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Fresh-Water Aquifer in the Knox Group (Cambrian–Ordovician) of Central Kentucky

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One of the major goals of the Kentucky Geological Survey is to make the results of basic and applied research easily accessible to the public. This is accomplished through the publication of both technical and nontechnical reports and maps, as well as providing information through open-file reports and public databases.

FRESH-WATER AQUIFER IN THE KNOX GROUP (CAMBRIAN–ORDOVICIAN) OF CENTRAL KENTUCKY

James A. Kipp

ABSTRACT

Fresh water can be found in Cambrian and Ordovician carbonate rocks of the Knox Group in central Kentucky. The top of the aquifer is as much as 300 ft above mean sea level (m.s.l.) on the crest of the Cincinnati Arch, but descends off the flanks of the arch. Water is normally found in the upper 100 to 250 ft of the Knox, primarily in secondary porosity apparently associated with the unconformity at the top of the unit. Knox wells commonly exceed 750 ft in total depth, but because the aquifer is artesian, water rises to an elevation of about 500 ft above m.s.l. in most wells in central Kentucky. Some wells near the crest of the Cincinnati Arch produce water with relatively low concentrations of dissolved solids (500 to 3,000 milligrams per liter [mg/L]). Concentrations of dissolved solids commonly exceed 10,000 mg/L away from the crest of the arch. The Knox aquifer provides modest quantities of water (normally on the order of 10 to 20 gallons per minute) with less than 1,000 mg/L of dissolved solids to several wells in the Inner Blue Grass Region. As a result, it is a potential source of water for rural domestic supplies in central Kentucky.

INTRODUCTION

A few deep wells in central Kentucky produce *fresh water.* These wells penetrate to the top of the Knox Group of *Cambrian to Ordovician age.* This report describes the Knox *aquifer* in central Kentucky, where it is a potential source of domestic drinking water. The report's primary objectives are to (1) identify areas where *potable water* in the Knox has been demonstrated, (2) estimate the quantity of water potentially available from Knox wells, using available information on water characteristics, and (3) evaluate water movement in the Knox, including the identification of possible *recharge* and *discharge areas* and the direction of ground-water movement. To achieve these objectives, this report summarizes available information on the geology, *hydrology,* and water quality of the Knox aquifer in central Kentucky. In addition, a glossary of terms is included in Appendix A. The first appearance of a glossary term in the text is *italicized.*

Prior to 1985, information on Knox wells was obtained from cooperative water-well drillers and their customers who somewhat randomly identified wells for testing and water-quality sampling. Since 1985, however, data for new Knox wells have become available as a result of the Certified Water Well Drillers Program administered by the Kentucky Division of Water (a division of the Natural Resources and Environmental Protection Cabinet). Information from both sources is currently available through the Kentucky Ground-Water Data Repository, housed at the Kentucky Geological Survey.

The distribution and quality of available information is still limited, and any conclusions derived from the existing data must be considered preliminary. Public interest in the Knox aquifer continues, however, because short-term variations in quantity and quality are less likely in this deep unit than in the near-surface *karst* aquifer that is more commonly used for rural domestic water supplies in central Kentucky.

REGIONAL GEOLOGY

The Blue Grass Region is situated in the north-central part of Kentucky (Fig. 1). The Cincinnati Arch is the major structural feature that passes through the region in a north–northeast direction. The Jessamine Dome, centered in Jessamine County, represents the structural high point on the arch. Rocks dip 20 to 40 ft/mi to the east and west and about 10 ft/mi to the north and south of this dome. Middle Ordovician limestones and shales are exposed in the center of the dome and are flanked by progressively younger rocks.

The *topography* in central Kentucky is gently rolling to rugged, varying with the composition of the underlying bedrock and proximity to major surface streams. Detailed descriptions of the near-surface rocks and information on the geographic distribution of stratigraphic units are included on U.S. Geological Survey 7.5-minute geologic quadrangle maps covering the area.

Faulting of bedrock is common in central Kentucky. The Kentucky River and Lexington Fault Systems are major northeast-trending fault systems that cut across the study area (Fig. 1). Both systems are composed of a number of *normal faults* and *grabens* with general displacement down to the southeast. Vertical displacement of rocks is as much as 600 ft. Along with the vertical motion, there is also evidence for lateral slip along the faults. This displacement is especially evident along the Kentucky River Fault System, where *joints* and fractures are also disturbed (Black and Haney, 1975). Within the Blue Grass Region, numerous northwest-trending normal faults and grabens are approximately at right angles to the major fault systems. These secondary faults generally display vertical displacements of less than 100 ft.

The Kentucky River Fault System and structural uplift associated with the Cincinnati Arch have altered the flow direction of the Kentucky River in the geologic past through southern Clark, Fayette, and Jessamine Counties from the northwest to the southwest. Northwesterly flow resumes in southern Jessamine County. The Kentucky River and its tributaries are entrenched more than 350 ft below the adjoining upland along the crest of the Cincinnati Arch. Relatively large solution openings in the *carbonate rocks* underlying the Kentucky River gorge have been encountered as deep as 100 ft below river level in some locations (Hopkins, 1966).

The Knox Group

The Knox Group is composed of a thick sequence of *dolomite* of Cambrian and Ordovician age that underlies the entire state of Kentucky; equivalent rock units occur in surrounding states. The Knox consists of four formations, which are, in descending order: the Mascot Dolomite, Kingsport Dolomite, Chepultepec Dolomite, and Copper Ridge Dolomite (Fig. 2) (Harris, 1969).

A regional *erosional unconformity* developed on top of the Knox Group during Early Ordovician time. Most of the Mascot was removed by erosion in central Kentucky, so that either the basal Mascot or the Kingsport is present at the unconformity in this area (Anderson, 1991). The top of the Knox, however, is still at its highest elevation in southern Fayette and eastern Jessamine Counties (Fig. 3).

During creation of the unconformity, uplands such as the Jessamine Dome apparently served as recharge areas, where precipitation entered a regional *paleo*aquifer system extending from central and south-central Kentucky into northern Tennessee (Harris, 1971). The addition of fresh water to the hydrologic system apparently facilitated the development of karst features in the carbonate units. The location and orientation of these karst features were undoubtedly influenced by existing fracture systems. The *secondary porosity* and *permeability* that developed in the upper Knox created a widespread aquifer system characterized by sinkholes, conduits, and *breccia*.

The unconformable surface on the top of the Knox appears uneven in the subsurface of south-central Kentucky (Anderson, 1991). Numerous ridges and valleys suggest the erosional nature of the unconformity. Sinkholes on the Knox paleosurface also indicate a karst paleotopography. The *porosity* and permeability in the upper Knox resulting from the paleoaquifer system played an important part in the development of a petroleum reservoir in parts of south-central Kentucky (Anderson, 1991). Similar karst features may have helped fresh water migrate into the top of the Knox Group in central Kentucky.

The Central Kentucky Mineral District covers part or all of 16 counties in the Blue Grass Region of central Kentucky. Barite, fluorite, calcite, galena, and sphalerite have been mined in the district. Pyrite, chalcopyrite, and marcasite, as well as *secondary minerals* including malachite, smithsonite, witherite, strontianite, cerussite, and other carbonates, have also been observed or reported (Anderson and others, 1982). The Knox is the host rock for some of these ore deposits. Anomalous dissolved metal concentrations in water from the Knox could be associated with orebodies in the region. These concentrations could be useful indicators for prospecting for economic mineral deposits, but in some cases they may also make the water from the Knox aquifer unsuitable for human consumption.

Previous Investigations

Palmquist and Hall (1961) estimated that fewer than half of the attempts to obtain adequate domestic water supplies from shallow bedrock wells in the Blue Grass Region have been successful. Shallow ground water in the Lexington area generally occurs in solution openings developed along joints and bedding planes in the Ordovician limestones. Cavity development is normally limited to about 100 ft below the land sur-

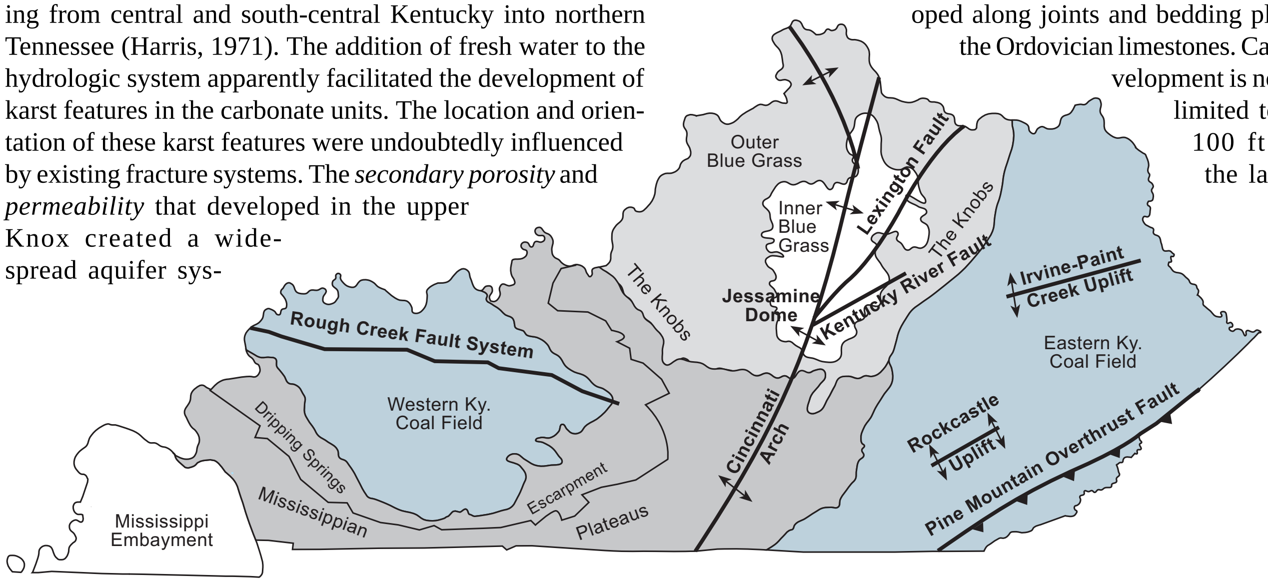

Figure 1. Structural and physiographic setting of the study area.

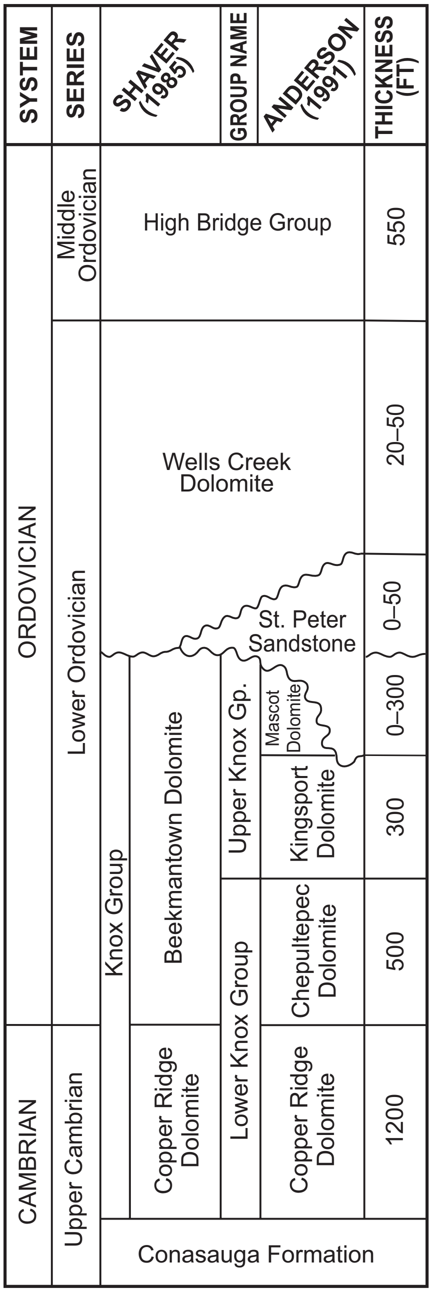

Figure 2. Generalized stratigraphy of the study area. Modified from Anderson (1991).

face (Thrailkill, 1984). Wells that fail to penetrate significant water-bearing openings generally do not furnish adequate water for even domestic supplies. The potential for bacterial contamination in wells that do produce water is high because of direct recharge of runoff and streamflow to the cavernous limestones (Faust, 1977). As a result, there has long been interest in tapping deeper geologic units as potential aquifers in the area.

In their publication on the geochemistry of natural water of the Blue Grass Region, Hendrickson and Krieger (1964, p. 1) stated that "at depths greater than 50–200 feet below local stream level, all ground water is of the sodium chloride type and too highly mineralized for domestic use." They indicated, however, that "fresh water has been reported from a few wells that are several hundred feet deep, but it has been impossible to determine the depths at which the fresh water enters these wells" (p. 69). This seems to imply that fresh water probably comes from shallow horizons, but does not rule out the possibility that it is produced from deeper formations such as the Knox.

The presence of relatively fresh water in the top of the Knox Group in central Kentucky was apparently first formally recognized during the preparation of the "Fresh-Saline Water Interface Map of Kentucky" (Hopkins, 1966). A brief reference to the occurrence is included in the text on that map: "…less *saline waters* are found well below the fresh-saline water interface in parts of the Knox Dolomite underlying the Blue Grass Region."

Following the publication of this map, Hopkins continued his investigation of the Knox for several years. Information he accumulated was assembled as an open-file report in the early 1970's, but the plates were misplaced. A final report was apparently never completed after Hopkins's transfer from Kentucky to the U.S. Geological Survey (USGS) office in Washington, D.C. Other reports for the region prepared by the USGS during this period, however, often mention the possibility of fresh water in the Knox in the vicinity of Lexington and suggest that sparse data indicate that sustained yields of less than 15 to 25 gallons per minute (gal/min) are possible (Mull, 1968; Faust, 1977).

In evaluating selected geologic units for potential use in underground storage of wastes, Cordiviola and others (1981) prepared a map showing the concentration of *total dissolved solids* for samples obtained from within 125 ft above and below the top of the Knox Dolomite (Fig. 4). This map was developed from only 17 widely scattered data points. The contours indicate increasing concentrations both east and west of a line running approximately down the center of the Blue Grass Region and nearly coinciding with the axis of the Cincinnati Arch.

Ground-water quality data for Cambrian and Ordovician formations in Kentucky included in USGS computer files as of September 30, 1981, were summarized by Sprinkle and others (1983). Although the median concentration of dissolved solids for these samples was 17,200 *milligrams per liter* (mg/L), four wells located in Fayette, Bourbon, and Jessamine Counties of the central Blue Grass produced water with less than 1,000 mg/L dissolved solids. Plate 1 of that report indicates that concentrations rise rapidly to the east, south, and west of this area, but rise more gradually to the north (Fig. 5).

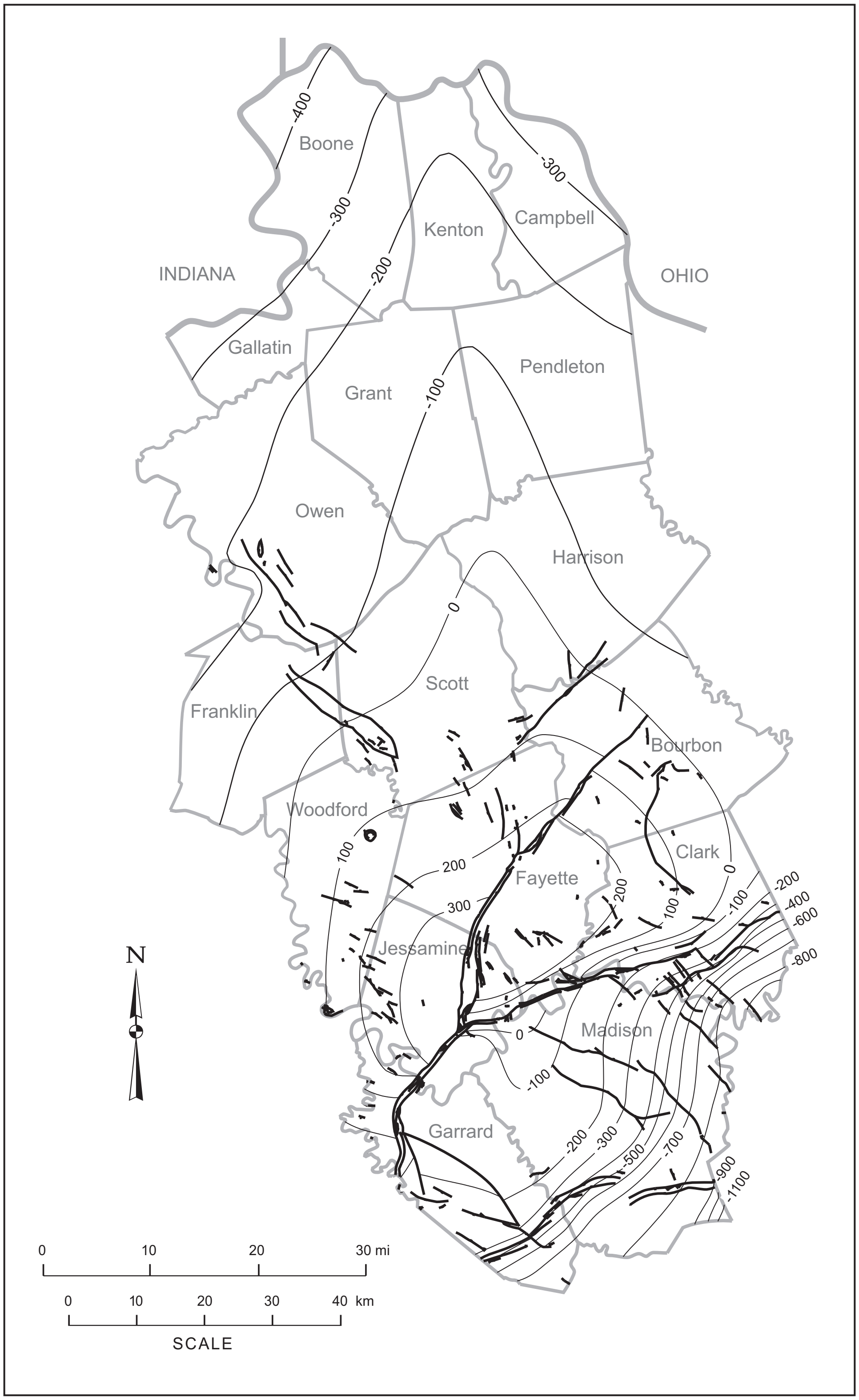

Figure 3. Structure on the top of the Knox Group.

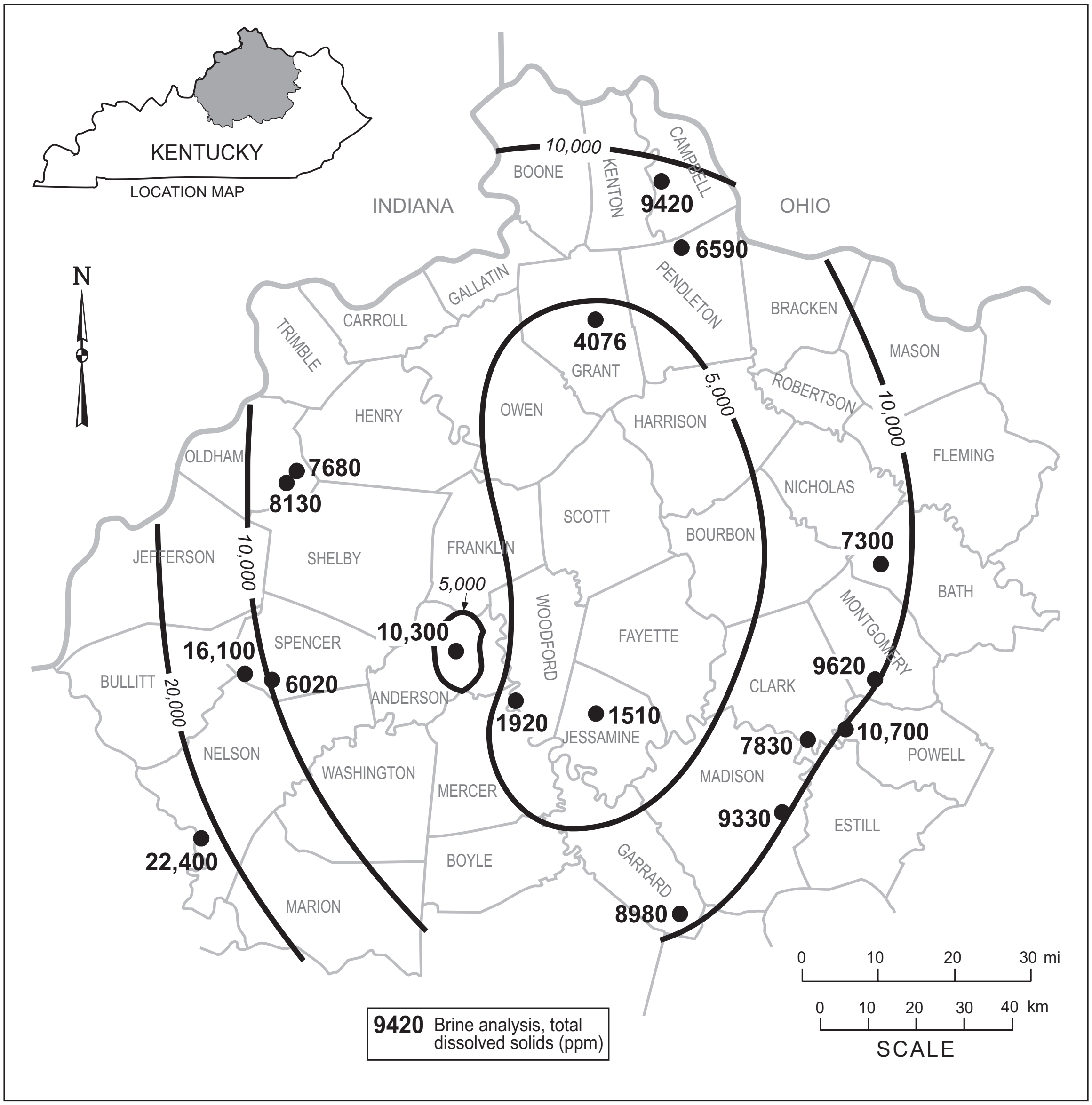

Figure 4. Generalized quality of ground water from the Knox Group. Modified from Cordiviola and others (1981).

Brahana and Bradley (1985) reported a similar occurrence of fresh water over the Nashville Dome in the Central Basin area of Tennessee, where the top of the Knox is within 330 ft of the land surface. They concluded that during the upwarping of the Nashville Dome the rocks at the crest were stretched, resulting in the formation of systematic joints. This secondary porosity serves as the primary avenue of recharge to the Knox. Within the Knox aquifer in Tennessee, porosity and permeability occur in the form of a network of small, interconnected, tubular voids that are often areally extensive. Thin zones of these voids (typically about 1 ft in thickness) are interspersed throughout the aquifer, but are commonly concentrated in the upper 200 ft of the unit. Wells near the center of the Central Basin generally provide water with lower concentrations of dissolved solids (500 to 2,500 mg/L) than do wells near the margin (1,000 to 6,500 mg/L). Outside the Central Basin, the concentration of dissolved solids in water from the Knox increases and approaches *brine* concentrations beneath the Cumberland Plateau. The Knox aquifer is an important source of water in the Central Basin of Tennessee, providing adequate amounts of water for a rural domestic supply to more than 99 percent of the wells that are completed in it. *Well yields* from the aquifer in Tennessee, however, normally do not exceed 10 gal/min.

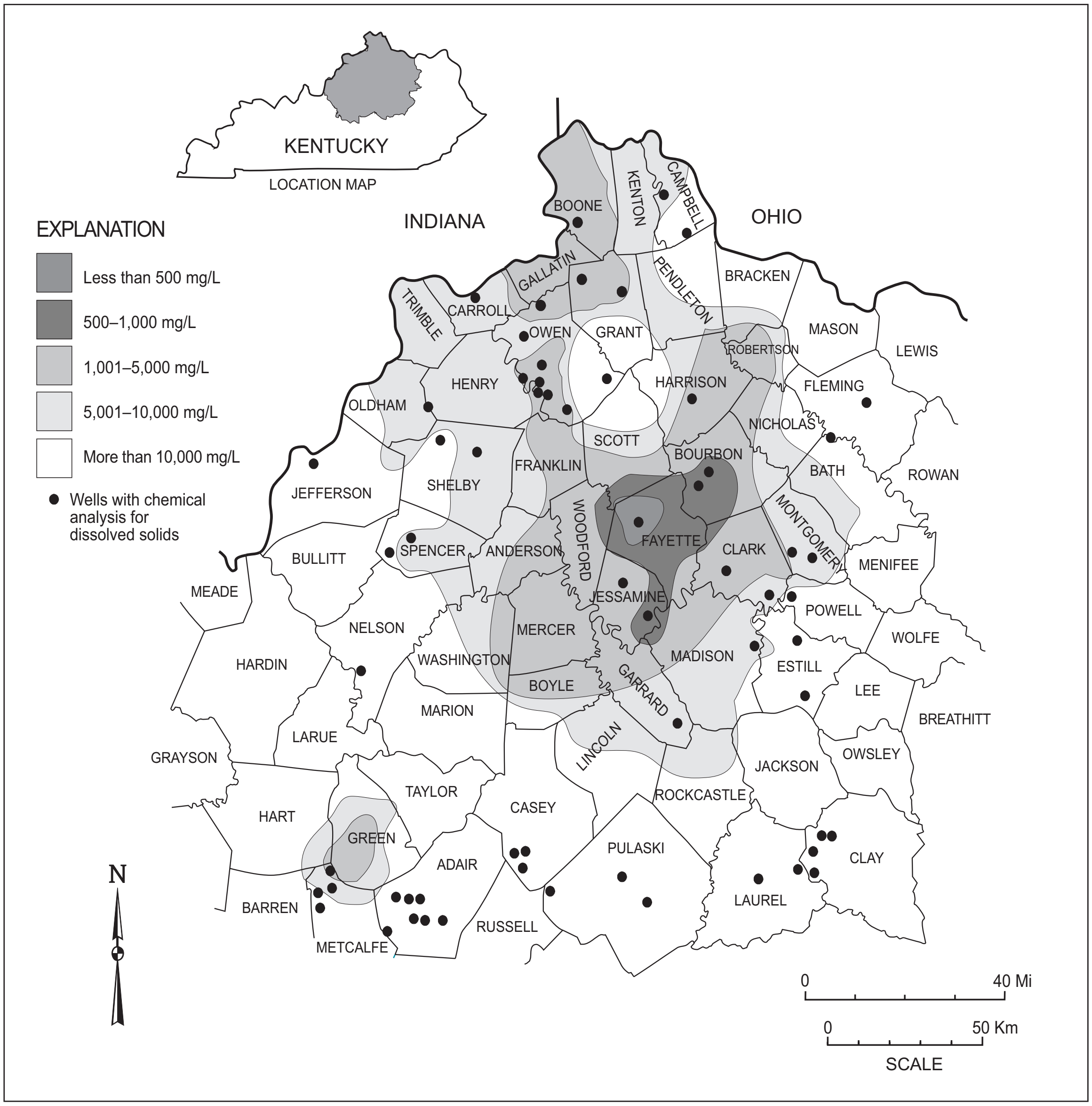

Figure 5. Concentrations of dissolved solids in ground water from Cambrian and Ordovician formations in central Kentucky. Modified from Sprinkle and others (1983).

THE KNOX AQUIFER IN CENTRAL KENTUCKY

Information considered for this publication was obtained from published and unpublished data of the U.S. Geological Survey, the Kentucky Geological Survey, and the Kentucky Natural Resources and Environmental Protection Cabinet–Division of Water. Table 1 lists information for wells used in this report. For the purposes of this investigation, the Knox aquifer is defined as the upper 250 ft of the Knox Group (Fig. 6). The hydrology of the Knox below this interval is generally untested and therefore unknown in central Kentucky. The following summarizes information on the Knox aquifer and identifies areas where it is an actual or potential source of potable water, based on quantity and quality considerations.

Porosity and Permeability

Porosity in the Knox Group of central Kentucky may be partially related to *lithology*. For example, in some areas in Fayette County, the top of the Knox is represented by the Lower Ordovician Mascot Dolomite. This unit is typically a finely to moderately crystalline dolomite with some pinpoint *vugular porosity* and poor to fair intercrystalline permeability. In areas of Jessamine County, the top of the Knox is in the Kingsport Dolomite, which has extremely vugular porosity, but only fair permeability. Secondary permeability,

Table 1. Data from selected deep-water wells in central Kentucky.

County	*ID No.*	*Quadrangle*	*Latitude*	*Longitude*	*Surface Elev. (ft m.s.l.)*	*Total Depth (ft)*	*Reported Static Water Level Elev. (ft m.s.l.)*	*Measured Static Water Level Elev. (ft m.s.l.)*	*Reported Yield (gal/min)*	*Measured Yield (gal/min)*	*Specific Conductance (µS)*	*Total Dissolved Solids (mg/L)*	*Fluoride Concentration (mg/L)*
Boone	1	Patriot	385145.00	844510.00							4,280	2,520	
Bourbon	2	Paris East	381450.00	840950.00	940	968	440	509	75		2,990	*1,766	
Bourbon	3	Paris East	381438.00	841012.00	930	947	530	507	40		2,600	*1,517	
Bourbon	4	Paris West	380923.73	841641.31	880	868	140		40			> 20,000	
Bourbon	5	Paris West	380948.93	841932.55	885	969		502		40	917	498	1.1
Bourbon	6	Millersburg	382025.70	840943.92	835	893	–58		70		4,320	2,765	
Bourbon	7	Paris West	381204.45	841923.55	910	792		468		22	992	531	0.2
Bourbon	8	Centerville	381314.83	842247.36	937	828				> 4	1,000	536	2.9
Bourbon	9	Paris West	381301.98	841634.83	880	772		508					
Bourbon	10	North Middletown	380833.61	840629.41	866	960							
Bourbon	11	North Middletown	381212.00	840648.00	970	940		340			> 8,000		
Clark	12	Palmer	375147.00	840532.00	760	1,618	–658				13,100	8,880	0.4
Clark	13	Winchester	375648.00	841258.00	930	1,562	568				2,790	1,470	0.6
Fayette	14	Clintonville	380256.00	842126.00	1,000	950			25		2,500	*1,453	
Fayette	15	Clintonville	380436.00	841733.00	1,000	1,107	100		200				
Fayette	16	Lexington East	380517.00	842900.00	965	1,010	615		20				
Fayette	17	Lexington West	380428.00	843421.00	945	900					565	326	
Fayette	18	Versailles	380202.00	843840.00	910	929			25			2,060	
Fayette	19	Versailles	380138.00	843833.00	930	908			25			2,250	
Fayette	20	Lexington East	380527.00	842906.00	965	1,007		586					
Garrard	21	Paint Lick	373225.00	842454.00		1,665					15,100	9,120	
Grant	22	Glencoe	384331.00	844639.00								4,504	
Grant	23	Berry	383703.00	842948.00	703	1,250		506			7,500	*4,651	
Harrison	24	Cynthiana	382449.00	841932.00		1,010					3,210	1,820	5.6
Jessamine	25	Nicholasville	375511.86	843613.73	915	999		507		12	2,050	1,110	
Jessamine	26	Keene	375415.00	843732.00	930	967	12		40				
Jessamine	27	Little Hickman	374536.09	843306.85	630	1,276	–616		5				
Jessamine	28	Nicholasville	375344.00	843555.00	890	886	440	500	35	15	1,760	*980	
Jessamine	29	Little Hickman	374946.00	843105.00		1,737					1,040	576	
Madison	30	Moberly	374331.00	840911.00		1,704					14,900	9,330	
Owen	31	New Liberty	383311.00	845731.00		1,084					5,390	3,050	
Woodford	32	Salvisa	375333.00	844740.00	725	866		500	30	10	770	*346	
Woodford	33	Salvisa	375614.00	844738.00	755	785		474		1.6	3,360	1,980	11.0

*Estimated value of total dissolved solids calculated from specific conductance data

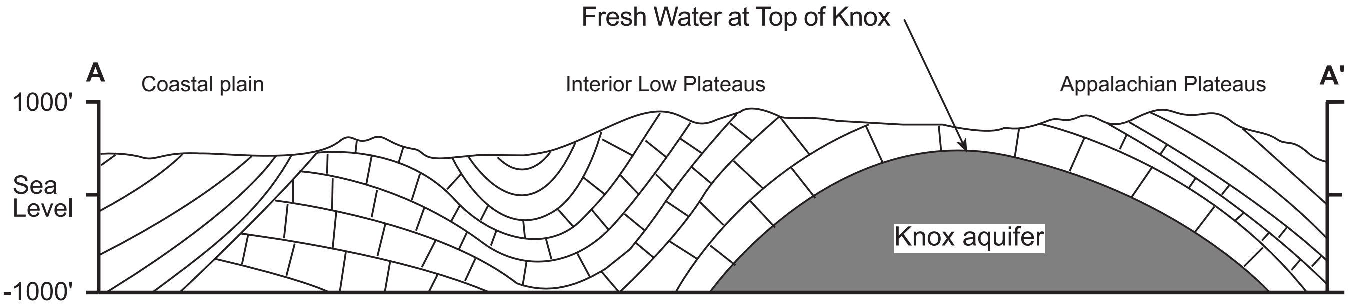

Figure 6. Fresh-water occurrence at the top of the Knox Group.

however, is often fracture-dominated in both the Mascot and Kingsport Dolomites (W.H. Anderson, oral commun., 1993). Individual permeable intervals tapped by water wells seem to be fairly thin, separated by relatively less permeable rocks, and occur throughout the aquifer zone at the top of the Knox. It is common for the drill string to suddenly drop several inches when one of these permeable horizons is encountered during drilling, and drill cuttings often contain evidence of secondary crystallization in these zones.

Flow System

The Knox aquifer is an *artesian aquifer*, meaning water is under *confined conditions* and rises above the top of the formation when wells are drilled into it. Depth to *static water level* is requested on the "Kentucky Water-Well Record Form," but drillers often list the locations of porous zones that store and transmit water within the Knox aquifer rather than the level to which water rises in the well after these horizons have been penetrated.

The static water levels reported by drillers on many other well-completion forms only grossly approximate the actual levels measured later. In these cases, either the methods used for determining water levels during well installation were unreliable or the wells had not completely stabilized when the measurements were taken immediately following the completion of drilling.

Few water-level measurements of deep wells in central Kentucky have been made in which the wells were allowed to stabilize for at least a few days following drilling. Most levels (8 of 12) are near an elevation of 500 ft (±10 ft) above mean sea level (m.s.l.). These estimates were obtained by subtracting depth to water from surface elevations taken from topographic maps; the elevations cover a rather large geographic area and include multiple wells in Jessamine and Bourbon Counties and single wells in Woodford and Grant Counties (Fig. 7). Given the limited accuracy of the elevation estimates, the calculated water levels for these wells fall into a surprisingly narrow range of elevation for an area of this extent. This suggests good hydraulic connection in the Knox aquifer throughout the area and that the average static water level is at an elevation of approximately 500 ft above mean sea level.

The four wells that do not conform to this general pattern may not accurately reflect the condition of the aquifer at the top of the Knox. One well is apparently completed approximately 100 ft above the top of the Knox (Fig. 7, well 7). Two other wells are completed almost 200 ft below the top of the Knox (Fig. 7, wells 20 and 33). The water level of the final well (Fig. 7, well 11) corresponds closely to a fracture identified in the *caliper log*. The fracture is apparently controlling the water level in this well.

Wells inferred to be near recharge areas, because of their relatively low concentrations of dissolved solids, apparently have static water levels similar to wells with higher concentrations of dissolved solids. A good example is well 5 (Table 1) in southern Bourbon County, which is adjacent to the Lexington Fault Zone. The low concentration of dissolved solids (498 mg/L) and above-average yield (40 gal/min) of this well suggest that the fault zone may facilitate recharge to the Knox aquifer at this location. Although the fault may be a recharge zone, the static water level (502 ft above m.s.l.) does not give a clear indication that the fault facilitates recharge.

A Knox well in southern Woodford County drilled from the top of a bluff next to the Kentucky River has a measured static water level of 500 ft above m.s.l. (Table 1, well 32). The normal pool elevation of the Kentucky River at this location (below lock 7 in southern Jessamine and Woodford Counties) is 497 ft above m.s.l. Above lock 7, the normal pool elevation is 514 ft above mean sea level. Measured water levels in Knox wells in central Kentucky generally fall between these river elevations. As a result, the relationship between the Kentucky River and the Knox aquifer (recharge zone or discharge zone) is not apparent. The top of the Knox Group is clearly within about 200 ft of the surface of the Kentucky River, however, and may also be no more than 100 ft below some of the relatively large openings in the younger carbonate rocks overlying the Knox in the Kentucky River gorge (Hopkins, 1966).

Not enough water-level information is available to allow identification of recharge zones, discharge zones, or direction and rate of water movement in central Kentucky, and to define a ground-water flow system. The Ohio River could serve as a regional discharge area for the Knox aquifer (pool elevation of 455 ft above Markland Locks and Dam, in the Florence quadrangle, Indiana-Kentucky), but the available water-level data do not indicate a strong regional gradient driving water in that direction.

Recharge to the aquifer probably moves through fractures and faults in the overlying rocks on the crest of the Cincinnati Arch, where the Knox is closest to the surface, as suggested by Brahana and Bradley (1985) for Tennessee. Water can then move either downdip off of the arch or along the strike of the arch toward the Ohio River. Overall, water-quality distribution in Knox wells seems to support this general pattern (Figs. 4–5). Concentrations of dissolved solids increase rapidly off the flanks of the arch, but remain fairly low along the crest.

Water Quality

Water for most domestic and industrial uses should contain less than 1,000 mg/L total dissolved solids (Davis and DeWiest, 1966). Livestock and domestic animals may begin to be distressed when the concentration of total dissolved solids reaches 3,000 mg/L, and supplies with less than 2,500 mg/L are generally more desirable (Lehr and others, 1980). The National Secondary Drinking Water Regulations set a secondary maximum contaminant level for total dissolved

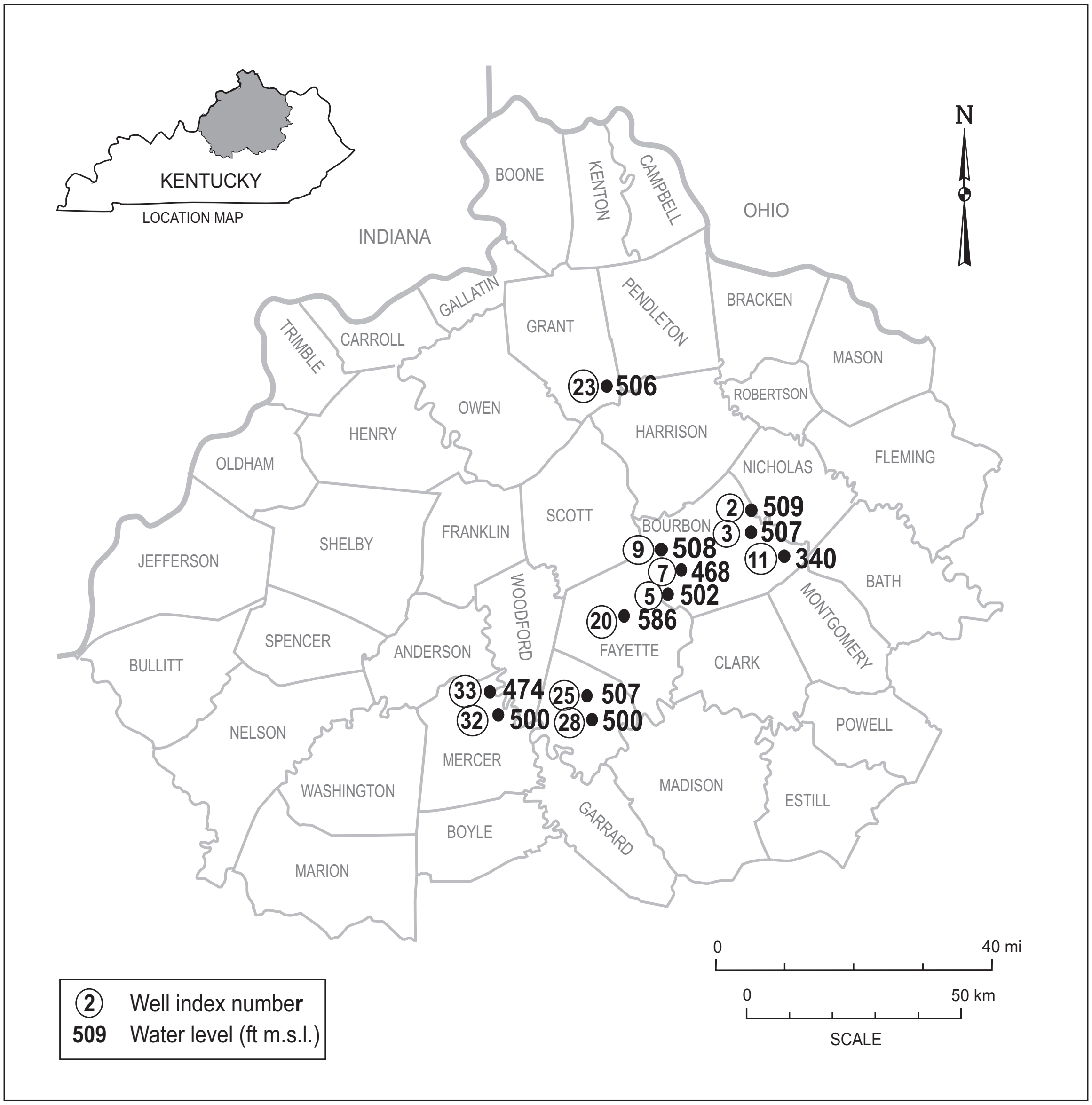

Figure 7. Water levels in Knox wells.

solids of 500 mg/L (Federal Register, 1979). This recommended limit is based on taste thresholds rather than physiological effects; concentrations in excess of 1,000 mg/L are commonly found in municipal supplies where less mineralized waters are not available (Lehr and others, 1980).

Ground water from the Knox aquifer is suitable for drinking-water use in some areas in the Blue Grass Region. In general, wells on top of the Jessamine Dome yield water with lower concentrations of dissolved solids (generally from 500 to 3,000 mg/L) than do wells off of its flanks. The lowest concentrations of dissolved solids have been found in Bourbon, Fayette, Jessamine, and Woodford Counties. Water-quality conditions vary widely even within these counties (Fig. 8). Most Knox wells produce water containing sodium and chloride as the dominant ions. Where dissolved solids are less than 500 mg/L, calcium bicarbonate (Fig. 8, well 17) and sodium bicarbonate (Fig. 8, well 5) water types have also been observed.

Other factors may be responsible for some of the variability in water quality. In most cases, wells to the Knox have been completed as open bedrock holes with minimal surface casing (often only to 20 ft). Typically, these wells do not encounter significant volumes of water from formations above the Knox. Minor flows of mineralized water from overlying formations, however, could easily affect the average quality of water coming from any specific well because the yield from the Knox is fairly low.

Water-quality changes have also been noted in individual wells. An initial sample from a well in southern Woodford County (well 32) had a *specific conductance* of 2,550 *microSiemens* (µS). This water was collected upon completion of drilling. Later, after a pump had been installed and the well had been more fully developed, a second sample was tested. This sample had a specific conductance of only 770 µS (Table 1). Water quality has also improved in other wells after pumping. As a consequence, time of sampling may contribute to some of the variability in water quality that has been observed.

Water from the Knox aquifer is generally poorly suited for irrigation because of its high dissolved mineral concentration and sodium content, which can cause toxic concentrations of salts to accumulate in the soil. Water containing sodium can also change the structure of soils containing clay minerals, making them less permeable. Low soil permeability further aggravates the salinity hazard caused by high concentrations of dissolved solids (Wilcox, 1948; U.S. Salinity Laboratory Staff, 1954). Water used for irrigation should generally contain less than 1,500 mg/L and preferably no more than 700 mg/L total dissolved solids (Lehr and others, 1980).

Several Knox wells yield water containing hydrogen sulfide gas, which has an objectionable “rotten egg” odor. In some cases this problem was not evident when the well was initially completed, but seemed to develop through time. This

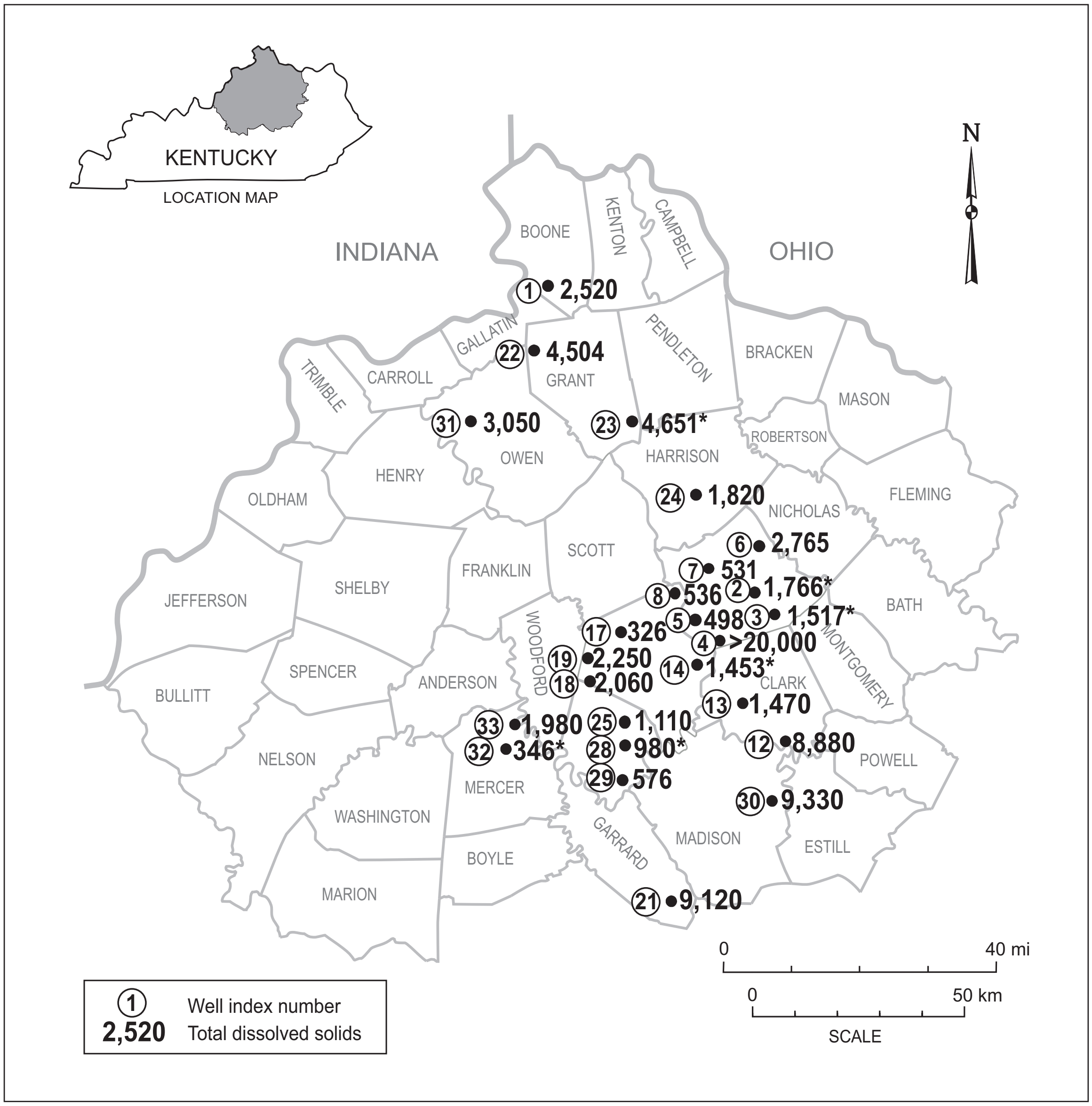

Figure 8. Concentrations of total dissolved solids in selected Knox wells. Asterisk indicates estimated total dissolved solids calculated from specific conductance values.

change may be related to biological activity by bacteria that require an anaerobic environment and a source of organic carbon for their metabolic process (Hoefs, 1987).

Fluoride concentrations in excess of the maximum recommended level of 2.4 mg/L for drinking water have been found in water from the Knox in central Kentucky. These elevated fluoride levels do not correlate well with specific conductance measurements, and therefore cannot be predicted by simple on-site testing of specific conductance (Table 1). Solubility conditions can limit the dissolved-fluoride concentration in natural water. In solutions that contain calcium, there is often an equilibrium with the mineral fluorite (CaF_2), so that high fluoride concentrations generally only occur in waters that have low calcium concentrations (Hem, 1985). The sodium water types typically encountered in the Knox, however, can often sustain fluoride concentrations above the National Primary Drinking Water Standard. As a result, water from all Knox wells intended for drinking-water consumption should be tested for fluoride.

The Knox aquifer provides water of drinking-water quality in limited areas of central Kentucky. At this time, however, no public water supplies in the State are known to use water from the Knox. This situation may be related to water quality, but undoubtedly also reflects the limited yield of the Knox aquifer.

Well Yield

Well-yield information is requested on the "Kentucky Water-Well Record Form." Drillers commonly determine the yields of newly completed wells by blowing water from the hole with air and either estimating the volume of water produced or observing the rate of water-level recovery in the well. Yields reported by drillers for 13 Knox wells in central Kentucky range between 5 and 200 gal/min, with a median of 35 gal/min (Table 1).

Yields measured under more controlled conditions during actual pumping are available for only seven wells. These wells produced from 1.6 to 40 gal/min, with a median of 12 gal/min (Table 1); these values are much more consistent with the data reported for Knox wells in Tennessee (Brahana and Bradley, 1985) than with the drillers' estimates. Two of the measured wells also have yield estimates provided by the drillers. Measured yields for these two wells were between two and three times less than the estimates reported earlier on the well-record forms (Table 1). If yields estimated by the drillers are divided by three, then minimum, maximum, and median values nearly coincide with those same parameters for the seven measured wells.

No detailed long-term *pumping tests* have been conducted in Knox wells, but *drawdown* and recovery in two wells (wells 5 and 32) suggest that the *hydraulic conductivity* of the upper Knox is in the range of 2×10^{-5} to 1×10^{-4} ft/min. Values reported in the literature for normal carbonate rocks range from 2×10^{-7} to 2×10^{-4} ft/min. Karst limestones can have hydraulic conductivities ranging between 2×10^{-3} and 2 ft/min (Freeze and Cherry, 1979).

Wells in carbonate rocks generally have yields between 5 and 20 gal/min. S*pecific capacities* from wells in indurated sedimentary rocks normally are at the lower end of the range. This relation is common in fractured carbonate rocks (Davis and DeWiest, 1966) and probably should be expected in the Knox aquifer.

The available data indicate that Knox wells do not appear to be capable of producing sufficient quantities of water for large-scale industrial and public water-supply use or for irrigation. Quantities of water available from all Knox wells in central Kentucky are, however, apparently adequate for individual rural domestic supply requirements.

Potential for Enhancement of Well Yield and Water Quality

Results from tests on a well adjacent to the Lexington Fault System in southern Bourbon County (well 5) suggest that Knox wells situated near major faults might have better than average yields and water quality. Two wells were sited and drilled along a mapped fault in western Fayette County to test this hypothesis (wells 18 and 19). Although the fault was expressed on the land surface as a line of sinkholes, these Knox wells produced only limited quantities of water, quality was poor, and they were abandoned. In this particular case, the fault was relatively short (12,000 ft long), was oriented in a northwest direction rather than the northeast direction of the dominant regional fault systems, and exhibited a maximum displacement of only about 100 ft. Even though this particular effort was not successful, it still may be possible to enhance water quality and well yield by locating Knox wells adjacent to major northeast-trending fault systems in central Kentucky.

Cost

The cost of a completed 6-in.-diameter Knox water well can range from $10,000 to $15,000 (depending on well depth) for locations in central Kentucky. This includes drilling, shallow surface casing, submersible pump and motor, power cable, discharge pipe, and labor. Casing installed from land surface to the top of the Knox to eliminate the effects of overlying strata (such as bacterial contamination or shallow brine production) could increase the cost by an additional $10,000 or more. As a result, Knox wells require a significant capital investment for small but dependable supplies that in many cases are of marginal quality.

POTENTIAL TOPICS FOR FUTURE STUDY

This report is based on a limited amount of general information (information of opportunity rather than structured data collection). More intensive drilling and sampling programs could provide additional data about well yield, water quality, existing static water level conditions, and the spatial distribution of these aquifer properties. Isotope analyses for samples from the Knox could also help determine if fresh water along the crest of the Cincinnati Arch is younger than more mineralized water on the flanks of the arch and to test the importance of recharge along major fractures.

Most existing Knox wells have only a minimal amount of shallow surface casing. Some of the observed variability in water quality may be caused by small amounts of mineralized water flowing from formations above the Knox into the open well bores. This hypothesis could be tested by installing variable amounts of casing in several wells drilled to the Knox in a single location.

Well-yield information for Knox wells is sparse. Additional data would greatly enhance the evaluation of the Knox aquifer as a water supply. In addition, the potential for well stimulation has not been investigated in Knox water wells in central Kentucky. Experience with carbonate rocks in other areas suggests that acid treatment increases average original well yield by about 1.6 times (Davis and DeWiest, 1966). Anticipated after-treatment yields would generally be from 15 to 30 gal/min, which would still be insufficient to support irrigation, industrial, or community supplies. Acid treatment could be useful, however, for cases where existing yield is insufficient for rural domestic supply purposes.

SUMMARY

Existing data on the chemical quality of water and yields from wells completed in the Knox Group are insufficient to fully evaluate the potential of this formation as a source of water in the Blue Grass. Concentrations of total dissolved solids are normally less than 3,500 mg/L throughout the central and northern parts of the region. Concentration generally increases to the east, south, and west. Although this overall pattern is consistent, local variability in water quality between adjacent wells is common. Only a few wells in Bourbon, Fayette, Jessamine, and Woodford Counties produce water with less than 500 mg/L dissolved solids (secondary drinking water standard). Well yields are commonly between 10 and 20 gal/min. This is sufficient for individual rural domestic drinking water supplies and for livestock use, but will not support large irrigation, public water supply, or most private industrial needs. Well completion and capital requirements should be carefully evaluated before drilling takes place.

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APPENDIX A: GLOSSARY

Aquifer—Rocks or unconsolidated materials that are saturated with water and able to transmit useful quantities of water to wells and springs.

Artesian aquifer—An aquifer bounded by layers of distinctly lower permeability, which enables the water in the aquifer to become pressurized so that it will rise above the top of the aquifer in a well.

Breccia—A rock made up of highly angular coarse fragments.

Brine—A concentrated salty solution.

Caliper log[1]—A well log that shows the variations with depth in the diameter of an uncased borehole. It is produced by spring-activated arms that measure the varying widths of the hole as the device is drawn upward.

Cambrian to Ordovician age—Approximately 500 million years old. Most of the rocks deposited in the area that is now Kentucky during the transition between the Cambrian and Ordovician Periods are carbonate types.

Carbonate rocks—Rocks such as limestone and dolostone, consisting predominantly of the carbonate minerals calcite and dolomite.

Confined conditions—An aquifer under artesian pressure due to the presence of layers with lower hydraulic conductivity.

Discharge area—An area in which ground water flows toward the surface and exits from an aquifer or flow system.

Dolomite—A carbonate mineral containing both calcium and magnesium.

Drawdown—The lowering of the water level in an aquifer, caused by pumping water from wells.

Erosional unconformity—A surface that separates younger strata from older rocks; formed by erosion that occurred after the older rocks were deposited.

Fault—A fracture or fracture zone along which there has been displacement of the two sides relative to one another.

Fresh water—Water that is not salty.

Graben—A block of rock that has been downthrown along bounding faults relative to rocks on either side.

Hydraulic conductivity—A measurement of the rate at which water can move through a permeable medium. It is normally reported as a velocity (distance/time), but actual rate of movement also depends on other factors such as porosity and pressure gradients in a flow system.

Hydrology[1]—The science that deals with water, its properties, circulation, and distribution, on and under the earth's surface and in the atmosphere.

Joint—A fracture in rock along which there has been no appreciable movement.

Karst—Features such as sinkholes, conduits, and caves that are formed by water dissolving carbonate rocks; or an area or rocky body with such features.

Lithology[1]—The physical character of a rock.

MicroSiemens—A unit of measure used for reporting the specific conductance of water. It is equivalent to the conductance of 1 micromho per centimeter of water (conductance is the opposite of resistance; a micromho is the inverse of an ohm).

Milligrams per liter—A unit of concentration used for describing the weight of dissolved minerals in a volume of solution. For dilute solutions in water, 1 milligram per liter is nearly equivalent to one part per million by weight.

Normal fault—A tensional feature generally associated with stretching that often accompanies vertical forces, such as uplifts.

Paleo-[1]—A prefix indicating occurrence in the geologic past. For example, a paleoaquifer is a stratigraphic unit that functioned as an aquifer at some time in the geologic past.

Permeability—The ability of a material to transmit a fluid.

Porosity—The ratio of the volume of void spaces in a rock or sediment to the total volume of a rock or sediment.

Potable water—Water suitable for human consumption.

Pumping test—A test made by pumping a well at a known rate for a period of time and observing the change in water level in the aquifer. A pumping test can be used to determine both the yield of a well and the hydraulic characteristics of the aquifer (such as hydraulic conductivity).

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[1] This definition is adapted from Bates and Jackson (1980).

Recharge area—An area where water moves downward into an aquifer or enters a flow system.

Saline water—Water containing excessive amounts of dissolved salts.

Secondary mineral[1]—A mineral formed later than the rock enclosing it as a result of weathering, metamorphism, or solution.

Secondary porosity—Porosity that forms after the initial deposition of a geologic unit. In carbonate rocks it is commonly in the form of joints, faults, and solution features.

Specific capacity—An expression of the relative productivity of a well obtained by dividing the rate of discharge from the well during pumping by the observed drawdown in the well at that rate.

Specific conductance—The ability of water to transmit an electrical current; related to the concentration and charge of ions present in the water. Specific conductance is closely related to concentration of total dissolved solids and can normally be used to estimate total dissolved solids.

Static water level—The natural water level in a well that has not been affected by pumping.

Topography[1]—The general configuration of a land surface or any part of the earth's surface.

Total dissolved solids—The weight of all dissolved solids per unit volume of water, commonly reported in milligrams per liter. Water with high concentration of dissolved solids is often unpalatable, and its usefulness for many other purposes may also be limited. The concentration of dissolved solids can usually be estimated from the specific conductance.

Vugular porosity—Porosity due to vugs in carbonate rocks. Vugs are cavities, often with a mineral lining of different composition than the surrounding rock.

Well yield—The quantity of water a well can produce (commonly reported in gallons per minute).

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[1] This definition is adapted from Bates and Jackson (1980).

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