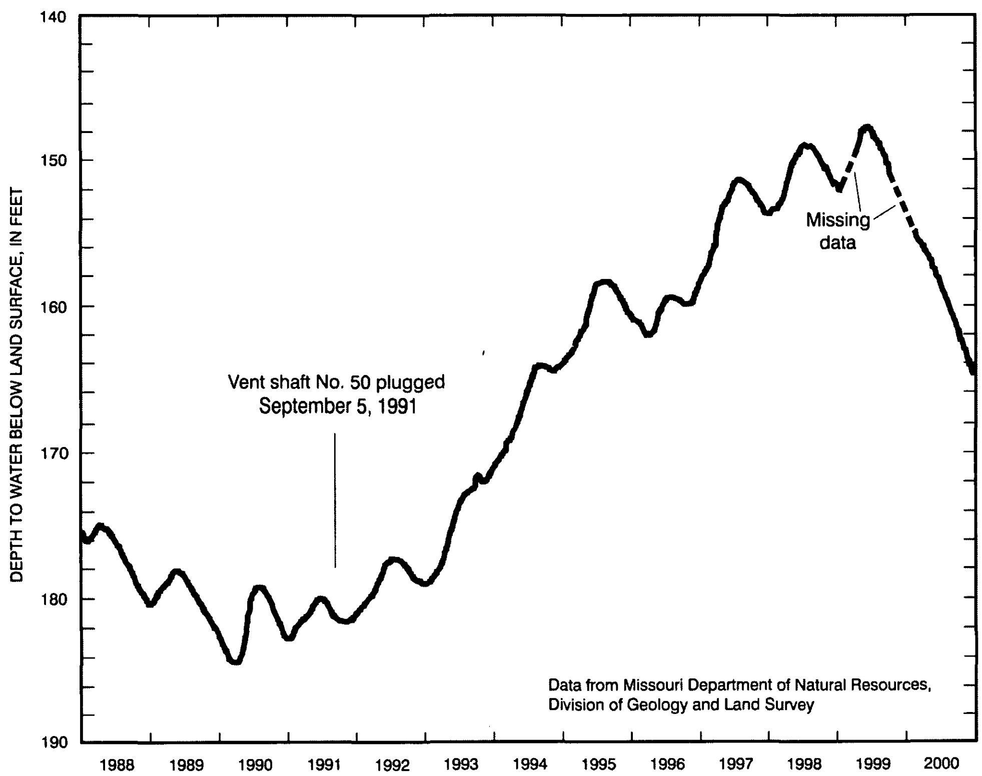


Figure 4. Hydrograph for observation well near Bixby (T. 34 N., R. 02 W., 01CCC), southeastern Missouri, 1988-2000.

GROUND-WATER LEVELS IN THE OZARK AQUIFER IN THE VIBURNUM TREND

Lead-zinc mines in the Viburnum Trend align approximately north-south near the eastern side of R. 02 W. between T. 31 N. and T. 35 N. (fig. 1). Data from a much larger area were collected, evaluated, and used in constructing the pre-mining potentiometric-surface map for the Ozark aquifer (fig. 5). As the study progressed and the 1999 water-level measurements were obtained and compared to pre-mining conditions, much of this larger area was determined to be not directly relevant to the scope of the study.

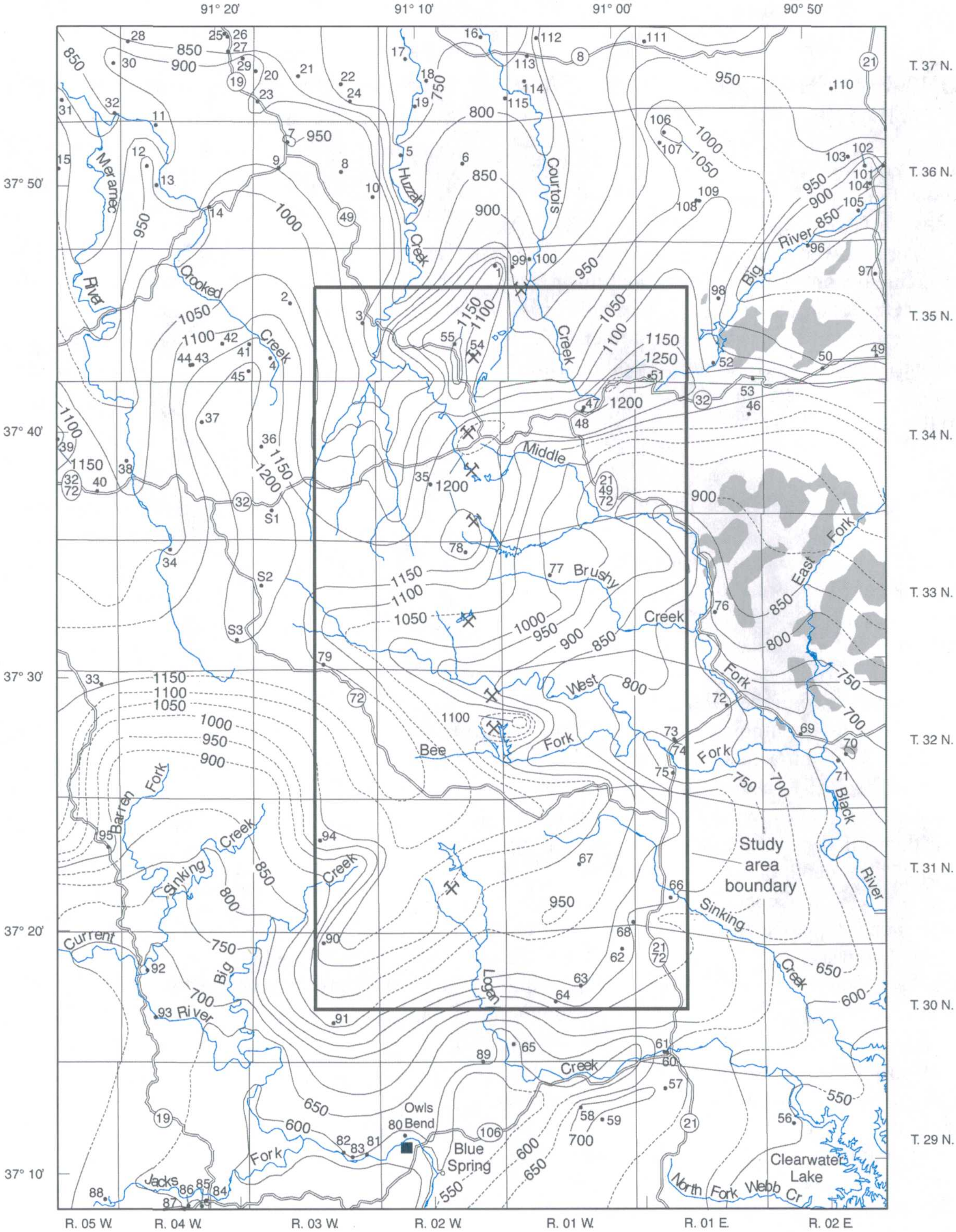
Pre-Mining Ground-Water Levels

The pre-mining potentiometric surface (fig. 5) for the Ozark aquifer was mapped using static water-level measurements that were recorded on well logs submitted to the DGLS office in Rolla, Missouri, before 1960. This criterion was used because mining had started in only two of the Viburnum Trend mines by 1960, and extensive pumping from the St. Francois aquifer had not been initiated at that time (Warner and others, 1974). Typically, the historic well logs provide general information such as well location, land-surface altitude at the well, depth to formation tops, total depth of the casing, total depth of the well, and the static water level in the well. Generally, well locations are given to the nearest quarter-quarter-quarter section and the altitude of land surface at the well is reported to the nearest 10 feet. The reported static water-level measurements were taken by the well drillers upon completion of the wells. Streambed altitudes of perennial streams also were used in construction of this potentiometric-surface map, as the Ozark aquifer is considered to be in direct hydraulic connection with streams. Historic dye-trace information, knowledge of areas of gaining and losing streams, and altitudes of perennial springs were also used in the construction of this potentiometric-surface map.

Historic water-level data were available for 273 wells in the expanded area; 115 of those water-level measurements were recorded before 1960 and used in the mapping of the pre-mining potentiometric surface (table 1). Only 21 of these static water-level measurements were located within the 600-square-mile study area boundary. The estimated altitude accuracy of the data points used to map the pre-mining potentiometric surface is plus or minus 15 feet. Because of the steep topography of the area, 7.5-minute USGS topographic maps for the area have a contour interval of 20 feet with an accuracy of plus or minus 0.5 the contour interval (plus or minus 10 feet). The static water-level measurements typically were reported to the nearest 10 feet, inferring an uncertainty of plus or minus 5 feet. Three historical water-level measurements (S1- S3; table 1) that did not meet the "pre-mining" criterion (water-level data measured before 1960) were used as supplemental data in an area away from the mines where no pre-mining data were available. These supplemental data helped define a potentiometric high in the western part of the study area (fig. 5).

The pre-mining potentiometric-surface map indicates that ground-water levels in the Ozark aquifer are appreciably controlled by the narrow ridges and the numerous perennial streams in the area. A potentiometric high forms part of a regional ground-water divide (T. 33-34 N., R. 03-04 W.) that trends near Missouri State Highway 32 eastward along the regional surface-water divide in the central part of the mapped area (T. 33 N., R. 04 W. to T. 34 N., R. 02 W.). Potentiometric highs also occur between most of the perennial streams in the area. In the southern part of the mapped area, several losing streams are present. The two largest stream basins that have losing stream reaches are Logan Creek and Sinking Creek. A potentiometric trough is evident in the south-central part of the mapped area that connects Logan Creek in the Black River Basin to Blue Spring (near Owls Bend) in the Current River Basin. This trough indicates the potential for interbasin transfer of ground water. The hydrologic connection from Logan Creek to Blue Spring has been verified using dye-tracing techniques (Vineyard and Feder, 1974).

Because the 115 pre-mining data points were not uniformly distributed, it was necessary to use supplemental data as an aid in defining the pre-mining potentiometric contours. Data are more sparse in the southern part of the area and along the ridge tops because much of this land is sparsely populated. Because homesteads commonly are located in the valleys, and not along the ridges, the altitude of many of the ground-water divides in figure 5 could not be accurately determined.



Base from U.S. Geological Survey
digital data, 1:100,000, 1983 and 1986
Universal Transverse Mercator projection
Zone 15

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

EXPLANATION

PRECAMBRIAN OUTCROP

—700··· POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased wells before 1960. Dashed where approximately located. Contour interval 50 feet. Datum is sea level

•81 LOCATION OF WATER-LEVEL MEASUREMENT IN THE OZARK AQUIFER AND SITE IDENTIFIER (table 1)

•S3 LOCATION OF SUPPLEMENTAL WATER-LEVEL MEASUREMENT IN THE OZARK AQUIFER AND SITE IDENTIFIER (table 1)

MINE

Figure 5. Pre-mining potentiometric surface of the Ozark aquifer in the Viburnum Trend area, southeastern Missouri.

Ground-Water Levels During 1999

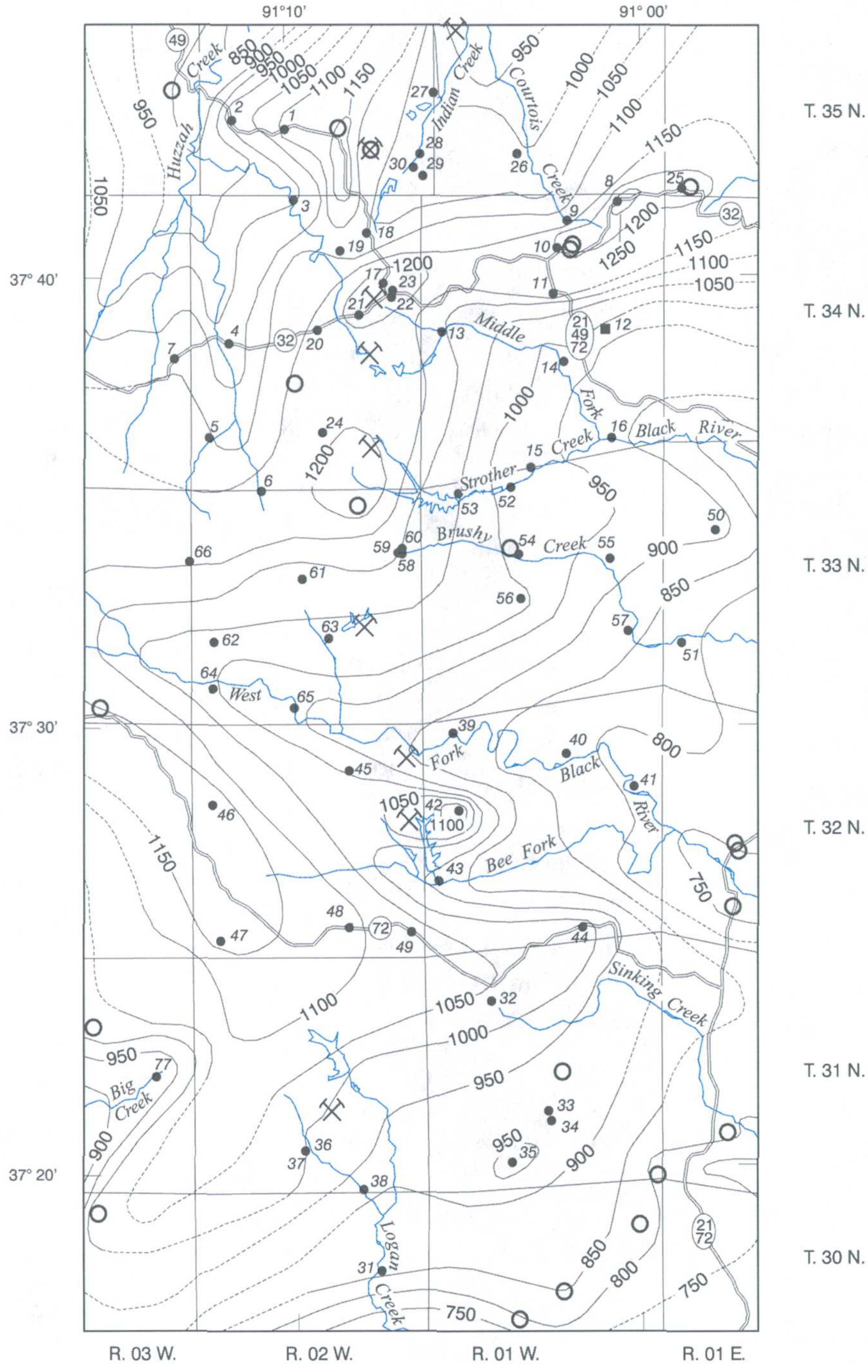
During the summer and fall 1999, USGS personnel conducted a well inventory in the known mining areas in the Viburnum Trend and collected water-level data from 59 domestic- and public-water-supply wells in the Ozark aquifer. One water-level measurement (site 12, table 2, at the back of this report) probably represents the potentiometric surface altitude in the St. Francois aquifer. Water levels were measured from the top of the well casing using an electric tape and read to the nearest 0.1 foot. The distance the well casing extended above land surface was measured and subtracted from the water-level measurement to determine the depth of the water level below land surface. Land-surface altitudes were obtained from 7.5-minute USGS topographic maps. Water-level measurements also were collected from 21 observation wells during this same period by a mining company contractor during routine sampling (Kelly Ray, Environmental Analysis, Inc., written commun., 1999). These observation wells typically were constructed around the perimeter of tailings ponds. Of the 21 water-level measurements from observation wells, 7 were taken from wells that are considered to have adequate total depth and casing to intercept the water table (top of the Ozark aquifer). These 7 wells ranged from 62 to 164 feet deep and are listed in table 2. The other 14 observation wells were considered to monitor perched water or did not have adequate location descriptions for plotting purposes. Water-level measurements from these 7 observation wells and the 59 domestic- and public-water-supply wells in the Ozark aquifer were used to prepare the 1999 potentiometric-surface map (fig. 6). The measurements are listed in table 2 along with one water-level measurement that probably represents the water-level altitude in the St. Francois aquifer.

Because the water-level measurements were measured to the nearest 0.1 foot, the largest source of error for the altitudes shown on the 1999 potentiometric map is from the topographic maps used to determine the land-surface altitude of the well. The estimated altitude accuracy of the data points used to prepare the potentiometric surface shown on figure 6 is plus or minus 10 feet.

Effects of Mining on Ground-Water Levels in the Ozark Aquifer

Almost three times as much water-level data were used to prepare the 1999 potentiometric surface near the Viburnum Trend than was used to prepare the pre-mining potentiometric surface in this same area. This resulted in a more detailed potentiometric surface being mapped for the 1999 data. When comparing the original pre-mining and the 1999 potentiometric surfaces, areas were identified that showed large water-level changes. However, all of these areas were at locations where water-level measurements were available for one data set but not the other. These areas were most obvious where a potentiometric high could be defined on one map but not on the other. Thus, these calculated water-level "changes" were at least partly a function of the data distribution and not necessarily real changes. To resolve this problem, the 21 pre-mining water-level measurements in the study area were added to the 1999 data set, and the combined data sets were contoured (not shown). The added pre-mining data did not conflict with the 1999 data, suggesting that water levels in the area changed little, if any, from pre-mining to 1999. The most important conclusion derived from this comparison is that, because the same potentiometric-surface map is consistent with both the pre-mining and 1999 water-level data, no large cones of depression were present in 1999 in the Ozark aquifer in the Viburnum Trend. Presumably, small water-level changes occurred between pre-mining and 1999. The potentiometric surfaces and water-level data were further analyzed digitally to identify these small changes.

The digital analysis was accomplished by computer interpolation of the pre-mining and 1999 data sets on a regular grid with 0.5-mile centers. The interpolated potentiometric values for the pre-mining data set included the pre-mining water-level measurements, the potentiometric-contour altitudes, streambed altitudes of perennial streams, and perennial spring altitudes. For the 1999 data set, the pre-mining water-level measurements were replaced by the 1999 water-level measurements, but the other data were not changed. By including the potentiometric-contour altitudes, perennial streambed altitudes, and spring altitudes in both data sets, reasonable potentiometric limits were placed in areas where water-level measurements were not available. The potentiometric altitude calculated for each node of the pre-mining grid was subtracted from the calculated potentiometric altitude at each corresponding node of the 1999 grid to quantify the water-



EXPLANATION

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

—700 ---- POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased wells in summer and fall 1999. Dashed where approximately located. Contour interval is 50 feet. Datum is sea level

● 34 LOCATION OF WATER-LEVEL MEASUREMENT IN THE OZARK AQUIFER AND SITE IDENTIFIER (table 2)

■ 12 LOCATION OF WATER-LEVEL MEASUREMENT IN THE ST. FRANCOIS AQUIFER AND SITE IDENTIFIER (table 2)

○ LOCATION OF PRE-MINING WATER LEVEL IN THE OZARK AQUIFER (table 1)

⚒ MINE

Figure 6. Potentiometric surface of the Ozark aquifer in the Viburnum Trend, southeastern Missouri, summer and fall 1999.

level changes. A negative difference indicated a lowering of the water level in that area from pre-mining (before 1960) to 1999.

The results of this analysis, shown in figure 7, indicate that generally the differences in the two data sets are small and are within the accuracy of the determined potentiometric altitudes, which are limited by the accuracy of the water-level measurements and topographic maps (plus or minus 15 feet). Water-level changes in most of the study area ranged from an increase of 15 feet to a decrease of 15 feet (fig. 7). Areas where water-level increases or declines were greater than 15 feet occurred where water-level measurements were made in a well during pre-mining or 1999 conditions, but not both. The areas of calculated water-level declines of greater than 15 feet in the Ozark aquifer are scattered throughout the study area, and generally are not associated with the mines or with municipal public-water supplies where water-level declines might be anticipated. The isolated areas of calculated water-level declines appear to be related to the distribution of the pre-mining and 1999 data, the accuracy of the water-level data, and inherent error in interpolating the water-level data, and not to actual water-level declines. The general conclusion of the grid analysis is that no large cones of depression are apparent in the potentiometric surface of the Ozark aquifer in the Viburnum Trend as a consequence of mining activity.

The fact that no large cones of depression were observed in the Viburnum Trend in the potentiometric surface of the Ozark aquifer during this study does not necessarily infer that small water-level declines have not occurred in the aquifer because of mining. Because of the sparse data distribution in areas directly over the mines, this analysis was not as thorough as desired. Evidence exists for the lowering of water levels near active mine sites. Examples include the previously mentioned opening of vent shaft number 50 at the Casteel Mine near Bixby (Miller and Vandike, 1997) and documented water-level declines in the observation well at the Sweetwater Mine (Warner and others, 1974). Leakage of water from the Ozark aquifer into the St. Francois aquifer probably is occurring at shafts, ventholes, and inadequately plugged exploration drill holes (Steffen Robertson and Kirsten, Inc.,1988). Therefore, there may be localized areas of small drawdowns.

The water level measured in one well (site 12, table 2, fig. 6) was about 100 feet lower than water levels in surrounding wells. The well is in a valley where the surface formation is the Potosi Dolomite, the lowest formation of the Ozark aquifer. Construction data show the well is 290 feet deep with 105 feet of casing that was set in the Derby-Doe Run Dolomite (part of the St. Francois confining unit). Based on log data from nearby wells, the bottom of the well is in the Davis Formation (part of the St. Francois confining unit) about 20 feet from the top of the underlying Bonneterre Formation (part of the St. Francois aquifer). The water level in the well is in the Davis Formation at 210 feet below land surface. Because the bottom of the well is only 20 feet above the Bonneterre Formation and casing has been set through the Potosi Dolomite, it is possible that the water level in the well is appreciably affected by conditions in the St. Francois aquifer. The low water-level altitude may reflect mine dewatering in the St. Francois aquifer. This low water level could occur in wells drilled in low lying areas, such as stream valleys, where the depth to the top of the St. Francois aquifer is shallow compared to other areas, and the well penetrates a substantial part of the St. Francois confining unit.

SUMMARY AND CONCLUSIONS

Pumpage from the St. Francois aquifer for mine dewatering in the Viburnum Trend was estimated to be 26 million gallons per day in 1971. In 1999, the total pumpage for mine dewatering was slightly larger, reported to be 27 million gallons per day. This continued pumpage could possibly lower water levels in the surficial Ozark aquifer regionally, and cause a reduction in the flow of water to area springs and streams and lower water levels in area wells. This report presents the results of a geohydrologic study designed to determine if water levels have declined in the Ozark aquifer in the Viburnum Trend as a result of long-term mine dewatering in the deeper St. Francois aquifer. The study was done in cooperation with the U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management; and the Missouri Department of Conservation.

The study area consists of about 600 square miles in an area that includes parts of Crawford, Iron, Washington, Dent, Reynolds, and Shannon Counties of southeastern Missouri. Much of the study area is within the boundaries of the Mark Twain National Forest. Within the National Forest boundaries, there are scattered parcels of private property with isolated homesteads or small communities. Most of the private

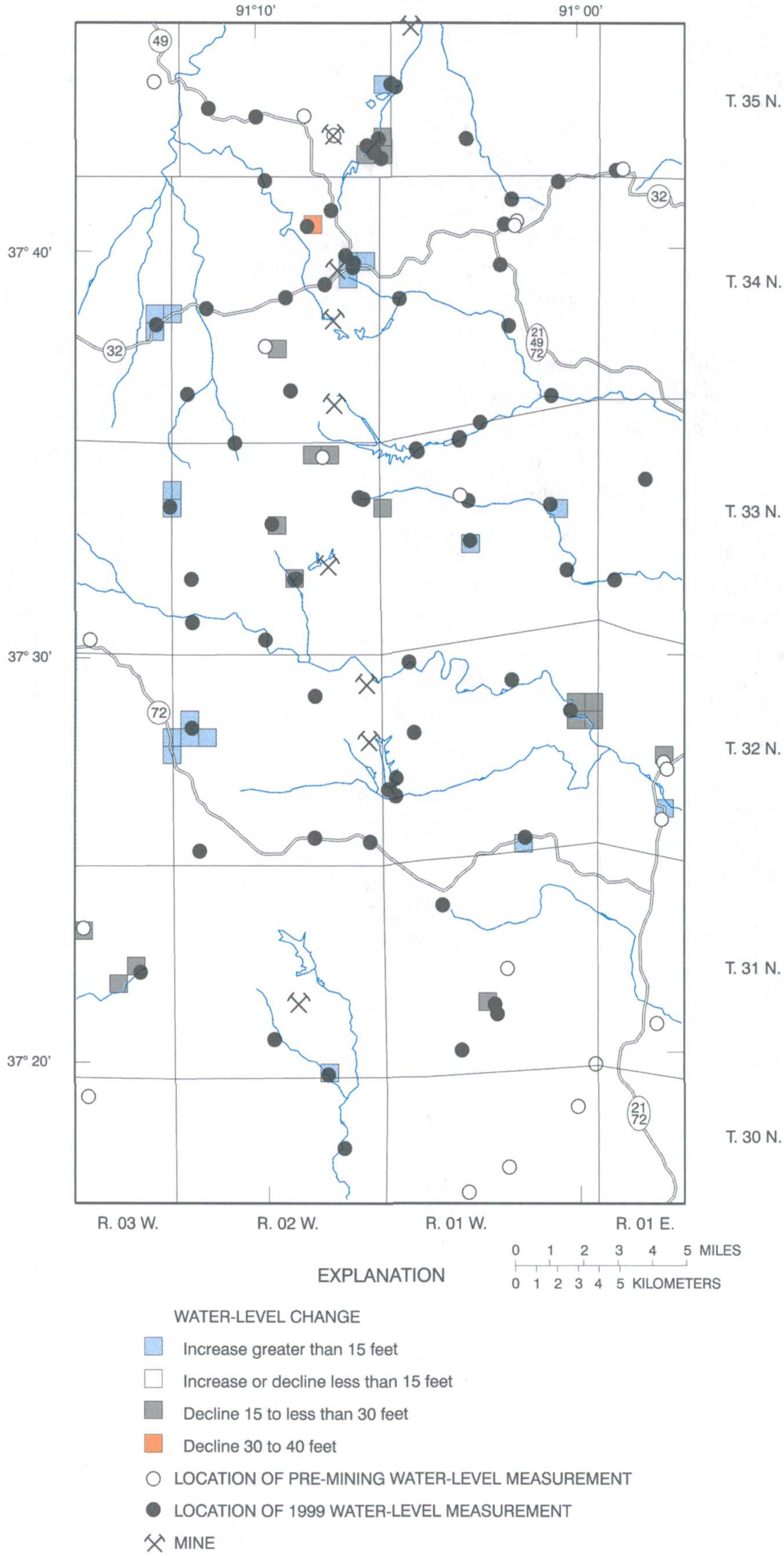


Figure 7. Water-level changes in the Ozark aquifer in the Viburnum Trend, southeastern Missouri between pre-1960 (pre-mining) and 1999.

property is concentrated along the major roads or along the stream valleys. The area is characterized by deep, narrow valleys, and narrow, steep-sided ridges with relief of more than 300 feet. The area lies within a large region of well-developed karst terrain that is characterized by the presence of caves, springs, sinkholes, and gaining and losing streams.

The lowermost geohydrologic unit underlying the study area is the Basement confining unit, which is dominantly Precambrian granite and rhyolite porphyry and is nearly impermeable. The Precambrian surface is irregular in the study area, and about 10 scattered, buried knobs exist. Formations overlying these Precambrian knobs may be thin or missing.

The St. Francois aquifer overlies the Basement confining unit and consists of the Lamotte Sandstone and the Bonneterre Formation (host formation for lead-zinc deposits). The thickness of the St. Francois aquifer can vary considerably because of the rugged surface of the underlying Precambrian basement rocks. The thickness of the aquifer in the study area varies from less than 100 feet over Precambrian knobs to about 800 feet, but typically the aquifer is 300 to 600 feet thick.

The St. Francois confining unit overlies the St. Francois aquifer and consists of fine-grained carbonates and shales of the Davis Formation and the Derby-Doerun Dolomite. The typical thickness of the confining unit in the study area is 200 to 300 feet. Laboratory vertical hydraulic conductivity values for rock core samples from the St. Francois confining unit ranged from 2×10^{-12} to less than 3×10^{-14} foot per second. These vertical hydraulic conductivities are small; therefore, the confining unit effectively impedes the flow of ground water between the Ozark aquifer and the St. Francois aquifer except where preferred path secondary permeability has developed along faults and fractures and appreciably increased the vertical hydraulic conductivity in the confining unit.

The Ozark aquifer is the uppermost geohydrologic unit, is primarily unconfined, and is the primary source of water for water supplies in much of southern Missouri. This predominantly carbonate aquifer consists of rocks from the base of the Potosi Dolomite through the Roubidoux Formation and typically ranges from 200 to 900 feet thick in the study area.

The pre-mining potentiometric surface for the Ozark aquifer was mapped using 115 static water-level measurements taken before 1960 and 3 post-1960 historical water-level measurements. Streambed altitudes of perennial streams, historic dye-trace information, knowledge of areas of gaining and losing streams, and altitudes of perennial springs were also used in the construction of this potentiometric-surface map. Only 21 pre-mining static water-level measurements were located within the 600-square mile study area boundary. The estimated altitude accuracy of the data points used to map the pre-mining potentiometric surface is plus or minus 15 feet. The potentiometric-surface map indicates that ground-water levels in the Ozark aquifer are appreciably controlled by the narrow ridges and perennial streams.

A potentiometric-surface map was prepared from water-level data collected by USGS personnel during the summer and fall 1999 in the known mining areas in the Viburnum Trend. The data included water levels from 7 observation wells and 59 domestic- and public-water-supply wells in the Ozark aquifer. The estimated altitude accuracy of the data points used to prepare the potentiometric surface is plus or minus 10 feet.

Almost three times as much water-level data were used to prepare the 1999 potentiometric surface near the Viburnum Trend than what was used to prepare the pre-mining potentiometric surface in this same area. This resulted in a more detailed potentiometric surface being mapped for the 1999 data. Areas showing large water-level changes were identified. However, all these areas were at locations where water-level measurements were available for one data set but not the other. Thus, these water-level "changes" were at least partly a function of the data distribution and not necessarily real changes. To resolve this problem, the 21 pre-mining water-level measurements in the study area were added to the 1999 data set, and the combined data sets were contoured. The added pre-mining data did not conflict with the 1999 data, suggesting that water levels in the area changed little, if any, from pre-mining to 1999. The most important conclusion derived from this comparison is that, no large cones of depression were present in 1999 in the Ozark aquifer in the Viburnum Trend.

A digital analysis was accomplished by computer interpolation of the pre-mining (prior to 1960) and 1999 data sets on a regular grid with 0.5-mile centers. The interpolated potentiometric values for the pre-mining data set included the pre-mining water-level measurements, the potentiometric-contour altitudes, streambed altitudes of perennial streams, and perennial spring altitudes. For the 1999 data set, the pre-mining water-level measurements were replaced by the 1999 water-level measurements, but the other data were not changed. The potentiometric altitude calculated for each node of the pre-mining grid was subtracted from the calculated potentiometric altitude at each corresponding node on the 1999 grid to quantify the water-level changes.

The results of this analysis indicate that the differences in the two data sets are small and are within the accuracy of the determined potentiometric altitudes, which are limited by the accuracy of the water-level measurements and topographic maps (plus or minus 15 feet). Areas where water-level increases or declines were greater than 15 feet occurred where water-level measurements were made in wells during pre-mining or 1999 conditions, but not both. The areas of calculated water-level declines of greater than 15 feet in the Ozark aquifer are scattered throughout the study area, and generally are not associated with the mines or with municipal public-water supplies where water-level declines might be anticipated. The isolated areas of calculated water-level declines appear to be related to the distribution of the pre-mining and 1999 data, the accuracy of the water-level data, and inherent error in interpolating the water-level data and not to actual water-level declines. The general conclusion is that no large cones of depression are apparent in the potentiometric surface of the Ozark aquifer in the Viburnum Trend as a consequence of mining activity. This does not necessarily infer that small water-level declines have not occurred in the aquifer because of mining. Leakage of water from the Ozark aquifer into the St. Francois aquifer probably is occurring at shafts, ventholes, and inadequately plugged exploration drill holes. Therefore, there may be localized areas of small drawdowns.

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TABLES

Table 1. Pre-mining (prior to 1960) water-level data for the Ozark aquifer in the Viburnum Trend, southeastern Missouri

[Altitudes are in feet above sea level; MM-YY, month, year; xx, month not available; --, data not available]

Site identification (fig. 5)	Local well number	Altitude of land surface	Well depth (feet)	Casing depth (feet)	Water-level date (MM-YY)	Water-level depth (feet)	Altitude of water level
			Crawford County				
1	T35N R02W 01CAD1	1,306	270	153	12-58	187	1,119
2	T35N R03W 14ADD1	1,150	1,027	70	05-35	90	1,060
3	T35N R03W 24ABD1	960	82	39	10-35	60	900
4	T35N R03W 30DDD1	1,224	77	44	07-48	40	1,184
5	T36N R02W 08CBB1	807	95	40	04-59	30	777
6	T36N R02W 10DDD1	885	175	17	xx-42	50	835
7	T36N R03W 05DDC1	1,018	91	37	12-51	60	958
8	T36N R03W 14BAC1	1,055	200	114	04-58	115	940
9	T36N R03W 17BAA1	1,097	204	120	12-58	150	947
10	T36N R03W 24ADC1	1,008	210	48	10-35	83	925
11	T36N R04W 05AB 1	888	125	34	xx-44	4	884
12	T36N R04W 17BBA1	1,068	170	112	11-55	80	988
13	T36N R04W 17DCC1	945	660	--	07-26	15	930
14	T36N R04W 23CCC1	1,015	105	20	09-40	12	1,003
15	T36N R05W 15BBB1	1,103	315	125	10-59	140	963
16	T37N R02W 14AAB1	756	163	44	07-38	12	744
17	T37N R02W 20BBA1	775	125	--	xx-55	55	720
18	T37N R02W 28BBA1	775	145	125	10-55	55	720
19	T37N R02W 32ACA1	770	80	--	xx-40	40	730
20	T37N R03W 19CAC1	1,029	155	136	xx-46	110	919
21	T37N R03W 21CDC1	912	160	63	07-48	70	842
22	T37N R03W 26BAC1	790	71	20	02-38	12	778
23	T37N R03W 31BAA1	1,017	216	60	xx-44	150	867
24	T37N R03W 35AAB1	801	41	10	02-38	8	793
25	T37N R04W 11DDC1	990	285	--	09-30	186	804
26	T37N R04W 14AAA1	997	255	144	05-55	170	827
27	T37N R04W 14DDA1	990	215	178	10-55	146	844
28	T37N R04W 18BAC1	1,000	177	82	xx-49	150	850

Table 1. Pre-mining (prior to 1960) water-level data for the Ozark aquifer in the Viburnum Trend, southeastern Missouri—Continued

[Altitudes are in feet above sea level; MM-YY, month, year; xx, month not available; --, data not available]

Site identification (fig. 5)	Local well number	Altitude of land surface	Well depth (feet)	Casing depth (feet)	Water-level date (MM-YY)	Water-level depth (feet)	Altitude of water level
			Crawford County—Continued				
29	T37N R04W 24ABB1	1,005	164	145	xx-46	100	905
30	T37N R05W 24ACA1	1,113	244	64	12-58	175	938
31	T37N R05W 27CCD1	989	185	22	xx-44	110	879
32	T37N R05W 36DAC1	906	160	40	xx-38	40	866
			Dent County				
33	T32N R05W 01CBA1	1,342	400	130	12-44	170	1,172
34	T33N R04W 04BCA1	1,117	150	20	10-48	35	1,082
35	T34N R02W 21AAC1	1,264	180	104	10-33	90	1,174
36	T34N R03W 07DAC1	1,208	160	43	06-41	32	1,176
37	T34N R04W 03DDB1	1,360	255	120	10-33	135	1,225
38	T34N R04W 18BAD1	1,120	175	152	06-42	85	1,035
39	T34N R05W 10BAC1	1,238	146	119	10-48	74	1,164
40	T34N R05W 24CBC1	1,130	100	30	07-41	70	1,060
41	T35N R04W 25ADA1	1,270	171	31	07-48	90	1,180
42	T35N R04W 26ABC1	1,152	300	150	02-40	18	1,134
43	T35N R04W 34BAC1	1,318	225	54	07-33	100	1,218
44	T35N R04W 34BAC2	1,320	455	207	08-34	190	1,130
45	T35N R04W 36DAA1	1,275	116	62	07-48	74	1,201
			Iron County				
46	T34N R01E 12BAD1	1,095	60	22	xx-47	20	1,075
47	T34N R01W 03CCA1	1,310	217	132	09-41	90	1,220
48	T34N R01W 03DCB1	1,363	400	256	03-58	160	1,203
49	T35N R02E 25CCD1	1,060	60	10	xx-41	20	1,040
50	T35N R02E 33ADB1	1,010	55	10	xx-41	7	1,003
51	T35N R01E 31DDB1	1,370	295	176	05-55	155	1,215
52	T35N R01E 34AAB1	1,102	50	24	xx-41	20	1,082

Table 1. Pre-mining (prior to 1960) water-level data for the Ozark aquifer in the Viburnum Trend, southeastern Missouri—Continued

[Altitudes are in feet above sea level; MM-YY, month, year; xx, month not available; --, data not available]

Site identification (fig. 5)	Local well number	Altitude of land surface	Well depth (feet)	Casing depth (feet)	Water-level date (MM-YY)	Water-level depth (feet)	Altitude of water level
			Iron County—Continued				
53	T35N R01E 36DCB1	1,180	800	--	10-34	40	1,140
54	T35N R02W 26CDA1	1,207	1,150	680	12-58	120	1,087
55	T35N R02W 27ABC1	1,250	435	78	11-58	100	1,150
			Reynolds County				
56	T29N R02E 17BBD1	615	485	0	xx-50	58	557
57	T29N R01E 05CDC1	806	160	153	06-38	110	696
58	T29N R01W 10BAD1	975	591	372	04-34	260	715
59	T29N R01W 14BAA1	900	372	153	12-58	213	687
60	T30N R01E 32CAA1	663	1,400	180	10-39	7	656
61	T30N R01E 32CAA2	662	400	38	05-56	15	647
62	T30N R01W 01CDC1	915	550	210	06-55	100	815
63	T30N R01W 15DBC1	1,050	725	120	08-55	200	850
64	T30N R01W 21BBD1	845	625	22	08-55	45	800
65	T30N R01W 31BAC1	830	655	--	12-55	260	570
66	T31N R01E 29DBA1	850	405	67	04-55	20	830
67	T31N R01W 22BAA1	1,176	280	250	06-57	250	926
68	T31N R01W 36DDD1	900	490	77	04-55	125	775
69	T32N R02E 17ACD1	723	130	77	xx-50	45	678
70	T32N R02E 22AAC1	720	165	--	12-55	15	705
71	T32N R02E 22CAA1	650	210	--	xx-55	8	642
72	T32N R01E 11BDB1	792	165	33	09-58	40	752
73	T32N R01E 20ADD1	826	154	137	08-36	50	776
74	T32N R01E 20ADD2	831	804	70	05-40	50	781
75	T32N R01E 29DDC1	747	240	38	02-41	17	730
76	T33N R01E 22AAC1	940	542	--	xx-47	100	840
77	T33N R01W 08DDD1	1,010	80	25	06-55	15	995
78	T33N R02W 02BDB1	1,264	125	26	07-57	40	1,224
79	T33N R03W 34DBD1	1,320	400	170	09-34	170	1,150

Table 1. Pre-mining (prior to 1960) water-level data for the Ozark aquifer in the Viburnum Trend, southeastern Missouri—Continued

[Altitudes are in feet above sea level; MM-YY, month, year; xx, month not available; --, data not available]

Site identification (fig. 5)	Local well number	Altitude of land surface	Well depth (feet)	Casing depth (feet)	Water-level date (MM-YY)	Water-level depth (feet)	Altitude of water level
			Shannon County				
80	T29N R02W 08CCA1	590	470	32	09-55	1	589
81	T29N R03W 13CAD1	725	355	131	08-41	138	587
82	T29N R03W 14CAA1	650	100	16	04-37	40	610
83	T29N R03W 14DDB1	665	160	39	04-37	65	600
84	T29N R04W 26CCB1	737	140	11	xx-51	65	672
85	T29N R04W 34AAA1	828	350	--	xx-43	180	648
86	T29N R04W 34BBA1	666	50	36	xx-57	10	656
87	T29N R04W 34BBC1	650	185	143	10-58	16	634
88	T29N R05W 25CAD1	756	434	306	11-33	83	673
89	T30N R02W 35DDD1	916	810	210	01-56	300	616
90	T30N R03W 03 1	1,206	470	146	12-46	160	1,046
91	T30N R03W 27AAD1	1,139	360	150	06-42	235	904
92	T30N R04W 08C 1	700	124	--	06-34	14	686
93	T30N R04W 20DCC1	679	60	10	05-58	20	659
94	T31N R03W 10CDA1	1,064	190	160	07-59	16	1,048
95	T31N R05W 13BAA1	1,156	407	92	12-45	237	919
			Washington County				
96	T35N R02E 04BAB1	904	40	4	xx-41	10	894
97	T35N R02E 12BC 1	923	150	60	05-36	30	893
98	T35N R01E 15AAA1	1,018	60	7	01-41	15	1,003
99	T35N R01W 07C 1	961	47	25	08-48	28	933
100	T35N R01W 08BCB1	897	52	42	07-47	8	889
101	T36N R02E 13CAA1	1,022	90	51	xx-56	60	962
102	T36N R02E 14DBA1	888	25	8	10-56	6	882
103	T36N R02E 15AAA1	1,003	259	26	xx-40	15	988
104	T36N R02E 23ADA1	874	83	20	10-56	12	862
105	T36N R02E 26CAB1	829	50	20	01-42	7	822

Table 1. Pre-mining (prior to 1960) water-level data for the Ozark aquifer in the Viburnum Trend, southeastern Missouri—Continued

[Altitudes are in feet above sea level; MM-YY, month, year; xx, month not available; --, data not available]

Site identification (fig. 5)	Local well number	Altitude of land surface	Well depth (feet)	Casing depth (feet)	Water-level date (MM-YY)	Water-level depth (feet)	Altitude of water level
			Washington County—Continued				
106	T36N R01E 05CDC1	1,133	1,335	14	04-50	75	1,058
107	T36N R01E 08BCC1	1,119	1,030	43	04-50	75	1,044
108	T36N R01E 21DDD1	1,088	65	28	08-56	50	1,038
109	T36N R01E 22CCC1	1,118	475	41	12-56	70	1,048
110	T37N R02E 34BBA1	978	115	10	10-56	45	933
111	T37N R01E 18CDD1	974	70	4	10-36	45	929
112	T37N R01W 17BAC1	1,050	285	416	05-35	202	848
113	T37N R01W 19AAA1	766	1,155	--	07-49	8	758
114	T37N R01W 30AAC1	813	1,340	--	08-49	47	766
115	T37N R02W 25DDD1	800	1,225	7	09-49	7	793
			Supplemental data				
S1	T34N R03W 29BC 1	1,372	215	107	03-61	140	1,232
S2	T33N R03W 18ABA1	1,425	275	216	07-63	180	1,245
S3	T33N R04W 25BCB	1,352	260	192	05-64	138	1,214

Table 2. Water-level data for the Ozark aquifer in the Viburnum Trend, southeastern Missouri, summer and fall 1999

[Altitudes are in feet above sea level; MM-DD-YY, month, day, year; --, data not available]

Site identification (fig. 6)	Local well number	Altitude of land surface	Well depth (feet)	Casing depth (feet)	Water-level date (MM-DD-YY)	Water-level depth (feet)	Altitude of water level
			Crawford County				
1	T35N R02W 28BCA1	1,225	320	--	12/2/99	115.4	1,110
2	T35N R02W 30AAB1	1,170	320	100	12/2/99	132.0	1,038
			Dent County				
3	T34N R02W 04ABA1	1,100	--	--	12/2/99	104.8	995
4	T34N R02W 17BBC1	1,140	1,000	116	6/22/99	99.5	1,040
5	T34N R02W 30DBB1	1,120	135	--	6/22/99	20.2	1,100
6	T34N R02W 32DDC1	1,165	--	--	6/22/99	12.2	1,153
7	T34N R03W 13DBC1	1,138	--	--	6/22/99	12.6	1,125
			Iron County				
8	T34N R01W 02AAB1	1,360	180	--	12/1/99	95.4	1,265
9	T34N R01W 03ACB1	1,125	--	80	7/1/99	5.1	1,120
10	T34N R01W 03CCA1	1,310	217	132	7/1/99	110.7	1,199
11	T34N R01W 10CBB1	1,310	310	125	7/1/99	149.4	1,161
[a]12	T34N R01W 14CDA1	1,020	290	105	7/1/99	209.7	810
13	T34N R01W 18BAA1	1,115	--	--	6/30/99	7.0	1,108
14	T34N R01W 22BDB1	1,000	--	--	7/2/99	1.7	998
15	T34N R01W 33DCB1	970	132	--	11/29/99	5.4	965
16	T34N R01W 35DBD1	920	--	--	11/29/99	15.5	904
17	T34N R02W 01CCC1	1,380	640	120	12/1/99	152.9	1,227
18	T34N R02W 02ACA1	1,325	--	--	12/2/99	272.2	1,053
19	T34N R02W 03DAA1	1,290	500	--	6/30/99	228.2	1,062
20	T34N R02W 10CDC1	1,322	190	--	6/21/99	139.4	1,183
21	T34N R02W 11CAA1	1,320	500	83	6/30/99	115.3	1,205
22	T34N R02W 12BAB1	1,390	545	--	6/30/99	156.7	1,233
23	T34N R02W 12CDC1	1,390	--	--	7/1/99	140.6	1,249
24	T34N R02W 27BDD1	1,345	190	--	11/18/99	146.8	1,198

Table 2. Water-level data for the Ozark aquifer in the Viburnum Trend, southeastern Missouri, summer and fall 1999—*Continued*

[Altitudes are in feet above sea level; MM-DD-YY, month, day, year; --, data not available]

Site identification (fig. 6)	Local well number	Altitude of land surface	Well depth (feet)	Casing depth (feet)	Water-level date (MM-DD-YY)	Water-level depth (feet)	Altitude of water level
			Iron County—Continued				
25	T35N R01E 31DCB1	1,335	--	--	12/1/99	116.0	1,219
26	T35N R01W 28CCD1	1,050	90	--	7/1/99	20.4	1,030
[b]27	T35N R01W 19BCD2	1,080	63	44	12/8/99	48.1	1,032
[b]28	T35N R02W 25DCD1	1,020	64	--	12/8/99	0	1,020
[b]29	T35N R02W 36ACD1	1,020	140	110	6/30/99	-1.8	1,022
[b]30	T35N R02W 36CBB1	1,023	100	70	12/8/99	0	1,023
			Reynolds County				
31	T30N R02W 11DDC1	890	--	--	12/1/99	30.4	860
32	T31N R01W 08ABC1	1,250	--	--	7/1/99	202.8	1,047
33	T31N R01W 27BBB1	1,060	274	--	12/1/99	140	920
34	T31N R01W 27BCD1	990	300	--	12/1/99	60	930
35	T31N R01W 33BCA1	1,160	--	--	12/1/99	183.4	977
36	T31N R02W 28DDC1	1,000	180	--	11/30/99	Flowing	1,000
37	T31N R02W 28DDC2	1,000	--	--	12/2/99	Flowing	1,000
38	T31N R02W 35CDC1	940	--	--	12/1/99	Flowing	940
39	T32N R01W 06ABC1	890	--	--	12/2/99	6.6	883
40	T32N R01W 10ABB1	840	--	--	12/2/99	12.3	828
41	T32N R01W 13BBD1	845	150	92	6/30/99	72.2	773
[b]42	T32N R01W 18ADB1	1,270	164	144	12/6/99	152.1	1,118
43	T32N R01W 30BAB1	940	--	--	12/2/99	6.3	934
44	T32N R01W 34DAD1	1,170	--	--	7/1/99	134.9	1,035
45	T32N R02W 11BBA1	990	167	84	6/29/99	4.9	985
46	T32N R02W 18ABB1	1,190	--	--	6/29/99	4.0	1,186
47	T32N R02W 31DAB1	1,260	292	211	6/29/99	93.5	1,166
48	T32N R02W 35BBC1	1,245	--	--	7/1/99	138.6	1,106
49	T32N R02W 36ACA1	1,220	--	--	6/30/99	156	1,064
50	T33N R01E 08BDD1	920	125	90	12/1/99	9.9	910

Table 2. Water-level data for the Ozark aquifer in the Viburnum Trend, southeastern Missouri, summer and fall 1999—Continued

[Altitudes are in feet above sea level; MM-DD-YY, month, day, year; --, data not available]

Site identification (fig. 6)	Local well number	Altitude of land surface	Well depth (feet)	Casing depth (feet)	Water-level date (MM-DD-YY)	Water-level depth (feet)	Altitude of water level
			Reynolds County—Continued				
51	T33N R01E 30CAA1	825	18	--	11/30/99	7.9	817
[b]52	T33N R01W 05AAD1	1,004	62	29	12/7/99	5.9	998
[b]53	T33N R01W 06ADC1	1,059	122	106	12/7/99	4.2	1,055
54	T33N R01W 09CCD1	1,000	245	135	11/23/99	16.9	983
55	T33N R01W 14ACC1	940	220	135	11/27/99	6.5	934
56	T33N R01W 21BAB1	1,035	--	--	11/23/99	12.5	1,022
57	T33N R01W 25BCC1	880	512	126	11/29/99	21.6	858
58	T33N R02W 12CAA1	1,110	90	20	11/23/99	9.5	1,100
59	T33N R02W 12CAA2	1,110	200	120	11/23/99	9.3	1,101
60	T33N R02W 12DBB1	1,110	475	425	11/23/99	47.9	1,062
61	T33N R02W 16ADA1	1,070	11	--	11/23/99	7.5	1,062
62	T33N R02W 19DCB1	1,050	145	--	11/18/99	14.7	1,035
63	T33N R02W 22DCB1	1,030	--	--	11/18/99	17.2	1,013
64	T33N R02W 31ABB1	1,040	300	--	11/18/99	19.8	1,020
65	T33N R02W 33DBA1	965	--	--	11/18/99	6.6	958
66	T33N R03W 12DDA1	1,170	400	400	7/2/99	Flowing	1,170
			Shannon County				
67	T31N R03W 13CCC1	950	--	--	11/30/99	33.9	916

[a]Well completed in the St. Francis confining unit, rather than the Ozark aquifer.

[b]Observation well.

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