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Ground Water in the Kentucky River Basin

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Donald C. Haney, State Geologist and Director
UNIVERSITY OF KENTUCKY, LEXINGTON

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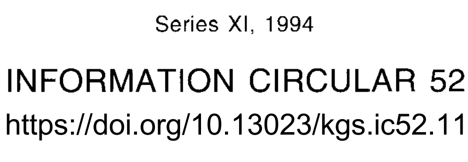

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GROUND WATER IN THE KENTUCKY RIVER BASIN

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ABSTRACT

Most private wells in the Kentucky River Basin are in unconfined or semi-confined bedrock aquifers. Within these aquifers, high-yield zones are irregularly distributed. The most productive wells are drilled into fractured bedrock and alluvium along the Kentucky River floodplain. The data indicate that ground water acts as a buffer to peak and low flows in Kentucky River Basin streams. At current withdrawal rates, ground-water usage does not seem to have an adverse impact on the Kentucky River. Privately owned ground-water sources supply approximately 135,000 people living in the basin-approximately 19 percent of the total population and 36 percent of the rural population. More than 50 percent of residential water supplies in eastern Kentucky rely on ground water. If aquifers are protected from pollution by wellhead protection programs and old wells are retrofitted to prevent direct contamination, then ground water will continue to provide a reliable water supply in many rural areas of the basin. However, for most of the basin, few wells will have yields adequate to supply a large demand. Ground water from present wells will not provide an adequate supply for communities with a population of over a few thousand. Limited discharge data available for springs and large wells in the basin strongly suggest that the potential for ground water to supplement current supplies should not be ignored. Discharge from well fields and springs could be used to augment surface supplies during drought. A better understanding of the distribution and quality of ground-water resources is crucial for the citizens of the basin to fully benefit from ground water.

INTRODUCTION

The availability and quality of *ground water* in the Kentucky River Basin are controlled by the geology of the basin and affected by the activities of those who live in the basin. The amount of water available from a well or spring is determined by the *hydrogeologic* properties of the *aquifer.* The quality of the water is influenced by the aquifer material, modifications to the aquifer caused by activities such as mining, and contamination from sources outside the aquifer. Ground water may be unfit to drink because of naturally occurring constituents such as salt or hydrogen sulfide, or because of pollutants introduced by humans, such as fecal coliform bacteria, nitrates, and pesticides.

The Kentucky Geological Survey (KGS) has in recent years completed a number of studies on various aspects of ground water in the Kentucky River Basin. These investigations have covered such diverse topics as the effects of oil production on water quality, high barium concentrations in ground water of eastern Kentucky, ground-water geochemistry in eastern Kentucky, a reconnaissance of ground-water resources, the relationship between ground water and surface water in the basin, production of fresh water from the Knox Group, and the quality of water from privately owned wells. This report presents a summary of the KGS research, together with additional information from local, State, and Federal sources. The report includes up to-date information on ground-water usage and the potential for developing additional ground-water supplies, an overview of ground-water quality, an examination of human activities that may threaten ground-water resources, and a discussion of contaminants that occur naturally in the basin.

A glossary of terms is included. The first appearance of a glossary term in the text is *italicized.*

HYDROGEOLOGY OF THE KENTUCKY RIVER BASIN

General Characteristics

The Kentucky River Basin drains an area of about 7,000 square miles (Plate 1), and includes all or parts of 42 counties. The river flows from the mountains of southeastern Kentucky northwestward through the rolling topography of central Kentucky to join the Ohio River near Carrollton in north-central Kentucky. The river, including the North Fork, is about 405 miles long. Along its course, the Kentucky River cuts through rocks and sediments that span about 460 million years of geologic time. The rocks in the Kentucky River Basin are of different types, and have different hydrogeologic properties, *mineralogy,* and structure. To a great extent these rocks define the characteristics of the ground-water aquifers in the basin.

The geology of the basin is described in detail by 161 geologic quadrangle maps, published at a scale of 1:24,000 by the U.S. Geological Survey (USGS) in cooperation with the Kentucky Geological Survey. More general geologic maps at scales of 1:250,000 and 1:500,000 have also been published.

Plate 1 is a generalized hydrogeologic map of the Kentucky River Basin. Each map unit represents a group of lithologic units that behave in a hydrogeologically similar manner. For example, the Ordovician limestones of the Inner Blue Grass and the Mississippian limestones of the Cumberland Escarpment are included in Unit 1 since they have similar properties. Table I lists geologic units that occur in the Kentucky River Basin, corresponding aquifer units, and lithologic descriptions.

Along Pine Mountain in eastern Kentucky, small tributaries of the Kentucky River originate from springs at the base of Upper Mississippian limestones exposed by the Pine Mountain thrust fault. In other areas of the headwater region, sandstones, siltstones, shales, and coals, typical of the Middle Pennsylvanian Breathitt Formation, are exposed along the three main forks and for a few miles down the main stem of the river. Elevated sulfate levels in the region's ground water are related to the occurrence of sulfide minerals, particularly pyrite, in the Breathitt Formation rocks. The irregularly distributed, coarse-grained sandstones of the Lower Pennsylvanian Lee Formation are mainly exposed in Jackson, Lee, and Wolfe Counties. This lithology (Plate 1, Unit 2) forms one of the major aquifers of the region (Price and others, 1962). The Mississippian limestones, which also include major aquifers, are once again exposed in eastern Madison, Estill, Powell, and Menifee Counties, (Plate 1, Units 1, 5, and 7).

Farther downstream the geology changes significantly. Lower Mississippian rocks, predominantly shales, siltstones, and dolomite, are exposed; most are poor water-storing and water-transmitting rocks (Plate 1, Unit 7). An exception is the Renfro Member of the Borden Formation (Unit 1), which commonly has springs draining the overlying limestones. Also, the lower members of the Borden have fine-grained sandstone zones, which locally act as aquifers. At the base of the Lower Mississippian is the New Albany Shale, a Mississippian-Devonian black shale containing abundant sulfide minerals (Plate 1, Unit 4). The New Albany produces some water from joints (fractures), but it is usually of poor quality. Below the New Albany are Middle Devonian and Silurian shales, dolomites, and limestones (Plate 1, Units 1 and 5). Where limestones and dolomites are of sufficient thickness and solubility, some domestic wells drilled into them obtain adequate water supplies.

Upper Ordovician units are exposed along the course of the river in Madison and Clark Counties (Plate 1, Unit 8). These rocks are composed largely of shale, limestone, and siltstone and form very poor aquifers. However, north of the Kentucky River Fault System, the bedrock changes again. Middle Ordovician limestones are exposed in the uplands and along the gorge of the Kentucky River (Plate 1, Unit 1). These rocks are relatively pure limestones in which caves and sinkhole terrane (karst) form. Karst is characterized hydrologically by a general absence of small tributary streams and the presence of large springs near major streams.

In Franklin County, the gentle dip of the strata changes to the northwest, and the Middle Ordovician limestones dip below the bed of the Kentucky River near Lockport. From there to the Ohio River the silty Upper Ordovician carbonates, interbedded with shale, crop out (Plate 1, Units 8 and 6). As in Clark and Madison Counties, here these rocks form poor aquifers. However, the alluvial deposits along the Kentucky River thicken toward the Ohio River (Plate 1, Unit 3). These alluvial units consist of unconsolidated silt, sand, clay, and gravel deposited by the river. Where the alluvium contains sand or gravel lenses, an aquifer is formed that is continually *recharged* by the surrounding upland and by infiltration from the river.

Table 1. Geologic units along the Kentucky River (from Currens and others, 1991).

Age	*Stratigraphic Name*	*Aquifer Units (Plate 1)*	*Description*
Quaternary	Alluvium and high-level terrace deposits (unconsolidated sediments)	3	Fluvial sands, silts, and clays in stream valleys or as terraces or upland remnants of terraces.
Pennsylvanian	Breathitt Formation	9	Shale, siltstone, sandstone, coal, and minor limestone.
	Lee Formation	2	Massive sandstone. Discontinuous.
Mississippian	Pennington Formation	5	Shale, siltstone, sandstone, and limestone.
	Newman Limestone	1, 8	Limestone and shale.
	Borden Formation	1, 7	Shale, siltstone, and dolostone.
Mississippian-Devonian	New Albany Shale (Ohio Shale)	4	Fissile black shale.
Devonian	Boyle Dolomite	1	Dolostone, fractured, and with minor solution features. Locally absent.
Silurian	Crab Orchard Formation	5	Shale and dolostone.
	Brassfield Dolomite	1	Dolostone.
Ordovician	Drakes Formation	6	Dolostone and shale.
	Grant Lake Limestone and Ashlock Formation	6 6	Limestone and shale. Laterally equivalent units.
	Calloway Creek Limestone and Fairview Formation	6 6	Limestone and shale. Laterally equivalent units.
	Clays Ferry Formation, Garrard Siltstone, and Kope Formation	8 7 6	Limestone, shale, and siltstone in widely varying proportions. In part, laterally equivalent units.
	Lexington Limestone	1	Limestone, massive to thin-bedded, shaly. Locally has solution features.
	High Bridge Group	1	Massive limestone and dolostone with solution features. Bentonitic shales near top.
	Wells Creek Formation	*	Dolostone.
	St. Peter Sandstone	*	Sandstone. Usually absent.
Cambrian-Ordovician	Knox Group	*	Massive dolostone. Fractured and weathered zone in unconformity at top of unit.

*Units do not crop out in Kentucky; present in subsurface beneath the basin.

Major Aquifers in the Kentucky River Basin

Many aquifers in the Kentucky River Basin are unconfined aquifers: they receive their recharge from precipitation percolating vertically downward. The quantity of water obtained from an aquifer is a function of its saturated thickness and *specific yield.* The major unconfined aquifers along the Kentucky River are the sandstones of the Pennsylvanian Breathitt and Lee Formations, the karst aquifers in the Ordovician Lexington Limestone and formations in the High Bridge Group of the Inner Blue Grass, and the alluvium along the Kentucky River.

Semi-confined aquifers also occur in the basin. These aquifers have rock units above them that restrict the movement of ground water. Recharge occurs where the aquifer crops out or is hydraulically connected to the surface through fractures. Slow recharge also occurs through the confining beds. Ground-water storage is determined by the pressure *head* in the aquifer and *storativity* of the unit, which is a measure of the aquifer's compressibility. *Hydrostatic* pressure is sometimes related to aquifer depth below the recharge area. The deeper aquifers are generally under greater pressure. Large pressure changes over extensive areas are normally required to produce substantial water yields from *confined* aquifers. Confined aquifers occur in the Lee sandstones and also in the Knox Group, which at its shallowest depth near Clays Ferry in Madison County lies roughly 250 feet below the bed of the Kentucky River.

Pennsylvanian Aquifers

Wells in the sandstones of the Lee and Breathitt Formations are among the best producers of ground water in the basin (Mull, 1965; Quinones and others, 1981). Except where salty water is encountered at shallow depth, the Lee Formation may produce quantities of fresh water greater than 500 gallons per day (gpd) from wells drilled in valleys. In some areas the sandstones of the Lee Formation are bounded by shales and form confined or artesian aquifers.

Plates 1 and 2 indicate that there are no high-yield wells known in the Lee Formation along its western outcrop in the basin. There are three possible explanations for this. First, high-yield but undocumented wells may exist in the area. Second, water-quality problems caused by the proximity of several major oil fields may have discouraged development. Third, the relatively sparse population in the area has not needed large quantities of ground water. Thus, there may be some potential for future ground-water development in the Lee Formation.

Ordovician Aquifers

Wells and springs in the Inner Blue Grass karst aquifers can produce significant quantities of water: tens to thousands of gallons per minute (gpm). However, wells drilled in any karst aquifer must intercept a conduit, or an enlarged fracture, to have significant production. Siting such wells can be difficult because conduits and fractures below the surface are generally not easily located. Conversely, springs that gather water from large drainage basins provide reliable quantities of water. Unfortunately, unless the drainage basin of the spring is protected, the water may become polluted.

The Knox aquifer (Kipp, in preparation) is composed of Cambrian and Ordovician carbonate rocks of the Knox Group. The top of the Knox Group is as much as 300 feet above sea level on the crest of the Cincinnati Arch in central Kentucky. Water is normally found in the upper 100 to 250 feet of the group in secondary porosity apparently associated with the unconformity at the top. Water is confined and rises to an elevation of about 500 feet above sea level in wells completed in the Knox in this area.

Knox wells in the Inner Blue Grass near the crest of the Cincinnati Arch yield water with relatively low dissolved solids, generally 500 to 3,500 milligrams per liter (mg/L). Dissolved solids concentrations generally in crease away from the Inner Blue Grass to the southeast, south, and west, where the Knox can be oil-bearing, and commonly exceed 10,000 mg/L throughout most of the remainder of the State. Although this overall pattern is consistent, local variability in water quality between relatively close wells is common, and only a few wells produce water with less than 1,000 mg/L dissolved solids.

Yields from Knox wells commonly range between 5 and 40 gpm. Because the Knox aquifer can provide modest quantities of water with less than 1,000 mg/L dissolved solids along the crest of the Cincinnati Arch, it is a potential source of water for individual rural domestic supplies in the central Blue Grass Region. But the limited yield of the existing wells indicates the Knox does not hold much promise for supporting larger public, community, or private industrial supplies.

Quaternary Aquifers

Wells in the alluvium of the Kentucky River may produce quantities of water sufficient for small industrial sites and small public water supplies. The water is produced from discontinuous sand and gravel deposits that commonly extend into the bed of the river. Pumping water from these wells can cause water to infiltrate from the river. The alluvial deposits filter the water, reducing the requirements for water treatment. Ground water flowing from upland areas toward the river also contributes to the alluvial aquifer.

Lithologic and Structural Control

Different rock types (lithologies) with different hydrogeologic properties are exposed along the course of the Kentucky River. Storativity and *hydraulic conductivity,* two hydrogeologic properties, also vary within lithologic units. These properties determine the usefulness of an aquifer. The shaly strata of the Outer Blue Grass impede the flow of ground water, and hence the productivity of a well. In the Eastern Kentucky Coal Field, bedrock is usually more weathered and fractured along stream valleys, resulting in enhanced porosity and *permeability.* Also, because aquifers in this area are unconfined, ground-water flow is generally from the ridge crests toward the valley. Therefore, water wells are more likely to be productive if situated in a stream valley.

One important advantage of using ground water is its continued availability during seasonal droughts. As a broad generalization, water in unconfined aquifers moves from areas of higher elevation to lower elevation, eventually discharging into a wetland, lake, or stream. This is analogous to the surface drainage system except for two significant differences: the rock area contributing flow to the ground-water system is much greater than the area of a stream channel, and the movement of water through aquifer materials is much slower than in a stream channel. These factors result in a much larger storage volume of ground water than surface water and a delay of weeks, months, or years between periods of low rainfall and depletion of groundwater supplies. Thus, by the time a seasonal drought ends, although *static water levels* may be dropping, there can still be a supply of ground water.

Relationship Between Ground Water and Surface Water in the Basin

Ground water flowing into stream channels sustains flow in the stream during droughts. This relationship was examined for the Kentucky River using historical weather data and flow data from main-stem and headwater monitoring stations. The level of detail of the study was necessarily restricted to regional phenomena since historical flow data exist at only a limited number of sites. This regional approach provides a basic understanding of the hydrology of the basin, and also provides guidance in determining areas where more detailed studies would be beneficial.

Long-Term Regional Hydrology

Flow data for the North, South, and Middle Forks of the Kentucky River; Locks 14,10,8, 6,4, and 2; and the Red River and Elkhorn Creek were used to analyze the hydrologic conditions in the basin. At least 30 years of daily flow data were available from all sites, and 84 years of data were available for Lock 10. There is, of course, a high correlation between mean annual flows at the different gaging stations along the river. This correlation allowed the historical data to be extended, using statistical methods, so that data estimates for mean annual flow were available for the 84-year period from 1907 to 1990 at each gaging station. Flow data from the North ' South, and Middle Forks were summed to represent the 2,360-square-mile headwater area. Based on the location of gaging stations, sub-regions were determined as shown on Figure 1, and are defined below:

Region 1: Combined North, South, and Middle Fork drainage areas at the Jackson, Booneville, and Tallega gages operated by the USGS, respectively.
Region 2: Drainage area between Region 1 and the USGS gage at Lock 14.
Region 3: Red River drainage area above the USGS gage at Clay City.
Region 4: Drainage area between Regions 2 and 3 and Lock 10.
Region 5: Drainage area between Lock 10 and Lock 8.
Region 6: Drainage area between Lock 8 and Lock 6.
Region 7: Drainage area between Lock 6 and Lock 4.
Region 8: Elkhorn Creek drainage area to the USGS gage near Frankfort.
Region 9: Drainage area between Regions 7 and 8 and Lock 2.

Flows for these regions are calculated as the difference between downstream and upstream flows. For example, the long-term average flows at Locks 4 and 6 are 7,059 cubic feet per second (cfs) and 6,701 cfs, respectively (Fig. 2b). This means that an average of 6,701 cfs flows into Region 7 and an average of 7,059 cfs flows out. Thus, we may infer that Region 7 produces an average net flow contribution of 358 cfs to the river.

We cannot compare different flows-1,000 cfs from one region and 2,000 cfs from another region-unless we can relate those flows to the size of the contributing areas. This basis for comparison is accomplished by dividing the water yield by the area of the region, resulting in the water yield per unit area, in cubic feet per second per square mile (csm). If the csm from one region is different from the csm from another region, then we know the two regions are hydrologically different in some way. Figures 2c and 3 show the average runoff per square mile from the different regions in the basin. For the whole basin down to Lock 2, the average runoff is 1.33 csm.

Rainwater may follow one of several paths after falling to the ground: it may evaporate or be transpired through vegetation to the air *(evapotranspiration);* it may run across the surface directly to a stream; it may infiltrate into the ground and return as streamflow in the region; or it may infiltrate to a deeper, regional groundwater aquifer and return to streamflow in a lower region. The average streamflow at Lock 2, 1.33 csm, is equivalent to 18.1 inches of rainfall over the basin in 1 year. Thus, of the 46 inches of average annual precipitation, about 40 percent returns to streams either as direct runoff or from a ground-water source (ground-water *discharge).*

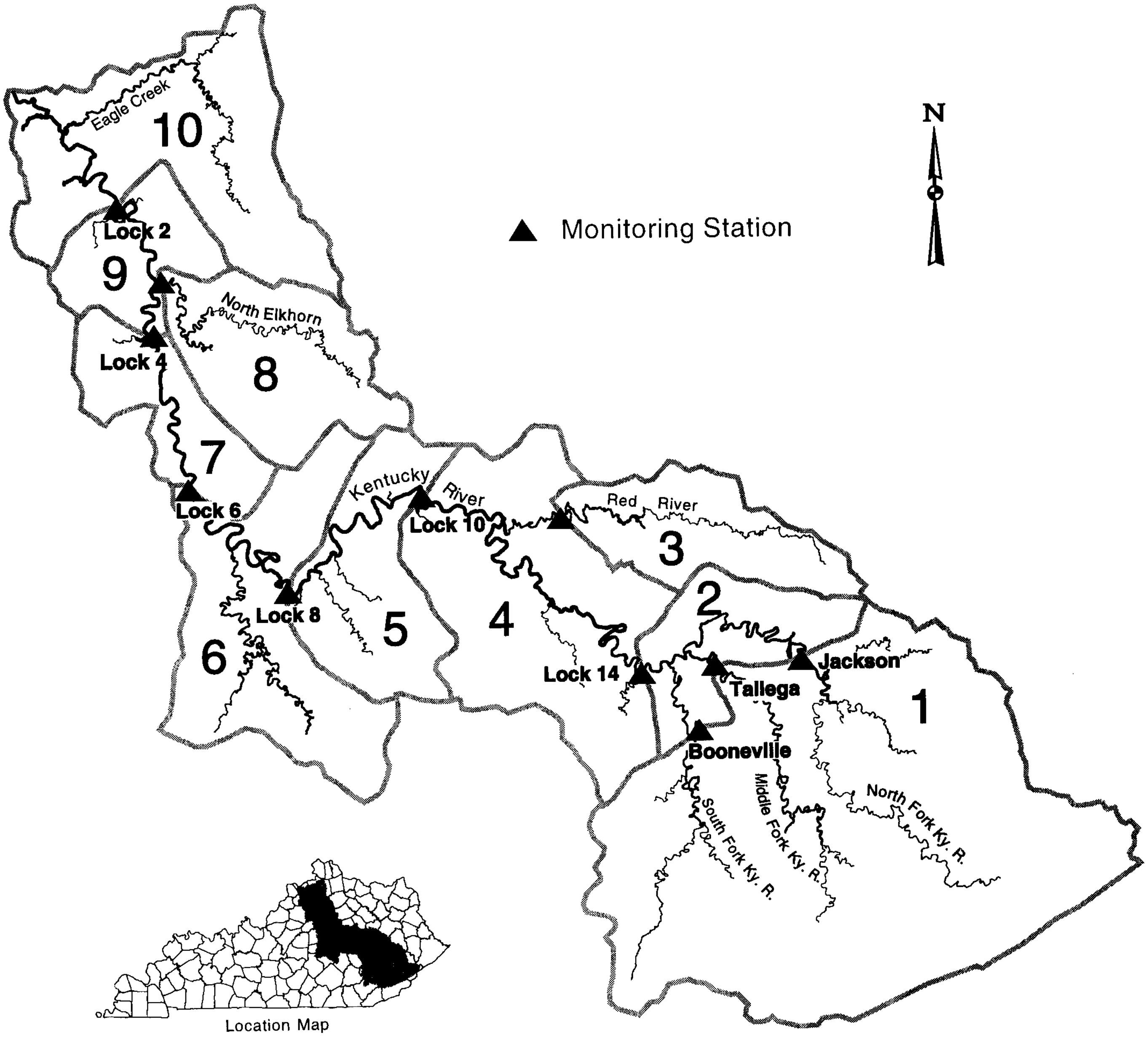
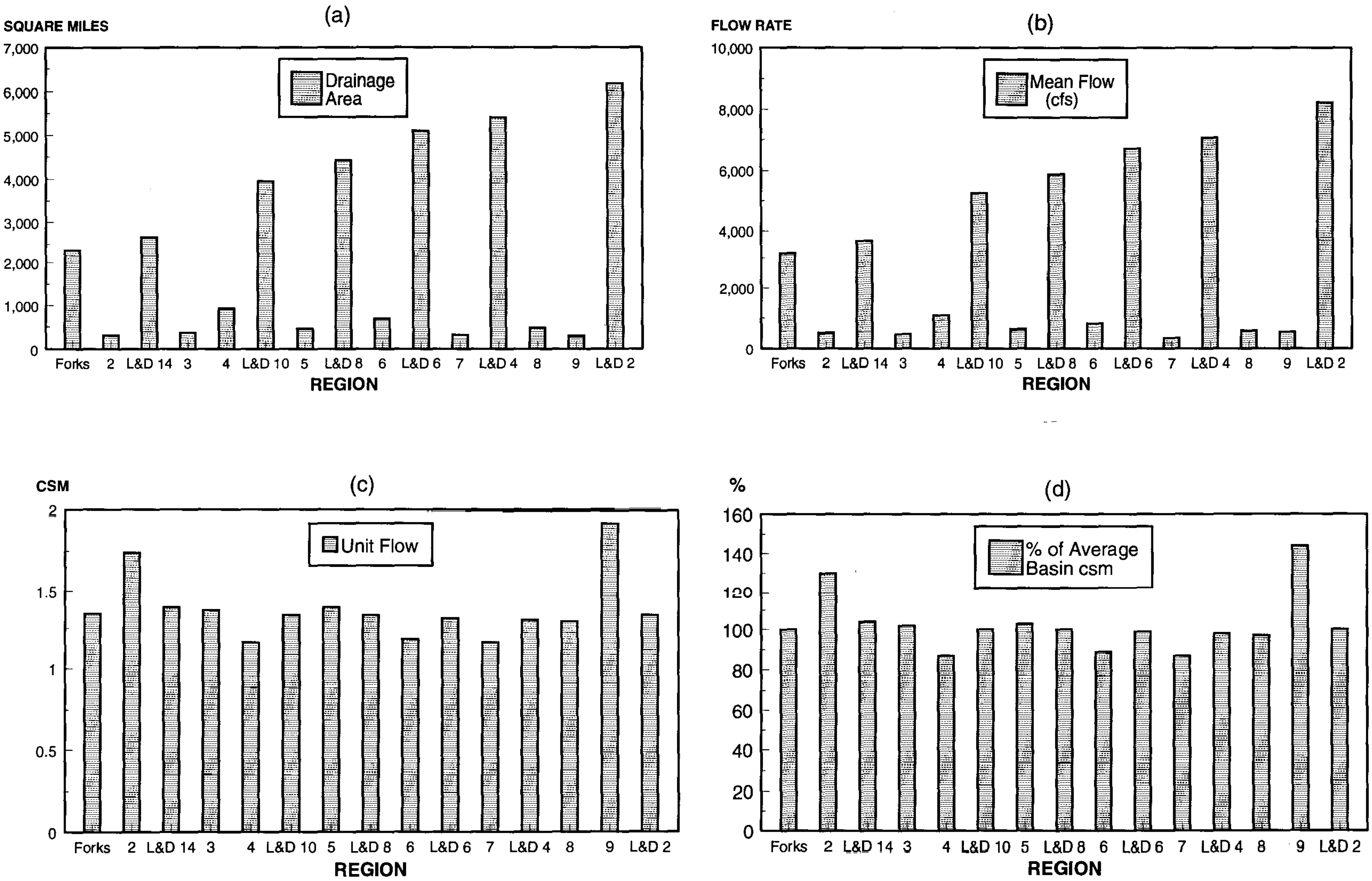


Figure 1. Sub-regions of the Kentucky River Basin.

Variations in csm between regions, as shown in Figure 3, may result from differences in rainfall, evapotranspiration, or ground-water flow. Although average rainfall is slightly higher in the southeastern mountains, so also is evapotranspiration, so differences in csm between regions due to rainfall or evapotranspiration should not be large. Based on rainfall and evapotranspiration, the amount of flow from each region per square mile should be about the same. In other words, the average amount of flow from a region should be proportional to its area. Figure 2d shows that this relationship is nearly exact for Regions 1, 3, 5, and 8. Average flows of 1.29 to 1.38 csm for Regions 1, 3, 5, and 8 are near the basin-wide average. Flows from Regions 4, 6, and 7-ranging from 1.16 to 1.18 csm-are less than their corresponding drainage areas would suggest. These regions apparently contribute to the recharge of deeper aquifers, possibly through the regional fault system. The average flows from Regions 2 and 9, 1.74 and 1.92 csm, respectively, are notably greater than their drainage areas would suggest. In Region 2 ground water from the Lee Formation sandstones, which crop out along the North Fork of the Kentucky River in Lee County, appears to provide additional flow. The higher



Note: csm = cubic feet per second per square mile. Forks = Drainage area of North, South, and Middle Forks of the Kentucky River.

Figure 2. Regional flow characteristics of the Kentucky River Basin.

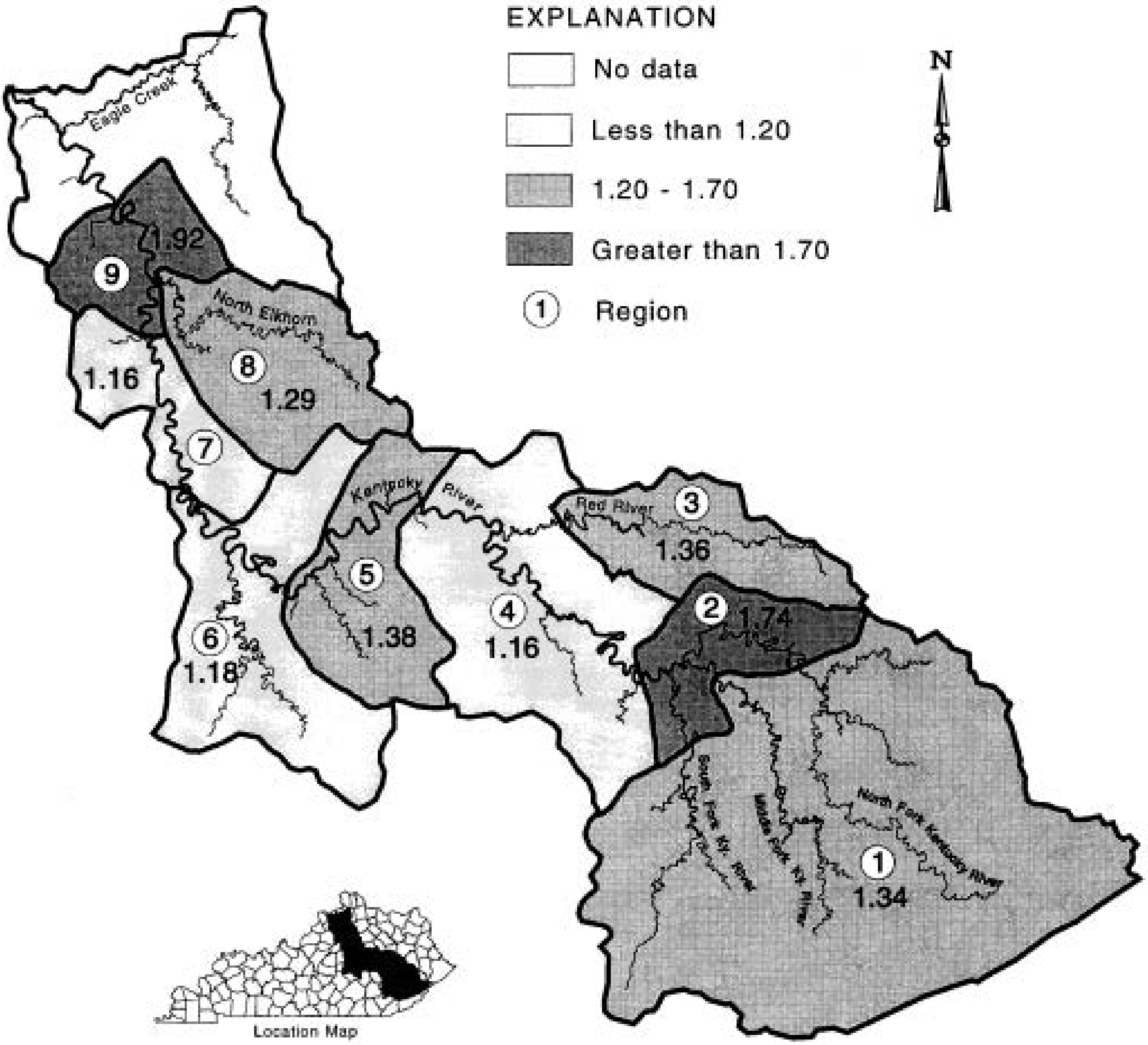


Figure 3. Regional water yield in cubic feet per second per square mile.

average unit flow from Region 9 is apparently due to ground-water discharge at outcrops along the Kentucky River from the Grier Limestone Member of the Lexington Limestone. Regions 7 and 8 are recharge areas for the Grier.

Relationship Between Ground Water and Surface Water During Droughts

In order to assess the relative importance of ground water in maintaining strearnflow from different regions in the Kentucky River Basin during drought conditions, published stream flow statistics for the 1953 drought were examined in detail (U.S. Geological Survey, 1953, 1954). The 1953 drought is the second most severe drought on record for the Kentucky River, and the most severe drought for which extensive stream flow data are available. (Many stream gaging stations in the basin were only started at the end of, or after, the drought of 1930, the most severe on record.) Aside from the locks and dams, Dix Dam was the only major control structure in operation during the 1953 drought. Flows downstream of the Dix River were adjusted to discount the effects of water released from Dix Dam (using USGS data).

Flows in the basin generally declined from June to October 1953, and remained low through mid-December 1953. Flow at Lock 10 for the period is shown in Figure 4. Normal flows at Lock 10 are 1,500, 930, 1,000, 2,700, and 5,900 cubic feet per second (cfs) for the months of August, September, October, November, and December, respectively. The 7-day, 10-year low flow (7Q10), or stream flow required to maintain water quality, at Lock 10 is 121 cfs. In 1953, flows at Lock 10 were at or below 121 cfs for the 129-day period from August 18 through December 25. Many creeks were completely dry during this time (Table 2).

Table 2. Dry streams in the Kentucky River Basin, 1953.

Stream	*Period of No Flow*
Troublesome Creek at Noble	October-November
South Fork of the Kentucky River at Booneville	October-November
Dix River at Danville	September-November
South Elkhorn Creek at Ft. Springs	September-November
North Elkhorn Creek at Georgetown	August-December
Eagle Creek at Glencoe	August-December

Rainfall data from Lexington, Heidelberg, Jackson, Hazard, and Hyden for the period are shown in Figure 5. The effects of rainfall on stream flows during the drought period were transitory, and, for the most part, main-stem flow for the period came from ground-water discharge. Rainfall at Lexington was about 42 percent below normal

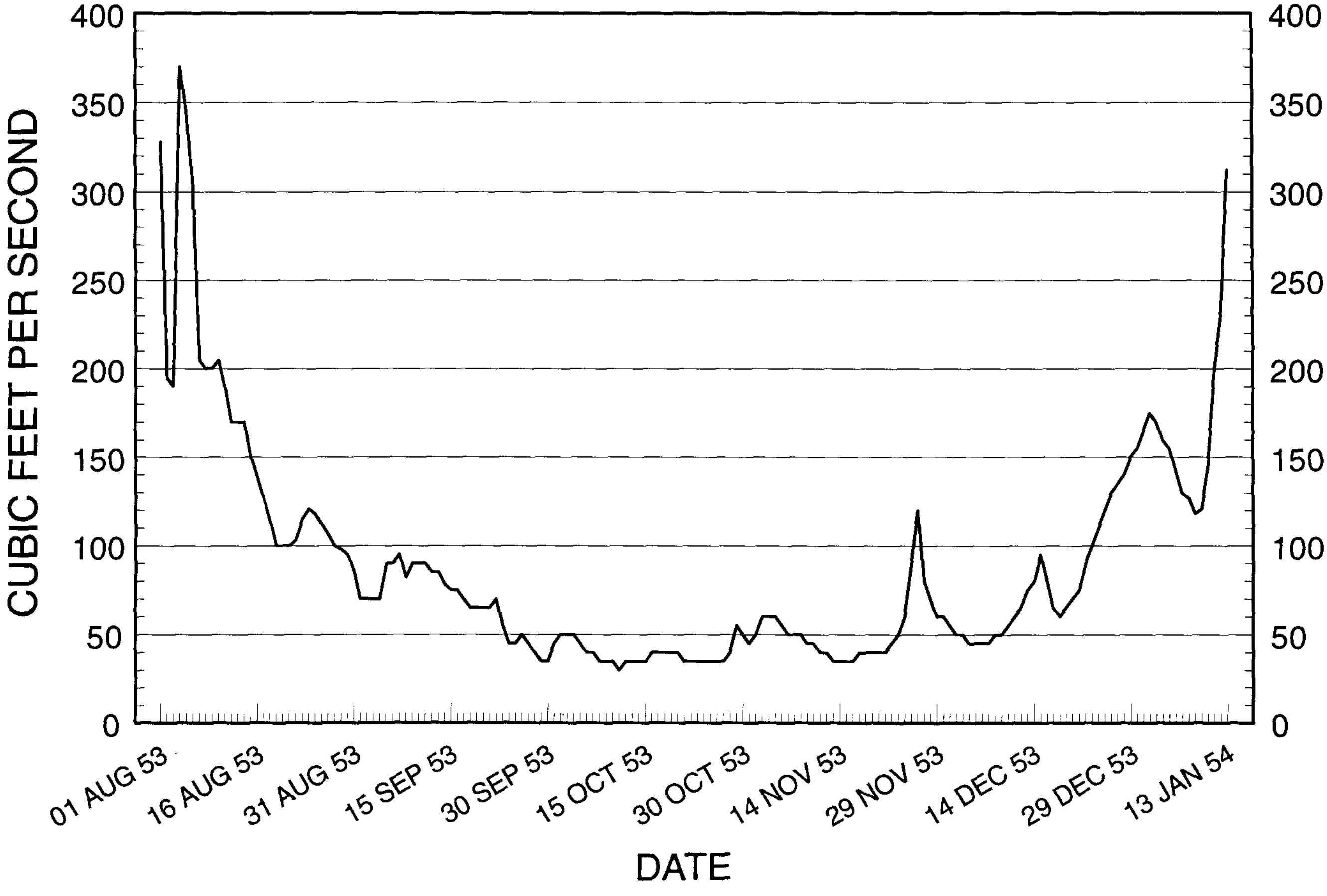


Figure 4. Average daily flow at Lock 10, Kentucky River.

from August through October, and rainfall in the Eastern Kentucky Coal Field was about 61 percent below normal.

Average daily flows in the basin from 1953 to 1954 are shown in Table 3. The interpretation of regional flow contributions is uncertain because of possible differential leakage rates from adjacent locks and dams (and subsequent refilling of below-normal pools). For instance, if Lock and Dam 4 did not leak, but Lock and Dam 5 leaked to the extent that its pool was drawn down, then the *drawdown* in pool 5 would be confused with flow contribution from Region 7. Since there is no information on the variations in pool levels for the 1953 drought, we assumed all locks and dams leaked at the same rate, if at all.

Lowest flows on the main stem of the Kentucky River occurred in October 1953. The minimum daily flow at Lock 10 was 30 cfs on October 11. The minimum flow at Lock 6 was 131 cfs, which occurred several times in October and November. Flows at Locks 6,4, and 2 were augmented by releases from Dix Dam. Mean monthly release rates from the dam were 26, 158, 137, 87, 147, and 323 cfs for July through December, respectively.

Average flow rates per square mile for each region of the basin during the drought are shown in Table 4. In general, flow dropped notably from June to October. Differences in flow rates per square mile for different regions indicate the relative importance of the region's ground-water discharge during low flows. Flow from Region 1 dropped severely from June to October. Flows from Regions 4 and 5 also dropped notably during the period. The Red River and Elkhorn Creek flows (Regions 3 and 8) also dropped steadily, but maintained a higher percentage of normal flow.

Flow in Regions 2 and 6 increased from August to October, with discharge rates per square mile two to three times higher than for the Red River and Elkhorn Creek. The increased flows represent an increase in ground-water flow from stream-bank aquifers. As the level of the river dropped, these aquifers drained at an increasing, albeit relatively small, rate. Regions 7 and 9 showed a net recharge from the river in June, and in October

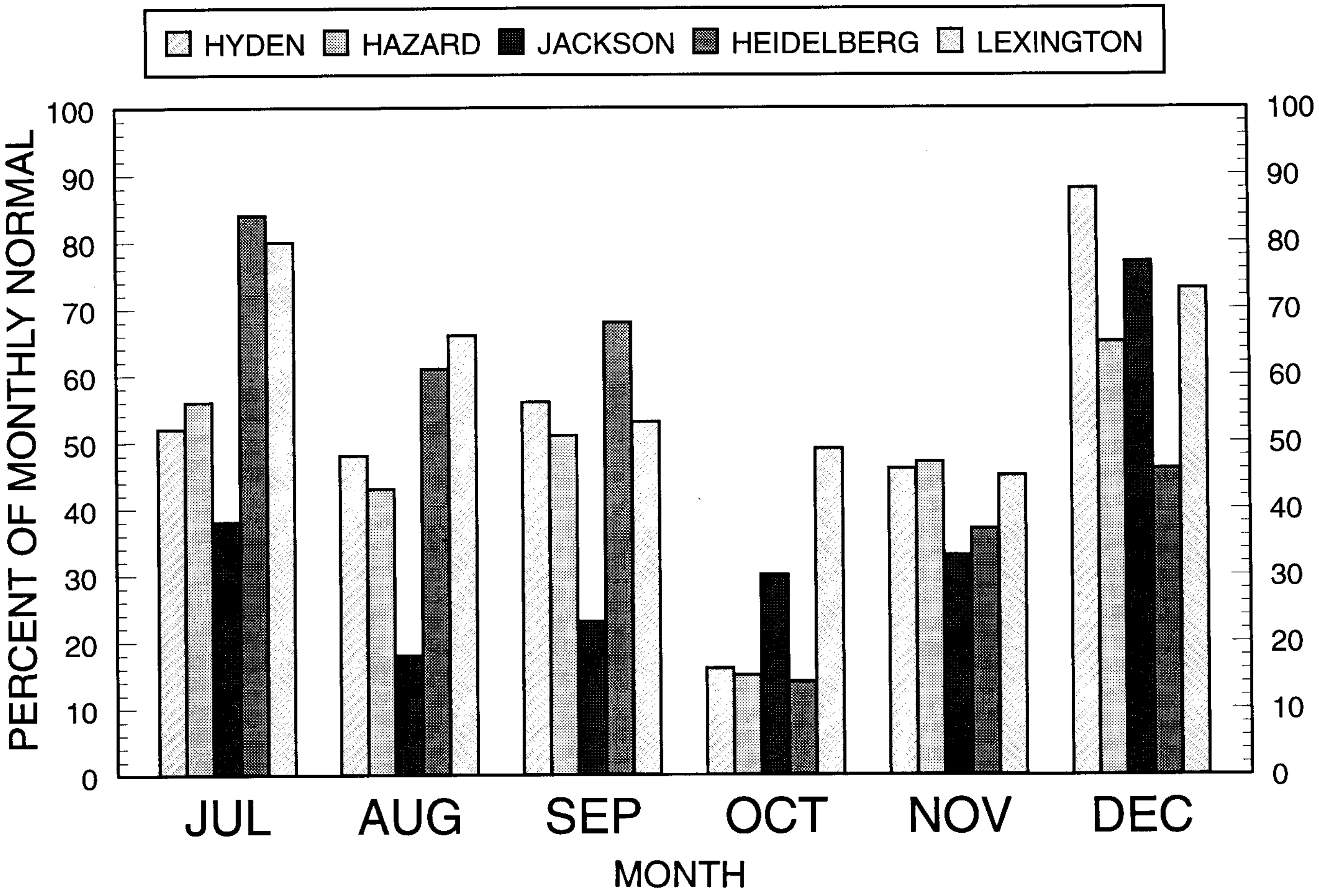


Figure 5. Rainfall in the Kentucky River Basin in 1953.

unit flow from these regions was two to seven times higher than from other regions, and about 46 times higher than unit flows from the headwaters.

During the 1953 drought the differences in flow contribution from different regions was more pronounced than during periods of normal flow (Fig. 6). The flows per square mile for Regions 2, 6, 7, and 9 in October were 200 to 500 percent of the basin-wide average. The geologic formations adjacent to the river, which are primarily responsible for base-flow maintenance, are:

Region 2: Corbin Sandstone Member of the Lee Formation (Unit 2 on Plate 1)
Region 6: Limestones of the High Bridge Group (Unit 1 on Plate 1)
Region 7: Limestones of the High Bridge Group andalluvium in Franklin County (Units 1 and 3 on Plate 1)
Region 9: Grier Limestone Member of the Lexington Limestone and alluvium (Unit 3 on Plate 1).

Regions 2, 6, 7, and 9 constitute 25.5 percent of the drainage area, but contributed 72.3 percent of the flow in October 1953 at Lock 2. Region 2 contains 11.2 percent of the drainage area above Lock 14, but contributed 75.8 percent of the flow at Lock 14 in October.

Figure 7 shows the daily flow hydrographs (plots of flow rate versus time) for Region 1 and for Lock 14. The difference between the two represents the net flow from Region 2. From August to mid-September flows at Lock 14 were fed by headwater flow. At mid-September, headwater flow dropped significantly, while flows at Lock 14 remained relatively stable. This represents a period of ground-water discharge from Region 2 to the river. Higher headwater flow near the end of November raised flow at Lock 14, but there was a strong attenuation of the hydrograph (indicating some recharge of Region 2). On December 7, headwater flows increased dramatically for about 10 days. Flows at Lock 14 did not rise proportionately, and the normal relationship between headwater flow and flow at Lock 14 did not return until the first of January. More than 5,200 acre-feet, or 1,700 million gallons, appears to have gone into recharge to the ground-water aquifers in Region 2 that had been partially depleted in September, October, and November.

Although Regions 2,6,7, and 9 appear to be of significantly greater importance during low flows, only Region 2 lies above points of significant water demand (Locks 8 through 14). Unfortunately, the amount of water flowing from Region 2 during a drought is quite small relative to downstream demands, and, therefore, its importance is negligible in terms of water supply. By comparing drought flow hydrographs with given demands, we can estimate what the water shortages would be if a given drought should recur.

Figure 8 shows the flow at Lock and Dam 10 during the drought. The area between the dashed line indicating water quality and the line indicating flow represents the amount of water required to maintain water quality (that is, the 7-day, 10-year low flow), which, during a 1953-magnitude drought, would be approximately 4.95 billion gallons (BG). In addition, about 344,000 people used an average of 52.6 million gallons per day (MG]D) in 1991 from pools 8 through 11 on the main stem of the Kentucky River. Reducing system leaks by 15 percent might reduce this requirement to 45 MGD. Conservation might reduce consumption another 20 percent, to 35 MGD. Finally, mandatory reductions might reduce consumption another 15 percent, to 30 MGD. Thirty MGD probably represents the minimum supply needed, and, in fact, is probably less than people would prefer for a 5- to 6-month period. The upper horizontally striped area of the figure represents these needs, about 4.19 BG. Thus, about 9.1 BG of water would be required to meet minimum demands during a recurrence of a drought as severe as that of 1953.

Table 3. Average daily flow (cfs) in the Kentucky River Basin, 1953–54.*

	Area (Figure 1)														
Month	*1*	*2*	*L14*	*3*	*4*	*L10*	*5*	*L8*	*6*	*L6*	*7*	*L4*	*8*	*9*	*L2*
May	6,942	959	7,901	784	1,735	10,420	810	11,230	2,244	13,474	310	13,784	996	1,084	15,864
June	565	90	655	108	719	1,482	269	1,751	298	2,049	-14	2,035	174	-46	2,163
July	341	76	417	65	349	831	172	1,003	236	1,239	-7	1,232	75	66	1,373
August	59	6	65	21	80	165	62	227	12	239	62	301	25	73	399
Sept.	24	10	34	9	26	69	20	89	22	111	5	116	9	63	188
Oct.	5	17	22	6	12	40	6	46	27	73	29	102	9	27	138
Nov.	17	2	19	10	24	53	11	64	46	109	34	143	15	35	193
Dec.	134	-84	49	20	14	83	9	92	81	173	59	232	25	83	340
Jan.	3,312	208	3,520	269	946	4,735	310	5,045	689	5,734	199	5,933	318	28	6,279

*Corrected for Dix Dam releases

Table 4. Average daily flow per square mile (CSM) in the Kentucky River Basin, 1953–54.*

	Area (Figure 1)														
Month	*1*	*2*	*L14*	*3*	*4*	*L10*	*5*	*L8*	*6*	*L6*	*7*	*L4*	*8*	*9*	*L2*
May	2.942	3.229	2.974	2.166	1.854	2.635	1.765	2.544	3.262	2.641	1.003	2.547	2.106	3.662	2.567
June	0.239	0.303	0.247	0.298	0.768	0.375	0.586	0.397	0.433	0.402	-0.045	0.376	0.368	-0.155	0.350
July	0.145	0.255	0.157	0.178	0.373	0.210	0.375	0.227	0.343	0.243	-0.023	0.228	0.159	0.223	0.222
August	0.025	0.020	0.024	0.057	0.085	0.042	0.135	0.051	0.017	0.047	0.201	0.056	0.052	0.248	0.065
Sept.	0.010	0.034	0.013	0.024	0.028	0.017	0.045	0.020	0.032	0.022	0.016	0.021	0.019	0.212	0.030
Oct.	0.002	0.057	0.008	0.016	0.013	0.010	0.013	0.010	0.037	0.014	0.094	0.019	0.020	0.090	0.022
Nov.	0.007	0.005	0.007	0.027	0.026	0.013	0.024	0.014	0.066	0.021	0.110	0.026	0.031	0.120	0.031
Dec.	0.057	-0.285	0.019	0.054	0.015	0.021	0.020	0.021	0.117	0.034	0.191	0.043	0.053	0.280	0.055
Jan.	1.403	0.700	1.325	0.743	1.011	1.197	0.675	1.143	1.001	1.124	0.644	1.096	0.672	0.095	1.016

*Corrected for Dix Dam releases

The drought of 1930 was more severe at Lock 10 than that of 1953 (Fig. 9). In 1930 the flow at Lock 10 was less than the 7Q10 for 165 days. Water-quality needs for a drought this severe would be 7.8 BG, with 5.1 BG for consumption of 30 MGD, or a total of 12.8 BG. No known ground-water sources in the basin could provide quantities of water this large.

Regional ground-water sources could, on the other hand, influence river water quality. The water quality of Region 2 could significantly influence downstream river water quality during periods of low flow. Any water-quality problems created in Region 2 would be more strongly felt during a drought than during higher flow.

GROUND-WATER USE

Use of ground water in the Kentucky River Basin was estimated using data from the Kentucky Division

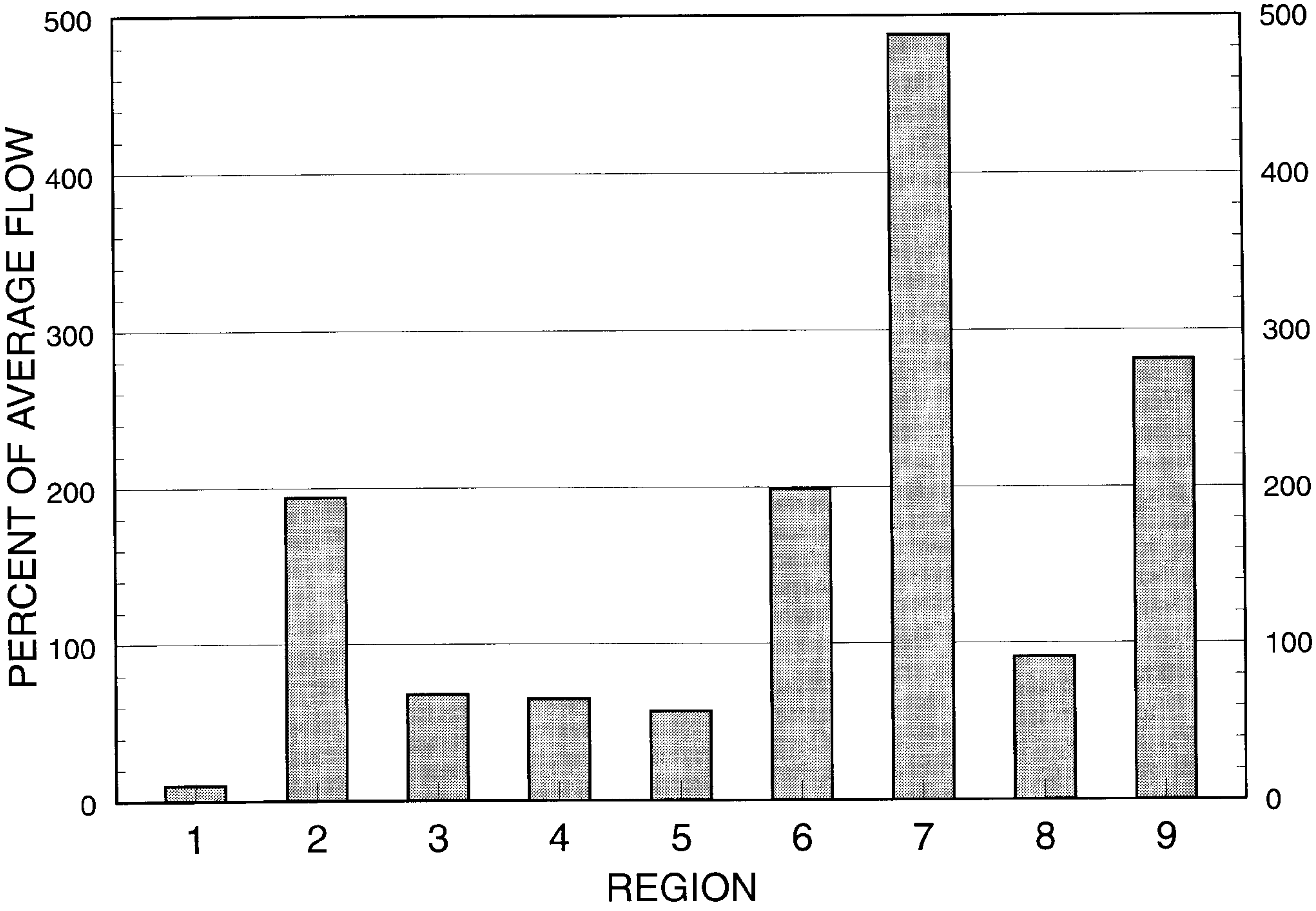


Figure 6. Percent of average flow in the Kentucky River Basin, October 1953.

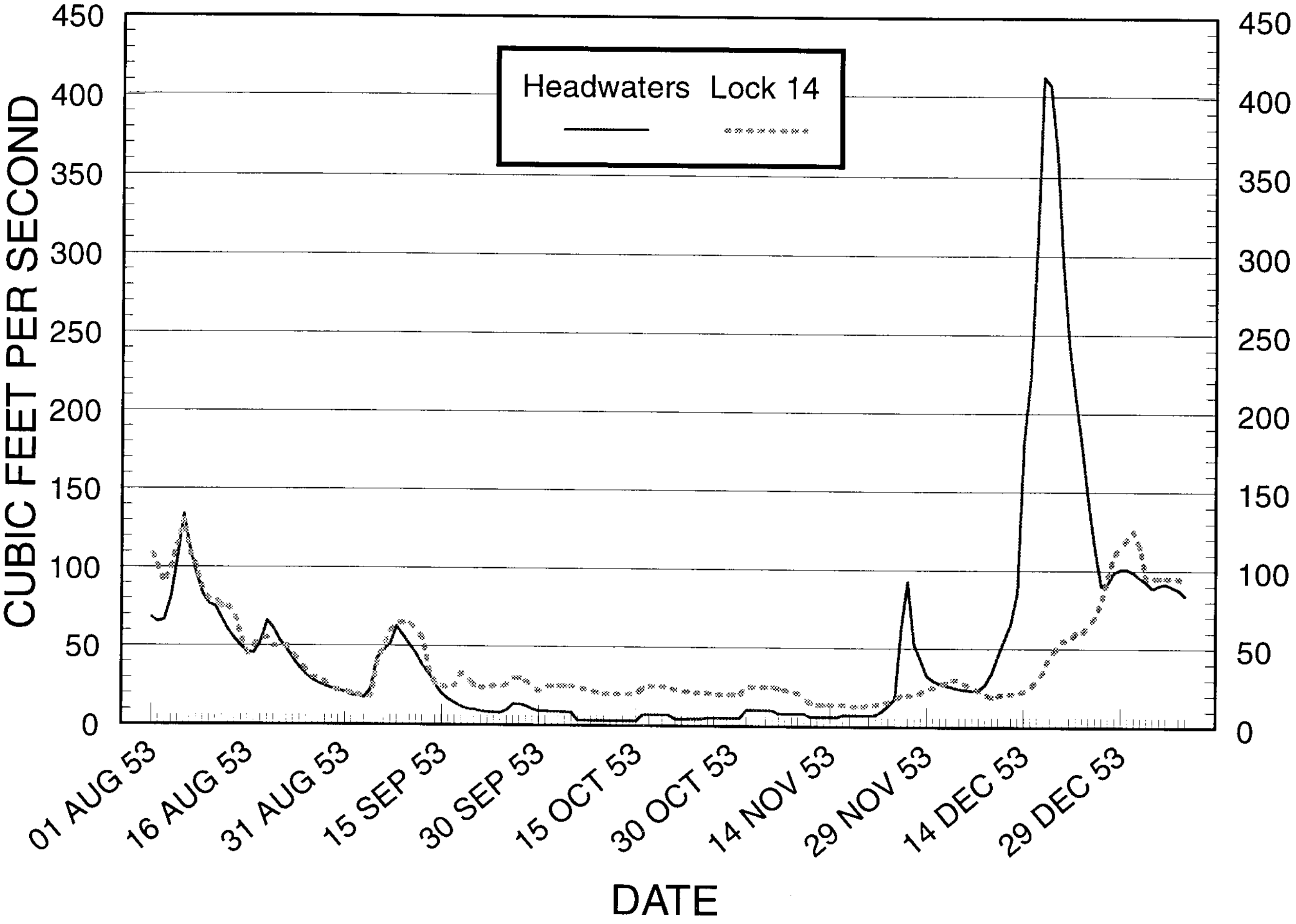


Figure 7. Average daily flows at the headwaters and Lock 14 of the Kentucky River.

of Water and the 1990 U.S. census (Table 5). About 24.5 percent of the population of the Kentucky River Basin depends upon ground water for domestic supplies. About 40,000 people are served by public ground-water supplies, and approximately 134,000 people rely on ground water from domestic supplies (Fig. 10). For comparison, about 535,000 people in the basin utilized publicly supplied surface water. Daily ground-water use in the basin, excluding that used for agriculture, is on the order of 10 MGD.

Figures 11 and 12 show that counties in the headwater region rely heavily on private, domestic wells, whereas counties in the Blue Grass Region are primarily served by public surface-water systems. A survey of about 400 private well owners in the Blue Grass Area Development District indicated that about 62.9 percent of the wells were used for domestic water, 65.8 percent for livestock, 11.0 percent for irrigation, and 8.4 percent for other uses (Carey and others, 1993). As part of the same survey, 472 well owners in the Kentucky River Area Development District indicated that about 94.5 percent of private wells were used for domestic water, 7.3 percent for livestock, 3.1 percent for irrigation, and 14.5 percent for other uses. (Since a well may have multiple uses, the percentages may exceed 100.)

Figures 13 and 14 show the total depth of water wells and the depth to water, respectively, for 2,170 typical wells in the basin.

GROUND-WATER QUALITY

The quality of ground water determines the suitability of that water for human consumption, livestock consumption, irrigation, and various industrial uses. One classification of ground water is based on total dissolved solids (Davis and DeWiest, 1966):

Types of Water

Name	*Concentration of total dissolved solids in parts per million (ppm)*
Fresh water	0–1,000
Brackish water	1,000–10,000
Salty water	10,000–100,000
Brine	more than 100,000

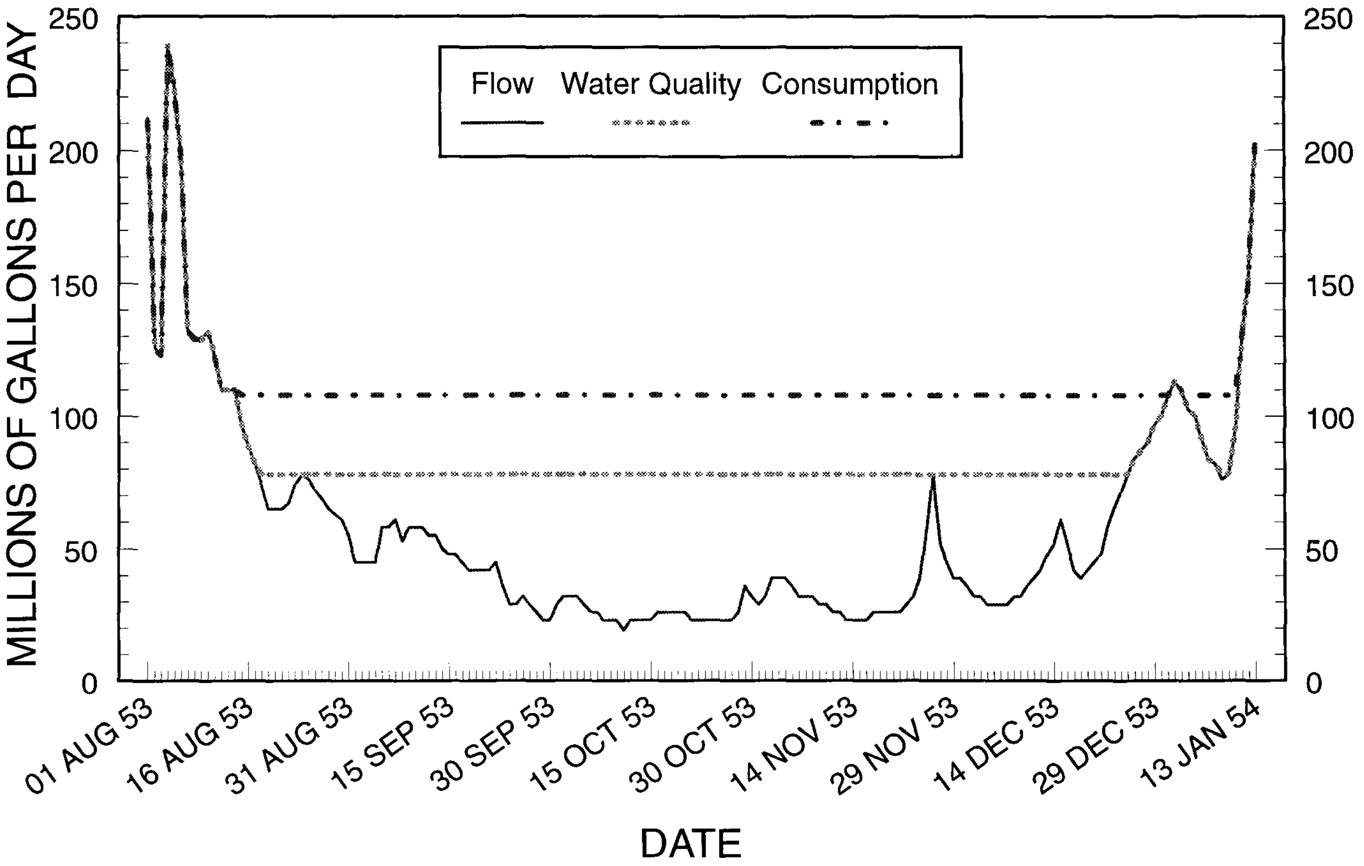


Figure 8. Flow deficit at Lock 10 of the Kentucky River during the drought of 1953.

Hopkins (1966) discussed the limitations on use of water based on total dissolved solids. Agricultulral uses of water include irrigating crops and watering livestock. All crops can be irrigated with water having total dissolved solids less than 525 ppm; most fruit and vegetable crops, except strawberries, apricots, green beans, celery, and radishes, and most forage crops, such as burnet, red clover, white Dutch clover, and ladine clover, commonly grown in Kentucky may be irrigated with water containing up to 1,400 pprn total dissolved solids.

Livestock can tolerate water of substantially poorer quality than humans can (500 mg/L recommended by U.S. EPA for human use). Upper limits of dissolvedsolids concentration (in ppm) in water to be consumed bv livestock are (Hopkins, 1966):

Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,000
Adult sheep	12,900

Many individual constituents are of concern for all of these uses. The use of lzround water may be limited by constituents that occur naturally, such as excessive iron or hardness, or it may be impaired as a result of human activities, such as improper disposal of wastes with subsequent pollution of ground water.

The chemistry of ground water in the Kentucky River Basin has been studied by a number of researchers. Several articles, theses, and dissertations, primarily focusing on the Inner Blue Grass and Eastern Kentucky Coal Field, have been completed. Detailed discussions of ground-water quality are found in Hendrickson and Krieger (1964), Mull (1965, 1968), Faust (1976), Quinones and others (1981), and Scanlon (1985,1989). Other water-quality data may be found in Faust and others (1980), Bienkowski (1990), Wunsch (1992), and in the USGS Hydrologic Atlas series: Hall and Palmquist (1960a-c), Palmquist and Hall (1960a-b), and Price and others (1962a-b).

Ground water is classified into types based on its dissolved mineral content. The following types occur naturally in the Kentucky River Basin: calcium-magnesiurn bicarbonate, sodium chloride, calcium-magnesium sulfate, sodium bicarbonate, and sodium sulfate. Wells drilled on ridge tops in the eastern half of the basin generally produce less water but may have fewer

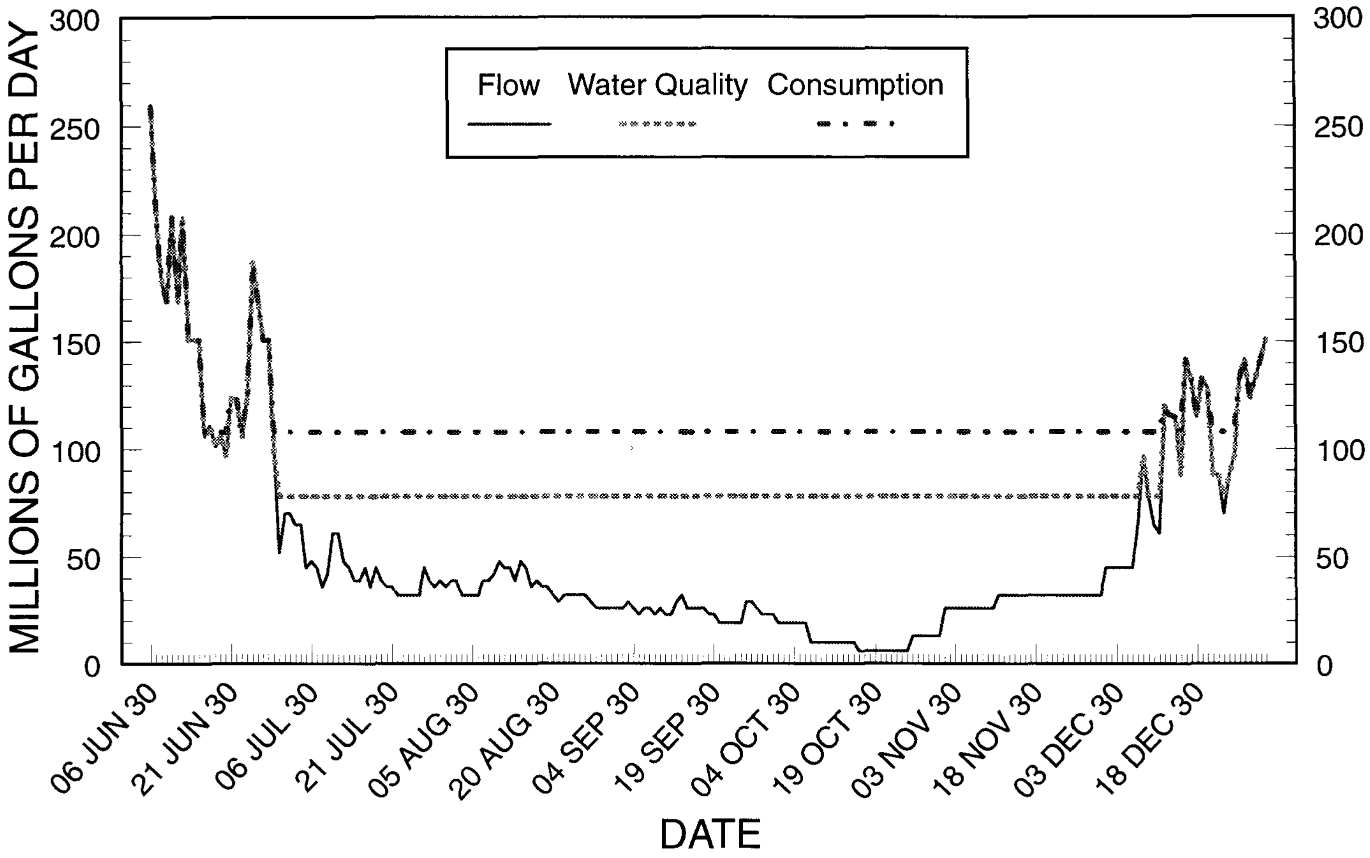


Figure 9. Flow deficit at Lock 10 of the Kentucky River during the drought of 1930.

Table 5. Summary of residential water data for the Kentucky River Basin (estimated from U.S. Census report, 1990).

1990 Basin Population	709,458	Urban	375,935	53.0% of total population
Average household size	2.45	Rural	333,523	47.0% of total population
Estimated population with public water: 575,744 81.2% of total population		Urban	375,935	100% of total urban
		Surface	361,746	96.2% of urban public
		Ground	14,189	3.8% of urban public
		Rural	199,809	59.9% of total rural
		Surface	173,829	87.0% of rural public
		Ground	25,980	13.0% of rural public
Self-supplied water: 133,714 18.8% of total population		Urban	0	0.0% of total population
		Rural	133,714	40.1% of total rural
		Wells	94,864	70.9% of rural self supply
		Other	38,850	29.1% of rural self supply

Population Served by Source						
Source	*Urban*		*Rural*		*Total*	*Total Percentage*
	Population	*Percentage*	*Population*	*Percentage*		
Surface	361,746	96.2%	173,829	52.1%	535,575	75.5%
Ground	14,189	3.8%	120,844	36.2%	135,033	19.0%
Other	0	0.0%	38,850	11.6%	38,850	5.5%
TOTAL	375,935		333,523		709,458	
30,727	individual drilled wells					
6,354	individual dug wells					
37,081	total wells					

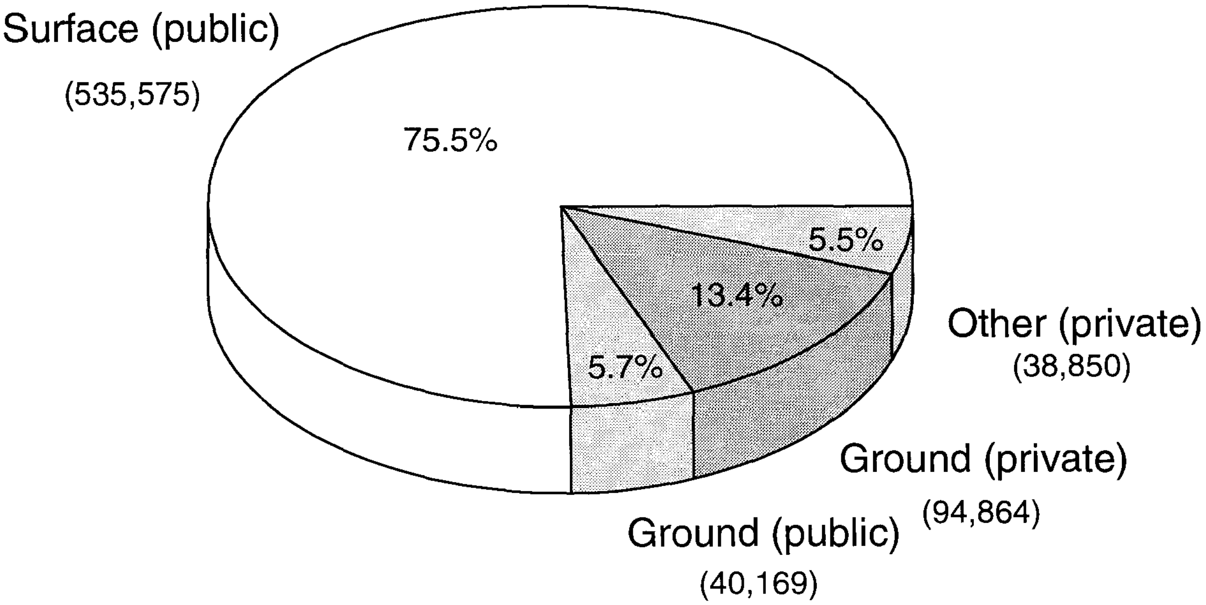


Figure 10. Percent of population served by drinking-water sources in the Kentucky River Basin. Number of users shown in parentheses.

dissolved minerals, while wells in valleys produce more water but tend to be more mineralized. Water from deeper wells is also, in general, more mineralized.

The quality of water from wells in the Blue Grass Region is highly variable because of the karstic nature of the aquifers. The aquifers are also susceptible to contamination. Deep wells in the karst areas commonly produce more highly mineralized ground water than shallow wells do. In general, however, well water quality depends on the local hydrogeology and the construction of the well.

Naturally Occurring Contaminants

Table 6, adapted from Palmquist and Hall (1961), lists some dissolved constituents in ground water, their source, and their significance. At some locations, the natural water quality may impose significant limitations on ground-water use.

In the Blue Grass Region, Palmquist and Hall (1961) found common salt in undesirable amounts in one in eight drilled wells and hydrogen sulfide in about one in five drilled wells. Hardness in the Blue Grass Region can exceed 1,000 mg/L of $CaC0_3$, and waters in most wells are hard or very hard because rocks in this area contain a large percentage of calcium carbonate. (See Table 6 for a definition of hardness.)

A common water-quality problem in eastern Kentucky is iron. Concentrations of iron in ground water range from 0.01 to 800 mg/L and commonly exceed the U.S. Environmental Protection Agency (EPA) recommended limit of 0.3 mg/L. Other common water-quality problems in eastern Kentucky are undesirable sulfate, chloride, and metal concentrations. Sulfate problems may occur in coal-mining areas. Sulfur-bearing minerals in the non-recovered coal and the rocks surrounding the coal oxidize and form iron and sulfuric acid in solution. Further reactions convert the sulfuric acid to sulfate in solution, which then precipitates iron and other metals. If this process occurs in a water well, bitter taste and stained fixtures and laundry may result, along with the possibility of other heavy metals remaining in solution or suspension. Elevated sulfate levels, not related to mining, may also occur in eastern Kentucky (Wunsch, 1992).

Barium and Fluoride in Ground Water In the Kentucky River Basin

Wunsch (1991) documented high concentrations of barium in the ground waters of eastern Kentucky. His survey of 130 wells tapping aquifers in Pennsylvanian, coal-bearing strata showed that 20 percent of the samples had barium concentrations in excess of the EPArecommended standard of 1.0 ppm. Barium affects the electrical and mechanical activity of muscle groups, especially the heart, in humans (Brenniman and others, 1979).

Wunsch (1991) showed that high-barium ground waters were restricted to drilled wells in bedrock. Samples from wells known to have high barium concentrations as well as those with low barium concentrations were analyzed, and showed high correlations between barium and sodium, calcium, and chloride. For the two

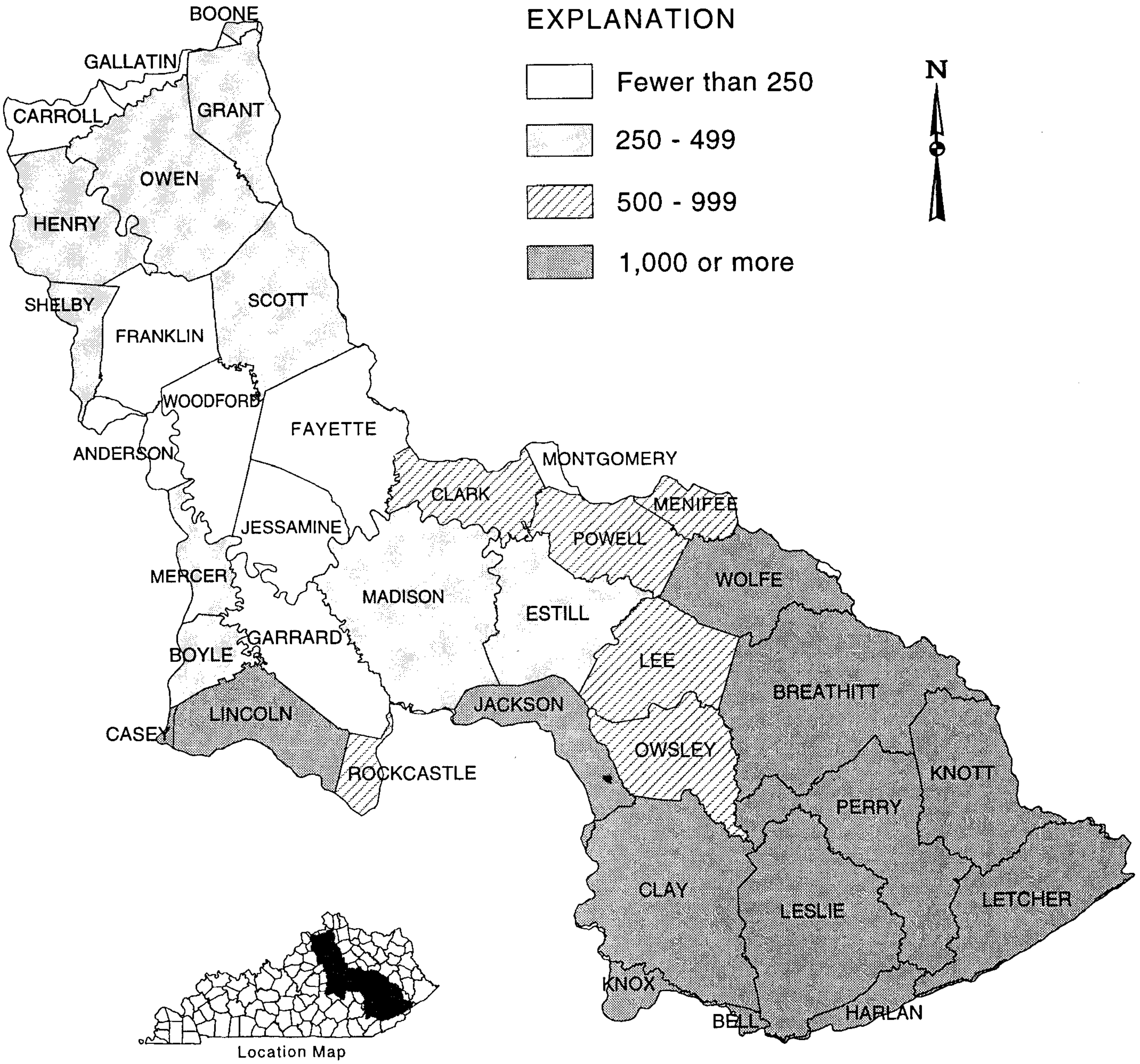


Figure 11. Water-well density in the Kentucky River Basin by county.

counties studied, wells in and around the town of Buckhorn, Kentucky, had the most samples with barium concentrations greater than 1 mg/L (mean barium concentration of 3.11 mg/L). The Buckhorn samples were also predominantly sodium-chlorine type waters.

Additional research by Wunsch (1992) showed that the risk of encountering ground water containing high barium concentrations increases if the water-producing well is located in a valley bottom near a major stream or river and encounters salty water with low sulfate concentrations. The increased ionic strength, or "saltiness" of the ground water, aids in the mobilization of the barium; that is, the salty water tends to keep the barium from precipitating out as barite. When sulfate is present in significant concentrations, it combines with barium to form the mineral barite (BaS04). Barite normally precipitates from the water, removing barium from the ground water. However, salty water created an environment that was conducive to the growth of sulfur-reducing bacteria, and these bacteria were then responsible for the consumption of sulfate and subsequent rise in barium concentrations. Isotopic analysis of sulfate, the presence of hydrogen sulfide, and low sulfate concentrations in ground water containing high

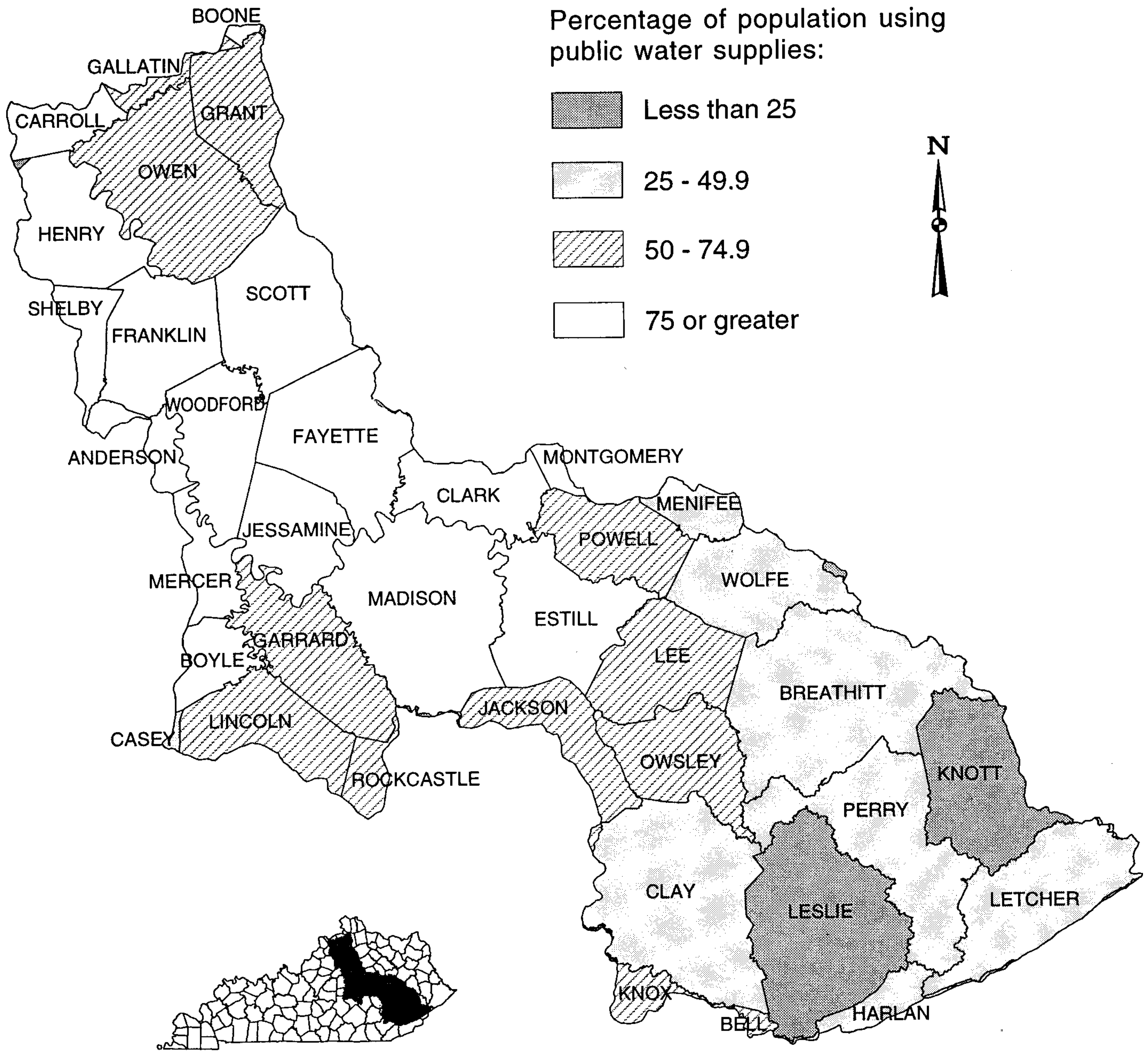


Figure 12. Usage of public water supplies in the Kentucky River Basin by county.

barium are further evidence in favor of this hypothesis. In addition, microbial analysis confirmed the presence of *Desulfovibrio,* a common type of sulfur-reducing bacteria.

Although most water softeners will remove barium from water, Wunsch (1991) suggested that well chlorination, and more important, a thorough well disinfection program, would help minimize barium concentrations in ground water by controlling the activity of sulfur-reducing bacteria.

Fluoride is a naturally occurring element in ground water in concentrations typically ranging from 0.1 to 20 mg/L (Freeze and Cherry, 1979). Municipal water supplies deficient in fluoride are commonly adjusted to the 1.0 mg/L range because of the beneficial effects on dental health. High concentrations (generally greater than 2.0 mg/L) can cause mottling of teeth, however. Skeletal fluorosis, which causes bones to become brittle, can occur if fluoride is present in concentrations greater than 10 mg/L.

Fleischer and Robinson (1963) examined the distribution of fluoride in ground water on a county-wide basis for each county in Kentucky. The data in their report indicate that some counties in eastern Kentucky

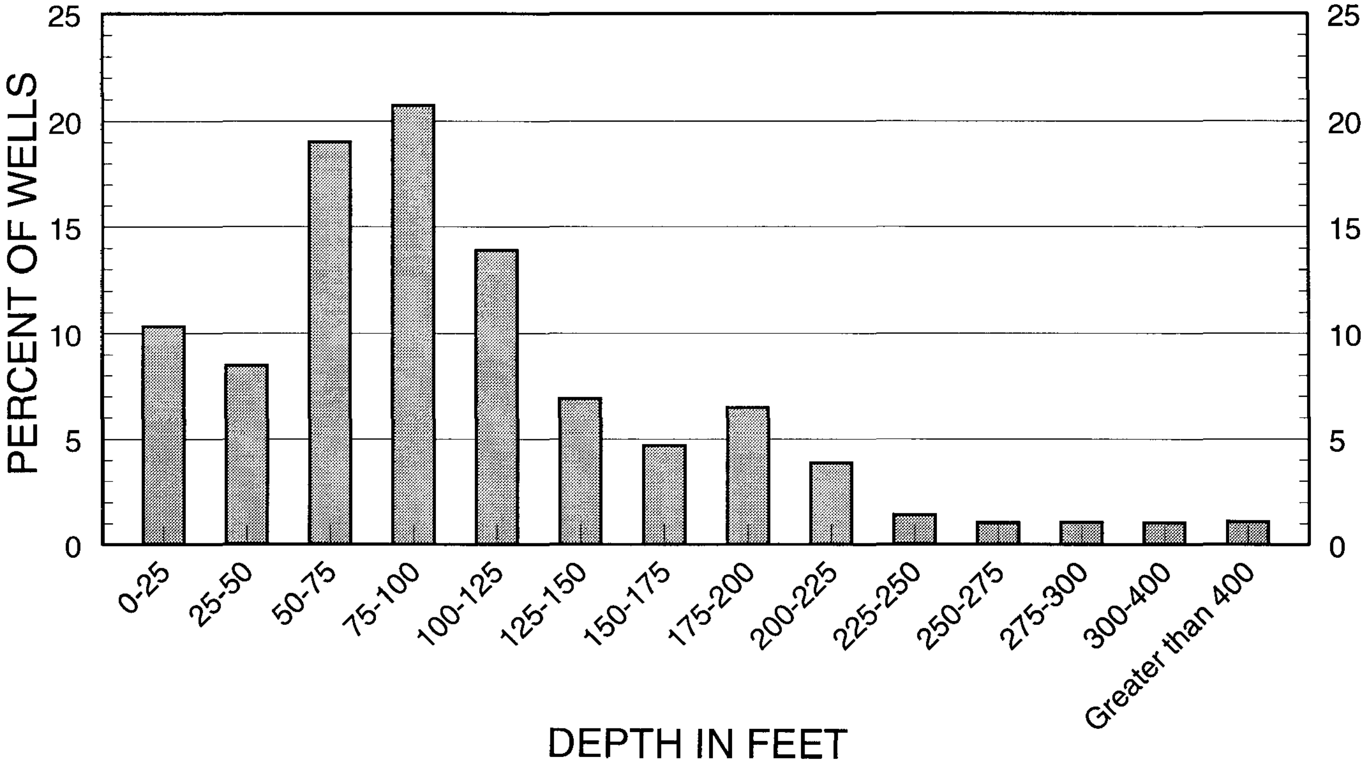


Figure 13. Percentage of wells in the Kentucky River Basin with total depth within given interval.

had fluoride values as high as 1.4 mg/L, while little or no data were available for other counties. Hopkins (1966) found fluoride concentrations as high as 2.6 mg/L, and concentrations frequently exceeded 0.3 mg/L in ground water in eastern Kentucky. Wunsch (1992) found fluoride concentrations as high as 2.1 mg/L.

These data do not indicate a health risk to groundwater users in eastern Kentucky. However, there may be areas where fluoride concentrations are significantly above 2.0 mg/L in eastern Kentucky. Corbett and others (1984) found fluoride concentrations as high as 5.9 mg/L in the coal-bearing rocks of eastern Ohio. The rocks that underlie eastern Ohio are very similar, both geologically and hydrogeologically, to the rocks that provide ground water in most of eastern Kentucky.

High fluoride concentrations are not restricted to eastern Kentucky; a well in the Knox Formation in Woodford County had a fluoride concentration of 11 mg/L, and several other Knox wells in central Kentucky had fluoride concentrations greater than 2 mg/L.

Ground-Water Contamination Caused by Human Activities

Oil and Gas Production

High chloride levels caused by salt-water intrusion into an aquifer can contaminate a well. This typically occurs in areas of petroleum production. A major source of salt-water intrusion is leaking oil wells. The pressurized fluid in the deep subsurface migrates through corroded casing or along poorly sealed casing into overlying fresh-water aquifers. Under KRS 353.550, the Kentucky Department of Mines and Minerals has the authority to set casing requirements for petroleum production wells. In many oil fields drilled prior to 1966, casing lining the well was pulled from abandoned wells for re-use, allowing salt water to migrate through the length of the hole and into fresh-water aquifers. This contamination can affect a large number of water wells in the immediate vicinity of an oil field. Also, during the pumping of petroleum wells brine is commonly brought to the surface along with the oil or gas. Brine from wells was formerly directly

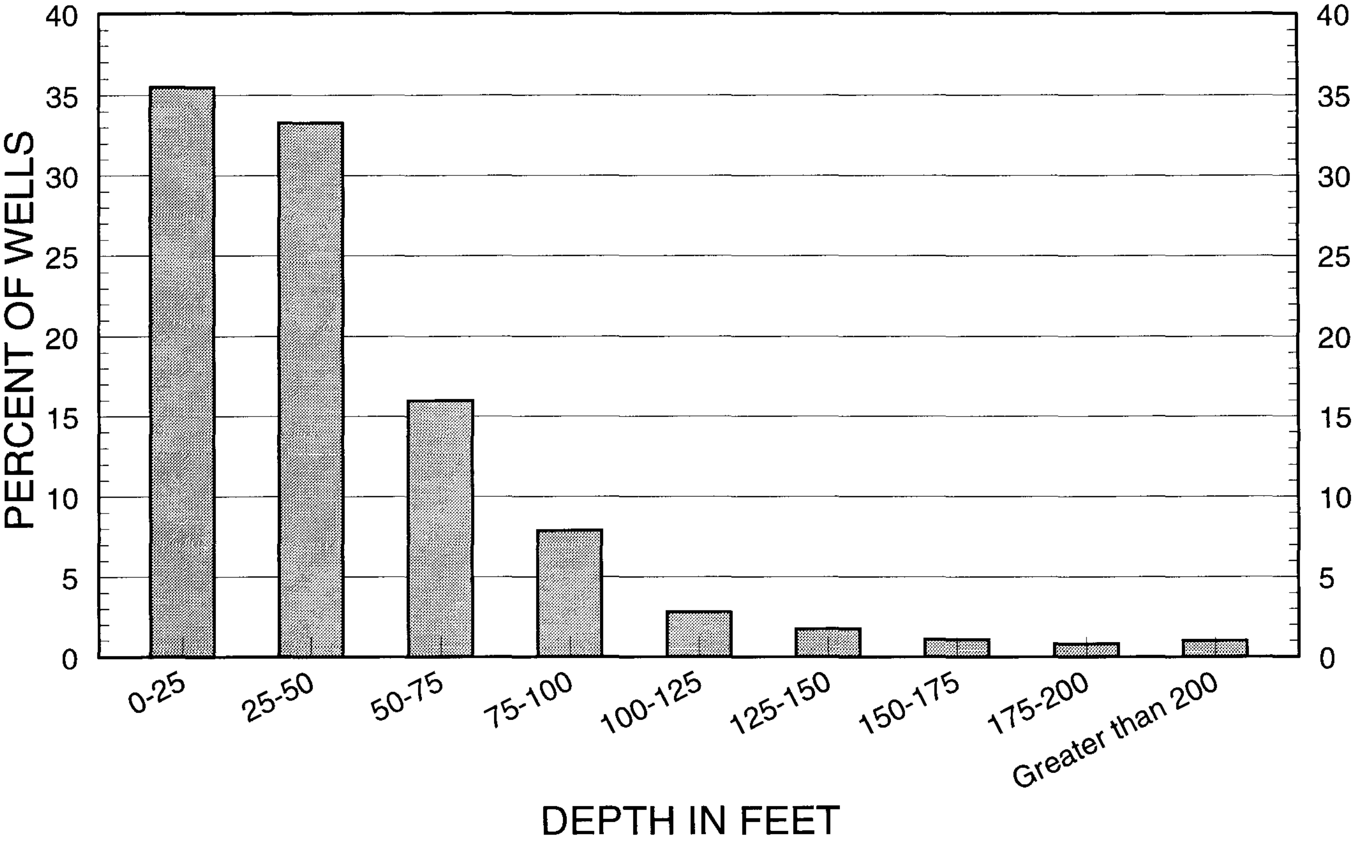


Figure 14. Percentage of wells in the Kentucky River Basin with depth to water within given interval.

discharged into streams, which affected shallow wells during dry periods. The fact that salt-water and sulfate contamination occur naturally in some areas (Hopkins, 1966) makes the determination of causes more difficult. Most oil wells in eastern Kentucky are stripper wells that produce less than 10 barrels of oil a day. Saline water is normally produced along with the oil. More than 10 barrels of saline water may be produced with each barrel of oil pumped from the ground. Kentucky regulations (401 KAR 5:090, Section 4) require the registration of petroleum-production facilities, including separators and storage tanks. Direct discharge of produced (saline) water to surface streams is allowed (within specified concentration limits) with a Kentucky Pollution Discharge Elimination System Permit from the Kentucky Division of Water (401 KAR 5:050 to 5:085). Injection of fresh water, or a mixture of fresh water and production water, into production formations for enhanced oil recovery is also a common practice. Reinjection is allowed by permit from the U.S. Environmental Protection Agency under the Underground Injection Control Program.

Petroleum production occurs in the headwaters of the Kentucky River, the headwaters of Millers Creek (eastern Estill County), and several tributaries of the Middle and South Forks of the Red River (Fig. 15). Tributaries of Millers Creek include Big Sinking Creek and Little Sinking Creek, which extend into western Lee County.

A reconnaissance study was completed by the Kentucky Geological Survey in 1985 to assess the effects of oil-brine disposal in the area between the Kentucky and Red Rivers. Based on this preliminary work, the Kentucky and U.S. Geological Surveys agreed to conduct an intensive cooperative study of ground water and surface water in that same region as part of the Kentucky River National Water Quality Assessment (NAWQA) Program. Synoptic water-quality sampling (done at a point in time, as opposed to over a long period of time) of surface waters throughout the Kentucky River Basin was also completed in both 1987 and 1988 as a part of the NAWQA Program. In addition, Bradfield and Porter (1990) indicated stream reaches in the Kentucky River Basin where aquatic biota were adversely affected by drainage from oil-production areas (Carey, 1992). Oil-brine pollution in surface streams was also documented in biannual reports to Congress (Kentucky Natural Resources and Environmental Protection Cabinet, 1984, 1986, 1988, 1990, 1992).

Table 6. Mineral constituents and their significance (modified from Palmquist and Hall, 1961).

Constituent	*Source or Cause*	*Significance*
Silica (SiO_2)	Dissolved from practically all rocks and soils, usually in small amounts from 1 to 30 ppm. High concentrations, as much as 100 ppm, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high-pressure boilers to form deposits in blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May be derived also from iron pipes, pumps, and other equipment. More than 1 or 2 ppm of soluble iron in surface water usually indicates acid mine wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown sediment. More than about 0.3 ppm stains laundry and utensils reddish brown. Objectionable for food processing, beverages, dyeing, bleaching, ice manufacture, brewing, and other processes. The MCL for iron in drinking water is 0.3 mg/L. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Manganese (Mn)	Dissolved from some rocks and soils. Not as common as iron. Large quantities often associated with high iron content and acid waters.	Same objectionable features as iron. Causes dark-brown or black stain. The MCL for manganese in drinking water is 0.3 mg/L.
Calcium (Ca) and magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in seawater.	Cause most of the hardness and scale-forming properties of water; soap consuming. (See "Hardness as $CaCO_3$.") Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and textile manufacturing.
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils. Found also in ancient brines, seawater, some industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers, and a high sodium ratio may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3)	Action of carbon dioxide in water on carbonated rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot-water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Usually present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. The MCL for sulfate in drinking water is 250 mg/L.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, seawater, and industrial brines.	In large amounts in combination with sodium gives salty taste to drinking water. In large quantities increases the corrosiveness of water. The MCL for chloride in drinking water is 250 mg/L.
Fluoride (Fl)	Dissolved in small to minute quantities from most rocks and soils.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the enamel, depending on the concentration of fluoride, age and susceptibility of the individual child, and amount of drinking water consumed. The MCL for fluoride is 1.5 mg/L.
Nitrate (NO_3)	Decaying organic matter, sewage, and nitrates in soil.	Concentrations much greater than the local average may suggest pollution. There is evidence that more than about 45 mg/L of nitrate may cause a type of infant cyanosis, sometimes fatal. Water of high nitrate content should not be used to feed babies. Nitrate has been shown to be helpful in reducing intercrystalline cracking of boiler steel. It encourages growth of algae and other organisms that produce undesirable tastes and odors.
Dissolved solids	Dissolved from rocks and soils. Chiefly mineral constituents. Includes any organic matter and some water of crystallization.	Drinking water standards recommend that dissolved solids not exceed 500 mg/L. Waters containing more than 1,000 mg/L of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	Most due to calcium and magnesium. Free acid and all the metallic cations other than the alkali metals also cause hardness.	Inhibits lathering of soap. Causes deposition of soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness of $CaCO_3$ is called noncarbonate hardness. Waters having a hardness up to 60 mg/L are considered soft; 61 to 120 mg/L, moderately hard; 121 to 200 mg/L, hard; more than 200 mg/L, very hard.

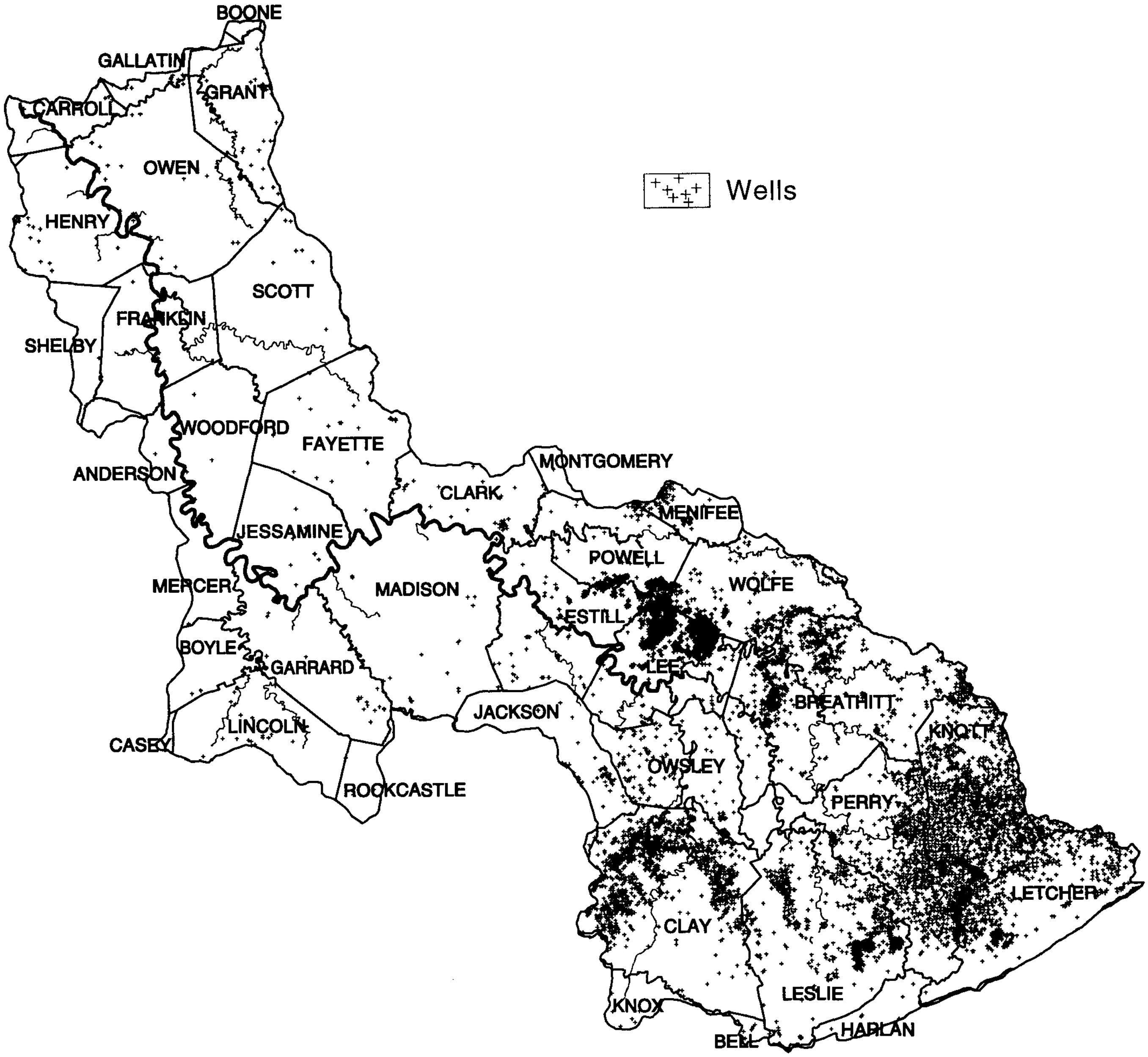


Figure 15. Locations of oil and gas wells in the Kentucky River Basin.

The goal of the intensive oil-brine segment of the NAWQA study was to describe the chemical nature of ground and surface water in active oil fields and to assess the effects of drainage from these fields on receiving waters of the Kentucky River Basin (Evaldi and Kipp, 1991). Three watersheds were included in the ground-water study. Big Sinking Creek and Furnace Fork had actively producing oil wells. The third watershed, Cat Creek, was used as a study control because it was adjacent to Furnace Fork and was underlain by similar geology, but no oil-production activities had taken place there.

Ground-water samples collected in the Furnace Fork watershed, which contained both oil-producing and non-producing sub-basins, indicated that shallow ground water was probably not widely affected by oil production. Water from springs, shallow bedrock wells, and hand-dug wells in the alluvium was usually the calcium-bicarbonate type. The *specific conductance* of nine springs and seven relatively shallow wells (3 to 63 feet deep) ranged from 50 to 440 microsiemens per centimeter (~tS/cm). Concentrations of constituents in water from these shallow wells and springs were also within the ranges reported by Hopkins (1966) as typical

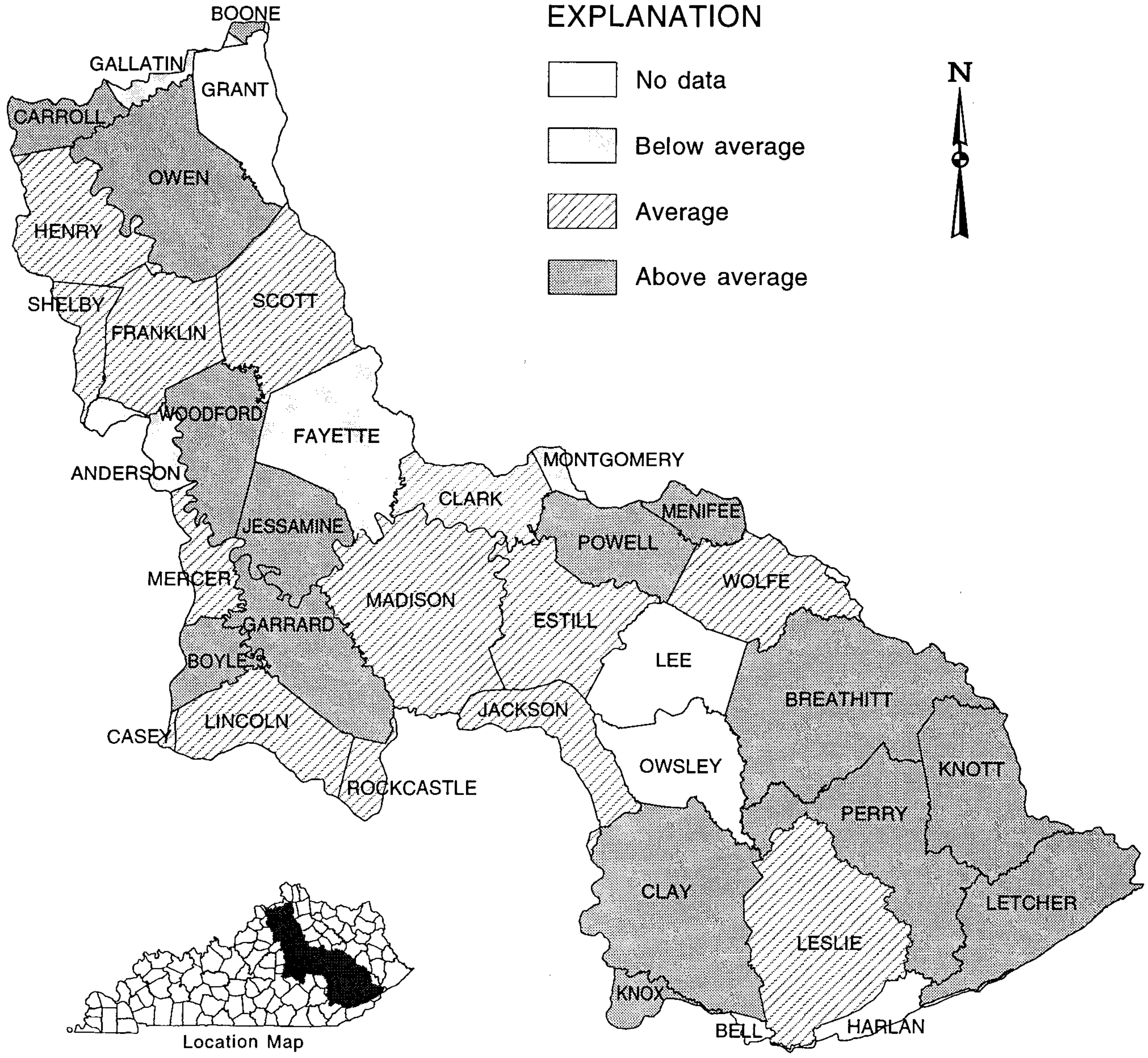


Figure 16. Average ammonia levels in private ground-water supplies by county in the Kentucky River Basin compared with Statewide averages.

for water above the fresh-water/saline-water interface in the area.

Water from deep wells, including oil-production water, was of the sodium chloride type. Analysis of water from deep water wells indicated a mixture of fresh water and saline water, but the source and pathway for the movement of the saline water was not obvious (Evaldi and Kipp, 1991). Water from the Devonian shale, which serves as a cap rock for the petroleum resources in the area, had a dissolved solids concentration in excess of 100,000 mg/L. Dilution of brine in the producing formation by fresh-water flooding for secondary oil recovery was suggested by dissolved solids concentrations that ranged from about 10,000 to 40,000 mg/L.

Although the adverse effects of oil production on surface-water quality in the Kentucky River Basin have been documented (Evaldi and Kipp, 1991), the overall effects of oil production on ground-water quality in the Kentucky River Basin are difficult to assess. Oil production has occurred for many decades, and information on the quality of water prior to the development of

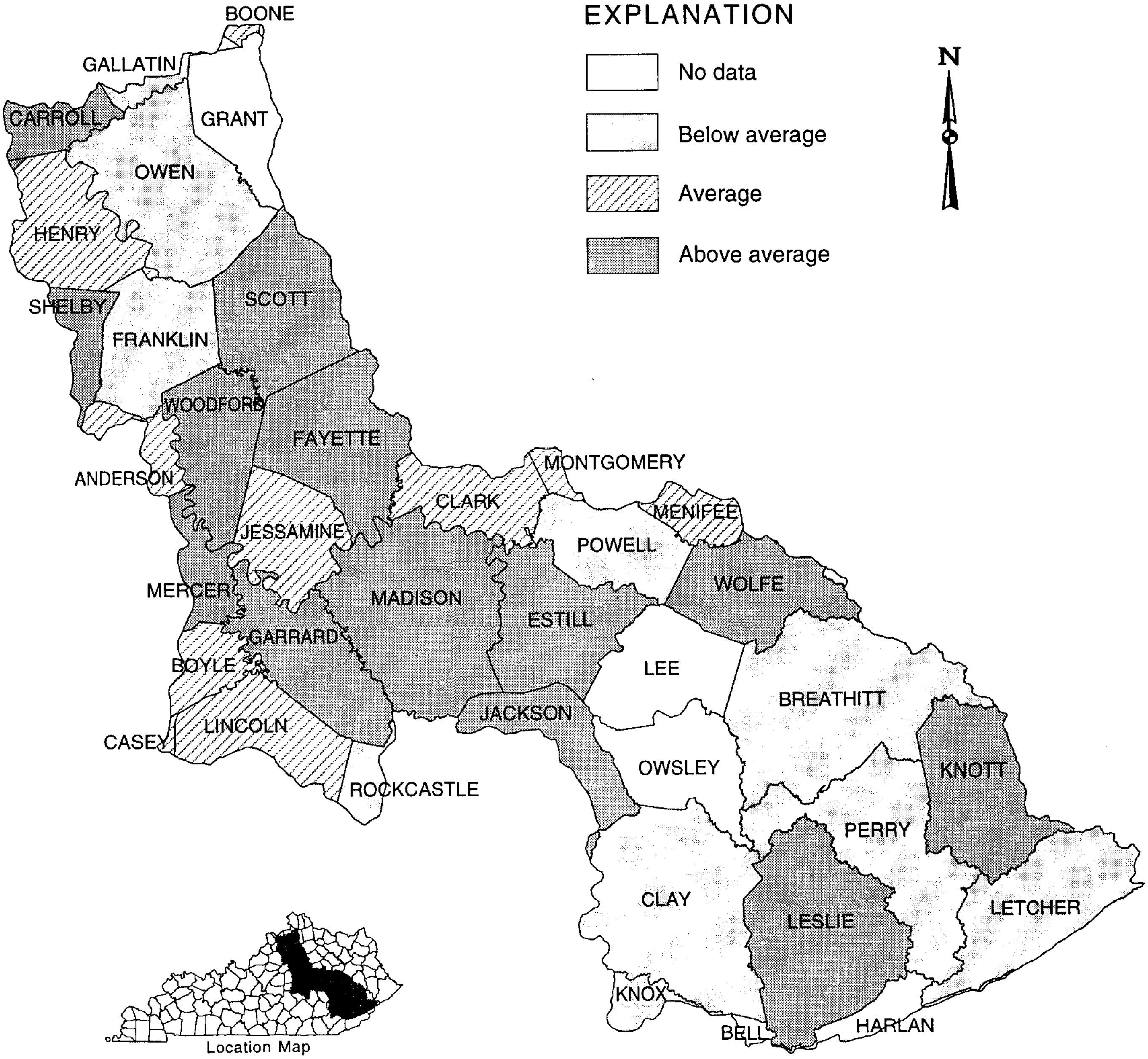


Figure 17. Average nitrite-N levels in private ground-water supplies by county in the Kentucky River Basin compared with Statewide averages.

petroleum in the area is not available. Salty water commonly occurs in wells more than 100 feet deep below major valley bottoms throughout much of eastern Kentucky (Hall and Palmquist, 1960; Palmquist and Hall, 1960; Price, and others, 1962). As a result, saline water can be expected naturally in most geologic formations in the headwaters portion of the basin. Analyses of water from wells outside of oil-production areas indicate large ranges in constituent concentrations in the Pennsylvanian, Mississippian, Devonian, and Silurian rocks. Total dissolved solids in excess of 100,000 mg/L have been measured in water from these units, even in areas where little or no petroleum production has oc curred.

Septic Systems, Fertilizers, Pesticides, and Herbicides

A Ground Water Education and Testing Program was conducted by the Kentucky Farm Bureau, the Kentucky Division of Conservation, the University of Kentucky Cooperative Extension Service, and the Kentucky Geological Survey from 1989 to 1992. Nearly

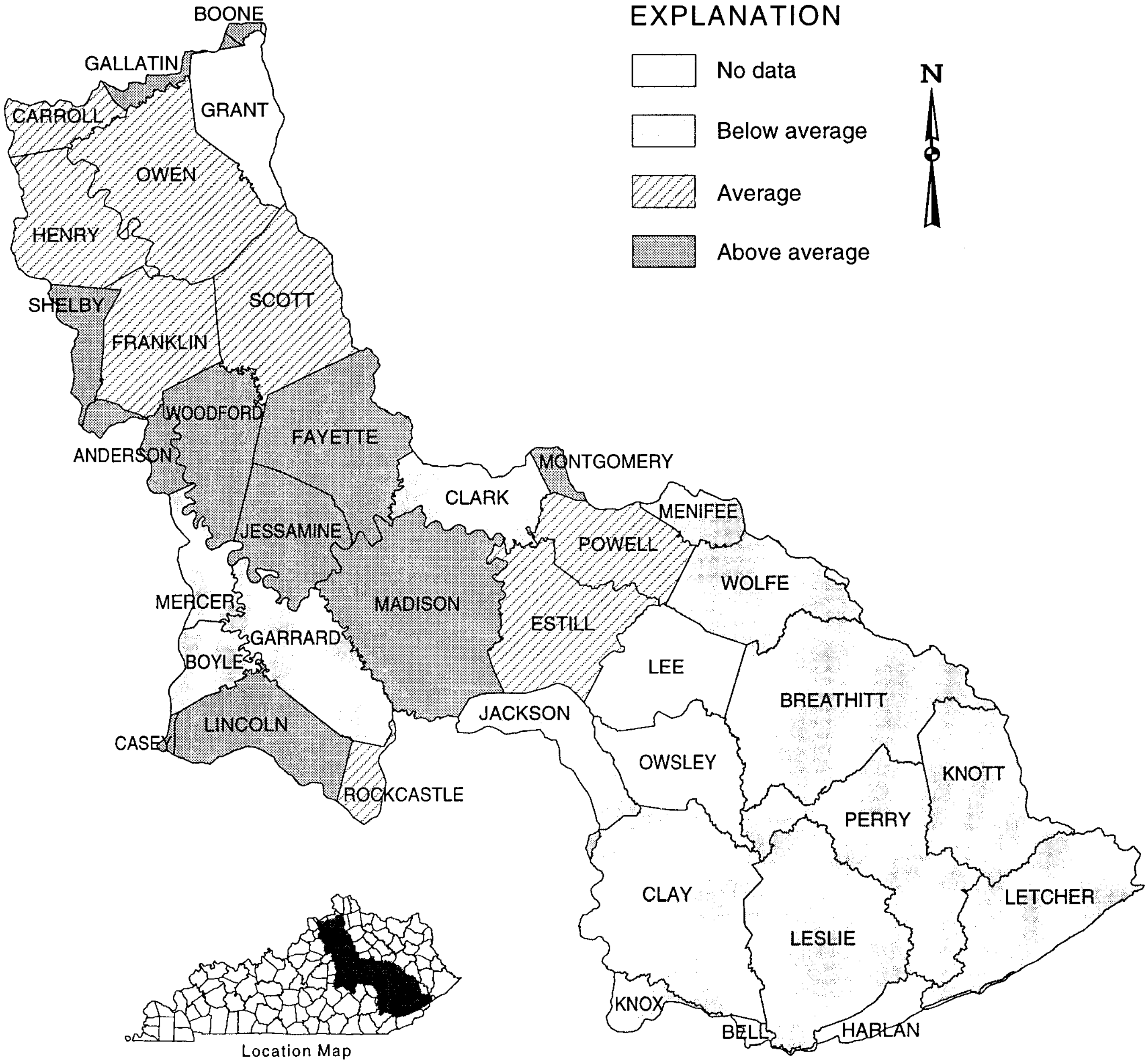


Figure 18. Average nitrate-N levels in private ground-water supplies by county in the Kentucky River Basin compared with Statewide averages.

5,000 wells across the State were tested for nitrogen compounds, chlorides, sulfates, herbicides, and conductivity (an indicator of dissolved solids). About 800 wells, or 2.2 percent of the domestic wells, were tested in the Kentucky River Basin. Average levels of each constituent were calculated for each county and compared with values for the rest of the State (Figs. 16-23). Figure 16 shows that eastern Kentucky had elevated values of ammonia in ground water compared with the rest of the State. This is probably because of the large number of septic systems (Fig. 24) and, perhaps, naturally occurring ammonia in coals (Byan, 1993). Nitrite- and nitrate-nitrogen levels (Figs. 17-18) were higher than average in the counties of the Inner Blue Grass Region and are probably primarily due to fertilizer application. Data for alachlor (LassoTM) and triazine (atrazine) were limited to the Blue Grass Region. The percentages of samples that exceeded the maximum contaminant level (MCL) recommendations of the EPA are:

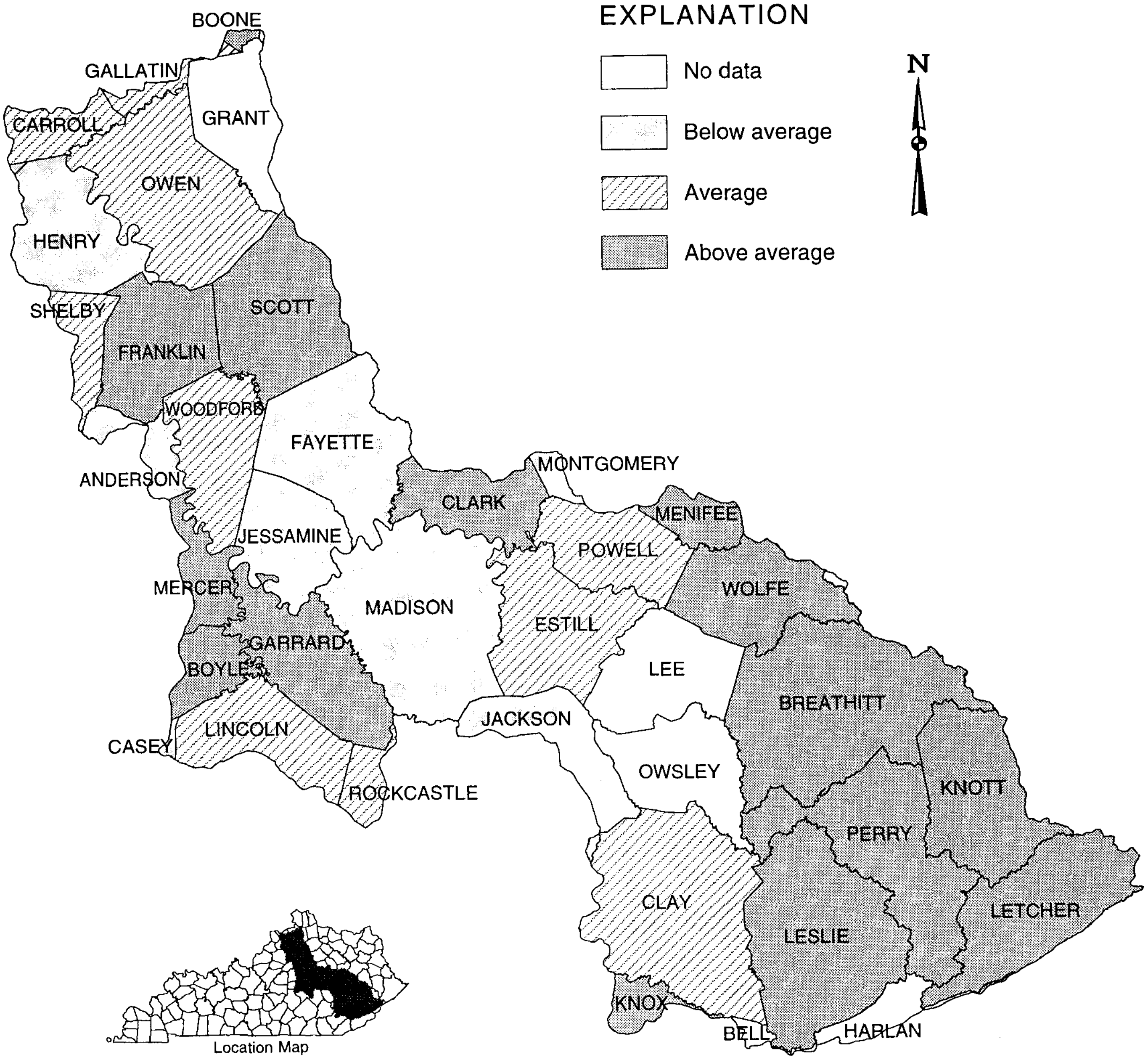


Figure 19. Average chloride levels in private ground-water supplies by county in the Kentucky River Basin compared with Statewide averages.

Element	*MCL*	*Percentage Exceeding*
Nitrite-nitrogen	1.0 mg/L	0.0
Nitrate-nitrogen	10.0 mg/L	2.1
Chloride	250.0 mg/L	2.6
Sulfate	250.0 mg/L	3.8
Conductivity	780.0 µS/cm	13.9
Alachlor	2.0 µg/L	0.0
Triazine	3.0 µg/L	0.0

Conductivity is an indication of total dissolved solids (TDS) in the water, and the 780 ~6/cm level for conductivity corresponds to the 500 mg/L limit recommended by EPA for TDS. A detailed summary of the survey data for each county and Area Development District is presented in "Quality of Private Ground-Water Supplies in Kentucky" (Carey and others, 1993).

Solid Waste Disposal

There are six active and over 40 inactive landfills in the basin, according to the Kentucky Department of

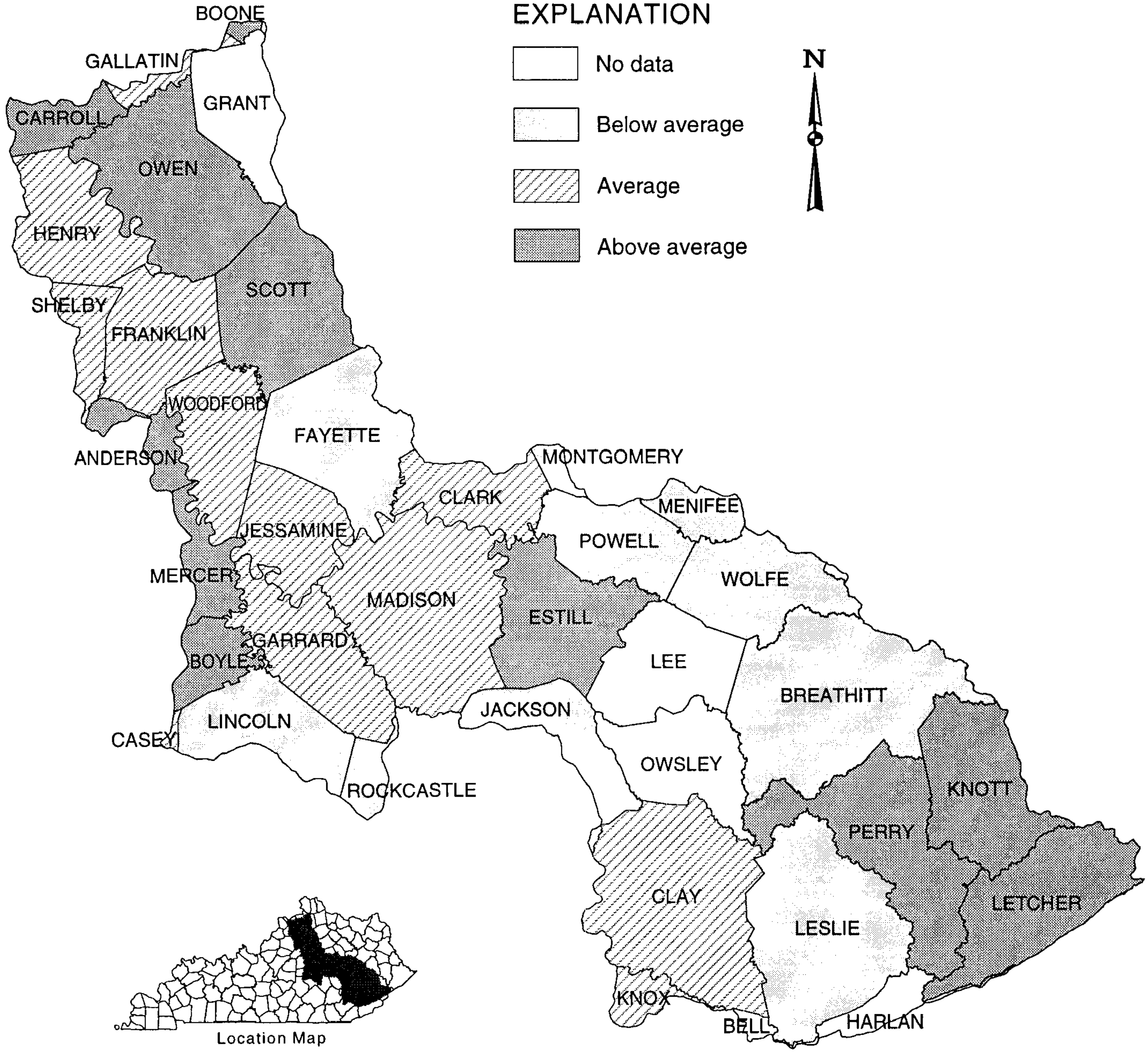


Figure 20. Average sulfate levels in private ground-water supplies by county in the Kentucky River Basin compared with Statewide averages.

Natural Resources and Environmental Protection's data base in 1994, as well as an unknown number of abandoned and open dumps. Problems from these sites are caused by lack of awareness of their existence and from illegal dumping. Areas being considered for a public ground-water supply, particularly the drainage basins of springs, should be thoroughly investigated for dumps and other potential sources of contamination. All waste-disposal areas have the potential to contaminate ground water. Contamination from these sites could render the ground water unfit for human consumption. However, since most bedrock aquifers in the basin are unconfined, well contamination would, in most cases, be limited to the immediate region downgradient from the sites. A well up-gradient might be totally unaffected. At this time, contamination from dumps is thought to have had an impact on a relatively small percentage of the ground-water resource in the Kentucky River Basin.

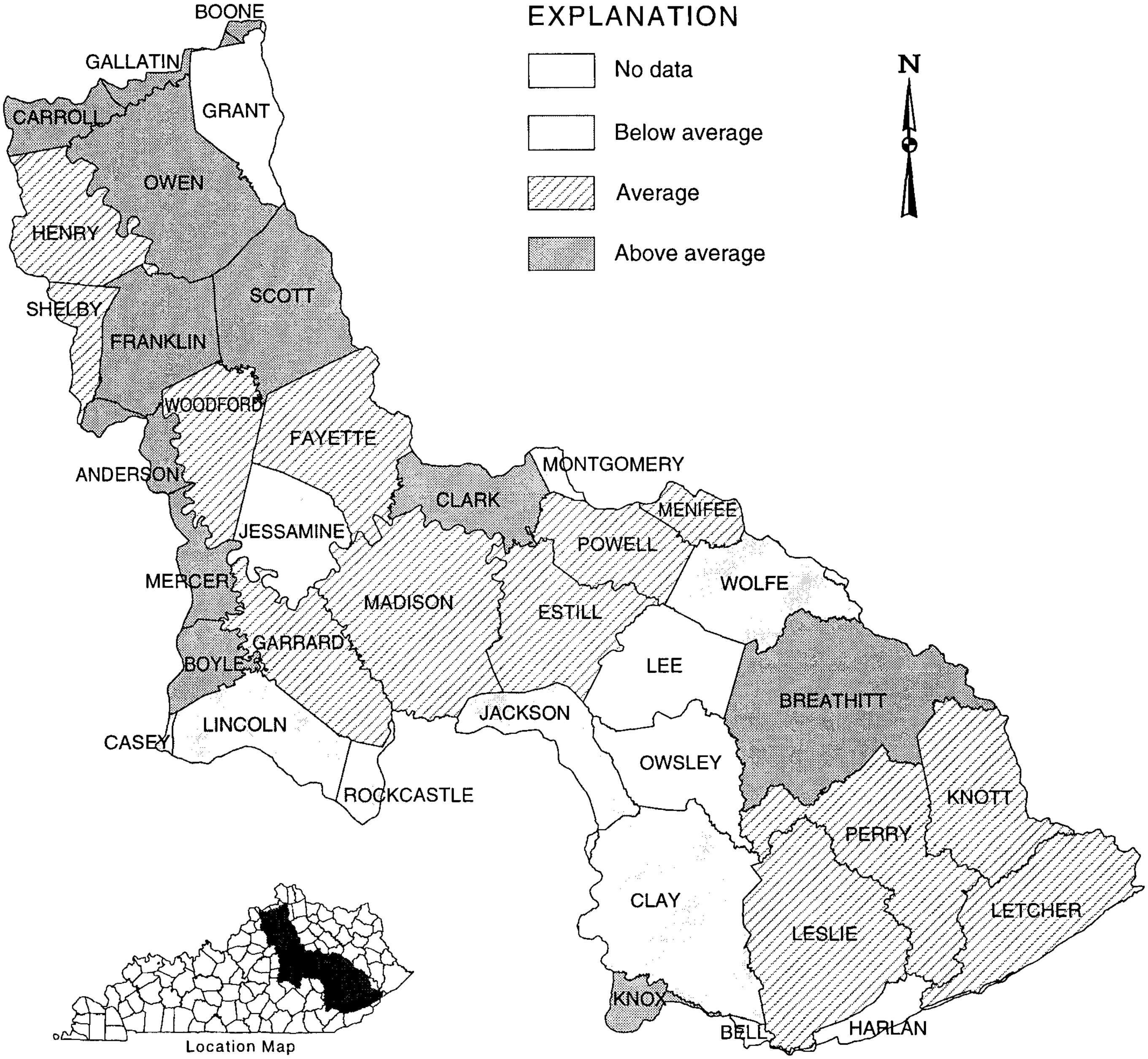


Figure 21. Average conductivity levels in private ground-water supplies by county in the Kentucky River Basin compared with Statewide averages.

Underground Storage Tanks

According to the Kentucky Environmental Quality Commission (1992, p. 60), "one of the greatest threats to groundwater resources is leaking underground storage tanks." About 38,000 underground storage tanks had been registered with the Division of Waste Management, Underground Storage Tank Branch, as of 1993. Data for 6,691 underground storage tanks in 24 counties in the Kentucky River Basin are given in Appendix B. Figure 25 shows the number of tanks registered by county. About five out of eight tanks are for gasoline storage (Fig. 26). Forty-six tanks contained hazardous materials as defined by the Federal Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA).

State efforts to clean up underground storage tanks have been ongoing since 1986. The state of Kentucky is also developing regulations for cleanup standards.

Bacterial Contamination

According to Waller (1988, p. 22)

> The most common water-quality problem in rural water supplies is bacterial contamination from septic-tank effluent. Prob-

ably the second most serious water-contamination problem in rural farm homes is from barnyard waste.

From July 1, 199 1, through June 30, 1992, 3,053 domestic wells in Kentucky were tested for fecal coliform contamination by the Kentucky Cabinet for Human Resources. Statewide, and in the Inner Blue Grass Region, about half the of the tested wells were "positive"; that is, samples contained at least 1 fecal coliform colony per 100 milliliters of water (Fig. 27). In the Outer Blue Grass and the Eastern Kentucky Coal Field about three in five of the tested wells were positive.

Septic-tank effluent that enters the aquifer supplying a homeowner's well introduces not only bacteria but possibly other contaminants. Many rural homeowners also discharge other waste products, including toxic material, into their septic systems, and these products gradually accumulate in the aquifer. What happens to these contaminants in the ground is not well known.

In a bacteria-contaminated water system, chlorination of the water pumped from the well is commonly

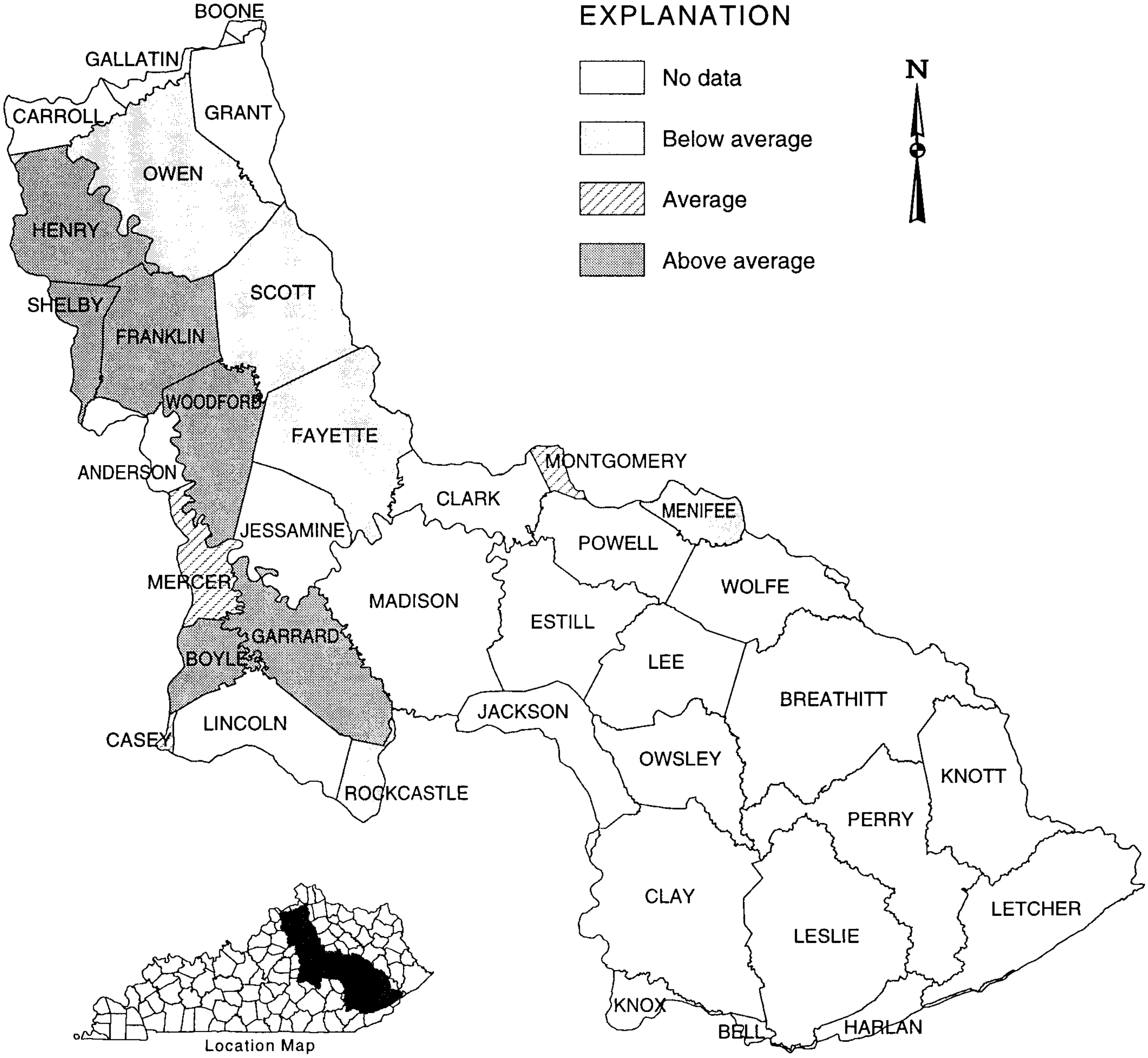


Figure 22. Average alachlor levels in private ground-water supplies by county in the Kentucky River Basin compared with Statewide averages.

recommended as a solution. Otherwise, a water supply must be obtained from a new well that is either up-gradient from the contaminating source or that taps a deeper aquifer. Deep wells are less likely to be contaminated by septic effluent than shallow wells.

Except for bacterial contamination, mostly caused by poor well construction, the water from most domestic wells is safe to use (Currens, 1989). Many water-quality problems, such as high dissolved iron content, can be effectively corrected by water-treatment systems. For a variety of reasons, however, many domestic systems do not achieve the level of treatment that is technologically possible. In many cases this situation could be improved by making treatment information more readily accessible to homeowners.

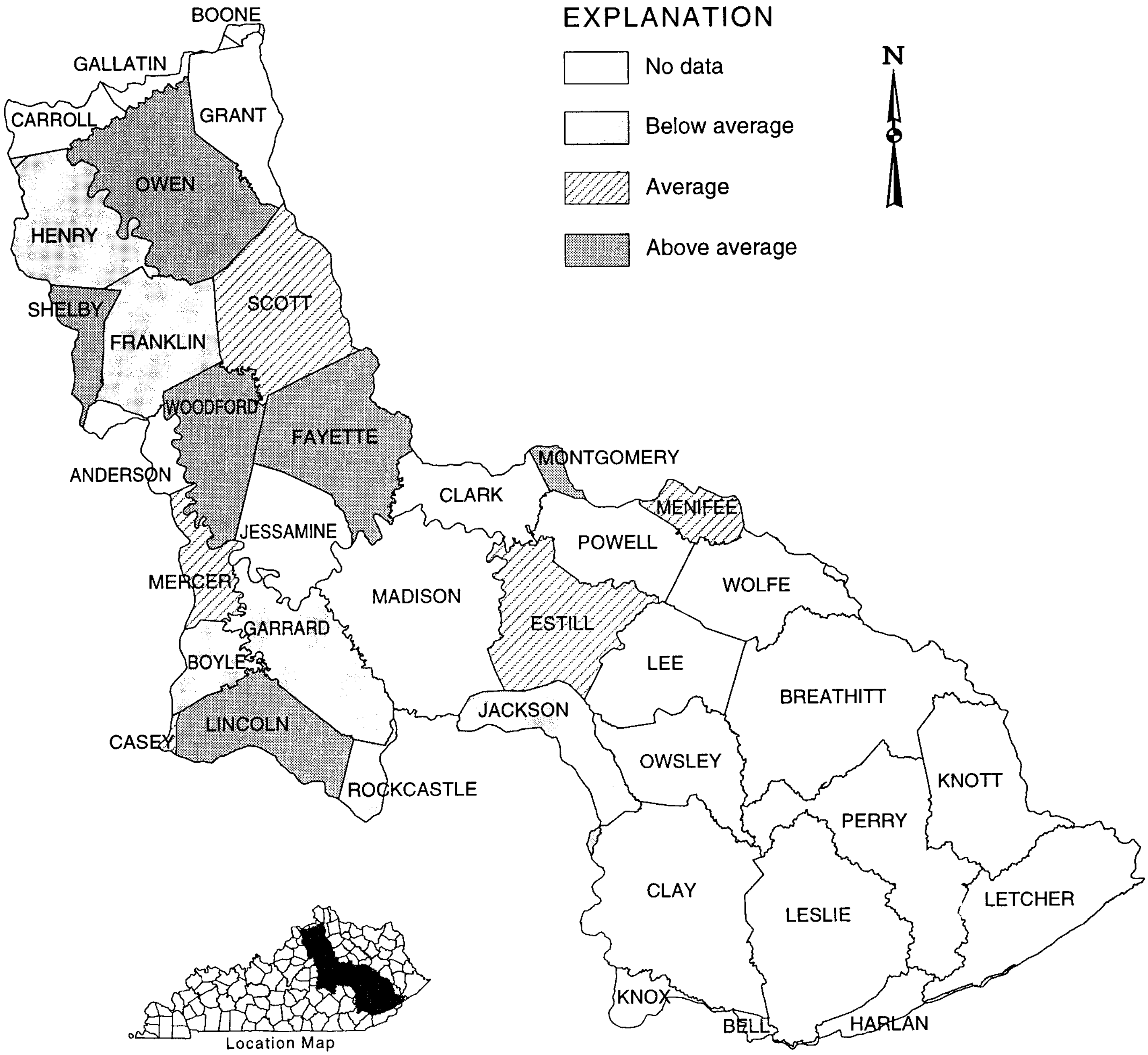


Figure 23. Average triazine levels in private ground-water supplies by county in the Kentucky River Basin compared with Statewide averages.

POTENTIAL FOR DEVELOPMENT OF GROUND WATER IN THE BASIN

Potential Development of Ground Water for Municipal Supplies

Whether an aquifer can support development for a municipal or industrial water supply depends on its ability to produce the required amount of water on either a continuous basis or during high-demand periods. To illustrate the distribution of aquifers that might supply large-capacity wells, a map showing wells drilled for uses that normally require a large volume of water was prepared (Plate 2). The local hydrogeologic setting of these wells was determined by using available drilling records and plotting well locations on geologic maps. The wells selected for the map are those being used for industrial, irrigation, municipal, institutional, and unspecified public supply. In addition, some wells being used for domestic and other purposes, which have relatively large specific capacities, were also included. Some springs that supply large quantity users are also shown. Appendix A briefly describes the hydrogeologic setting of the wells and springs shown on Plate 2. These wells primarily occur in the alluvium of the Kentucky River, coarser grained sandstones of the Breathitt and Lee Formations, and joints or conduits in the Ordovician and Mississippian limestones. The highest capacity wells, which are in Letcher County, are probably sited in faulted and fractured sandstones of the Breathitt Formation along the base of Pine Mountain.

The specific capacity of a well provides a normalized measure of the water-well yield in lieu of hydraulic conductivity data. Hydraulic conductivities are not readily determined because of the expensive and timeconsuming technical nature of such testing. In unconfined aquifers specific capacities normally decrease as the drawdown increases. In theory, drawdown in the well will stabilize for a given discharge rate, and the specific capacity can then be determined. In the Kentucky River Basin, only a few wells have data for pumping tests that resulted in a stabilized drawdown. Therefore, specific capacities for selected wells in the basin shown in Table 7 are based on a common pumping period of 1 hour.

Reported well yield is another measure of groundwater availability. Some fortuitously sited wells in the Inner Blue Grass may have sustainable yields over 2,000 gpm. Some wells in the Whitesburg area may have yields upwards of 6,000 gpm. One well near Whitesburg (ID No. 12884) was pumped at 325 gpm, the maximum capacity of the pump, for over 30 hours with a drawdown of only 13 feet (Quinones and others, 1981.) Wells sited along fault zones may produce hundreds of gallons per minute. Most wells in the Kentucky River Basin would not be adequate for users requiring sustained pumping rates of 1,000 gpm or more, however, and it does not seem likely that ground water would provide a source for major municipalities. For example, the average daily withdrawal from the Kentucky River by the Kentucky-American Water Company for the central Kentucky region was 38.2 MGD (26,500 gpm) in 1991. A field of 27 wells yielding 1,000 gpm would be required just to meet average demand.

Springs in the Kentucky River Basin, particularly in the Inner Blue Grass, are an under-utilized water resource. Several springs, not now being used for public supplies, discharge tens to thousands of gallons per minute. Many of these springs are near population centers. Springs gather their discharge from relatively large areas. The large catchment provides large spring discharges in a region where wells typically have much smaller yields. Because the spring is discharging from a ground-water basin, essentially a roofed reservoir, little water will be lost to evaporation. This is emphasized by recent work in the Garretts Spring drainage basin (Gary Felton and LXA. Sendlein, oral commun., 1990), which has shown that at least some springs would maintain flow well into a seasonal drought.

Restraints to using springs include their private ownership, their scattered locations far away from areas of high demand, and their susceptibility to contamination. All of these limitations can be overcome. Purchase of the spring property would be required, as would right of way for transmission lines to deliver raw water to a treatment plant. A pumping station at the spring would be needed, as well as a small impoundment to buffer peak-demand periods. The possibility of contamination could be reduced by controlling land-use activities within the recharge area. Water treatment would be the same as for any surface-water supply. A network of pumping stations fed by springs could easily supply a community with 1 to 5 MCD. If the collective discharge of several springs exceeded demand, a temporary interruption of supply from one spring caused by a chemical spill would not have a devastating effect on the entire water distribution system.

Although not evaluated in this report, abandoned underground coal mines are perhaps another under-utilized source of water in the basin. Mull and others (1981) examined the factors affecting the development of water supplies from underground mines in Johnson and Martin Counties.

A field of wells sited along major fault zones, or a group of springs integrated into a collection system, or a combination of both, could have the potential to either

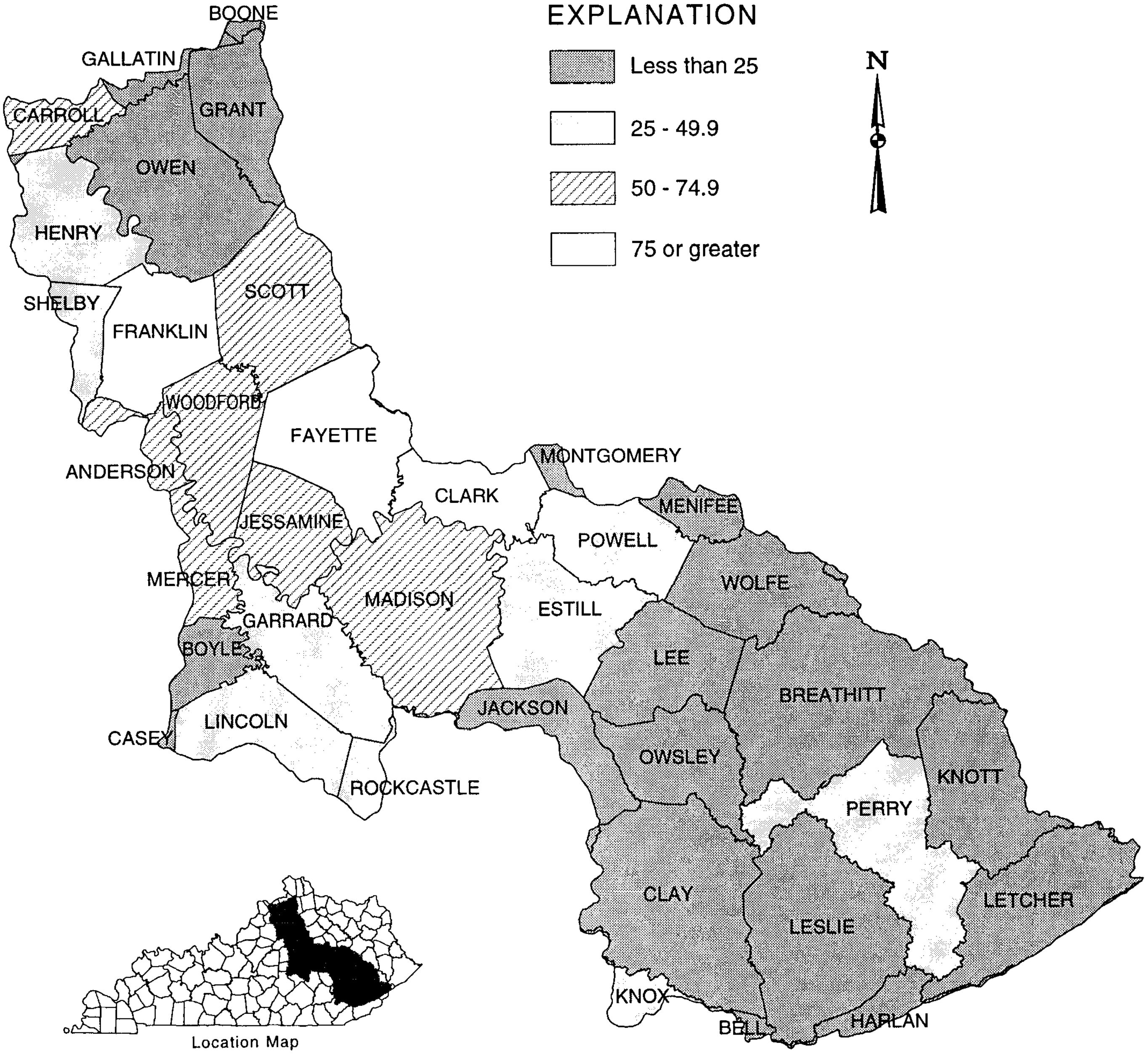


Figure 24. Percentage of county population with public sewers in the Kentucky River Basin.

supplement a large community or supply an industry or smaller community.

Potential Use of Ground Water as a Dependable Rural, Domestic Supply

Many rural residents of the Kentucky River Basin do not have access to public water supplies and must rely on ground water, hauled water, or cisterns. Estimates of the amount of ground water used in the basin are uncertain at best. Data on residential and commercial ground-water use are limited, and essentially no data are collected on agricultural withdrawals. What is certain, however, is that adding the 134,000 Kentuckians in the basin who rely on private water supplies to already strained surface-water-supplied public systems could create serious supply problems. Therefore, a reasonable strategy to conserve surface-water supplies is to preserve ground-water resources.

Most Kentucky River Basin aquifers are unconfined and are recharged by rainfall more quickly than confined aquifers. Except during periods of extreme and

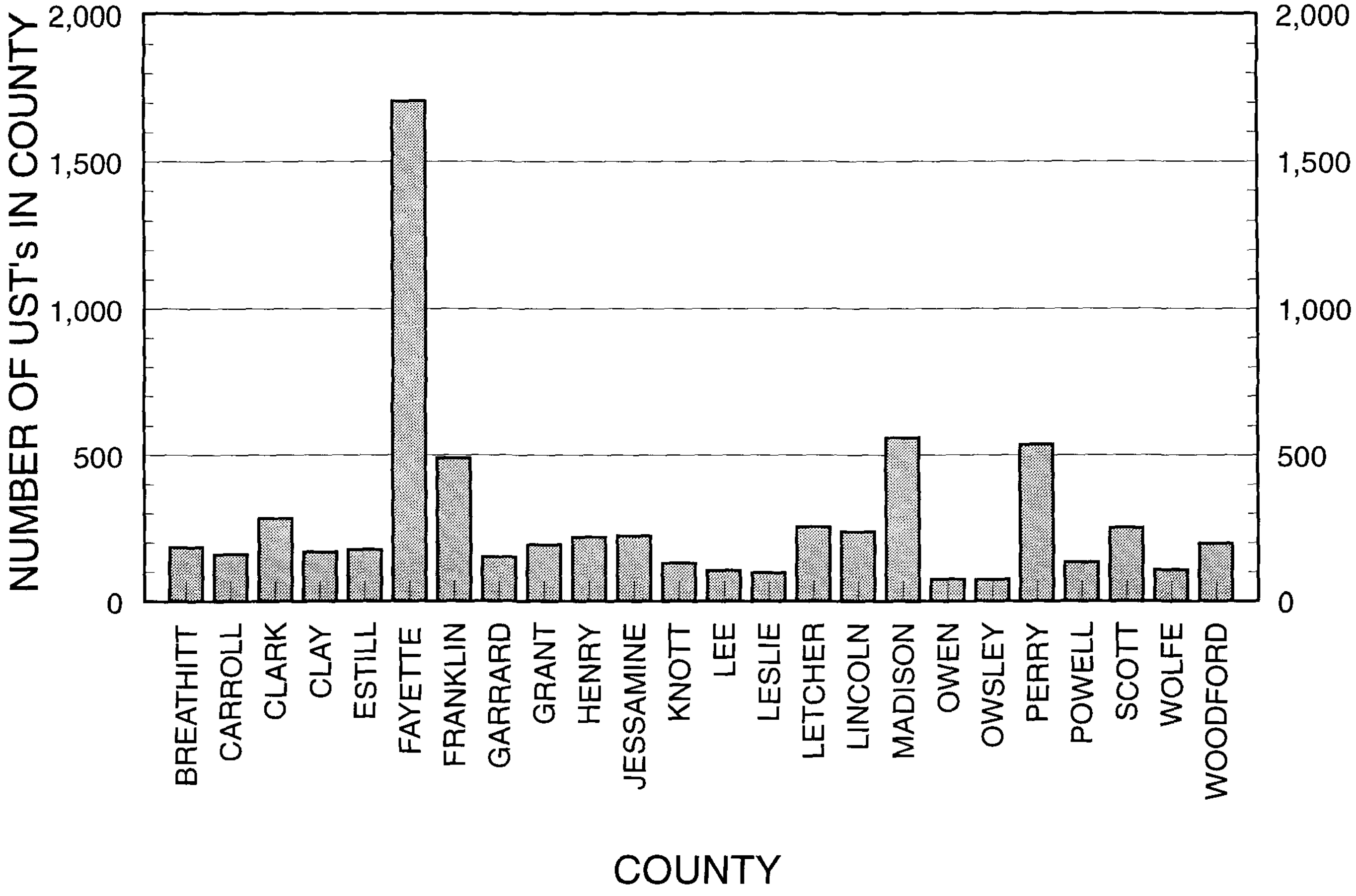


Figure 25. Number of underground storage tanks by county in the Kentucky River Basin.

prolonged drought, the annual precipitation is sufficient to recharge most aquifers, Furthermore, most ground-water users are in rural areas, and their wells or springs are widely scattered. This dispersal tends to distribute the demand for ground water over sufficiently large areas so that, under normal conditions, recharge keeps pace with withdrawal. Although complaints about wells going dry because of nearby excessive use are not unknown, they are not common: the depletion of aquifers is not currently a problem.

Assuming the homeowner lives in an area where suitable aquifers exist, the quality of the water becomes the limiting factor. Measures to correct existing waterquality problems and the protection of ground-water recharge areas are essential to maintaining rural ground-water supplies. Studies have shown that many water-quality problems with domestic wells are caused by poor well construction (Currens, 1989). A program of retrofitting old, improperly constructed wells in order to correct and prevent contamination could reduce the need to extend public water lines and the associated increased demand on surface-water supplies. More widespread educational programs could also help to improve ground-water quality maintenance and protection by raising awareness of issues and solutions.

Development of New Ground-Water Sources

Fracture Traces and Well Siting

Wells with higher than normal yields are sometimes produced by drilling where vertical fractures in bedrock appear to be concentrated or enlarged. The surface expression of such fractured zones is termed a fracture trace. If a large number of fractures or a single enlarged fracture is pierced by a borehole, then water can enter the well at a higher rate than at nearby locations with fewer or smaller fractures. Drilling into rock where fractures are more concentrated has been attempted with moderate success in various parts of the country, and has been used with some success in Kentucky.

The earliest study on using fracture traces involved comparing yields of 11 bedrock wells in carbonate rocks of central Pennsylvania (Lattman and Parizek, 1964). The yields of wells drilled into fracture traces were higher, and in some cases far higher, than the

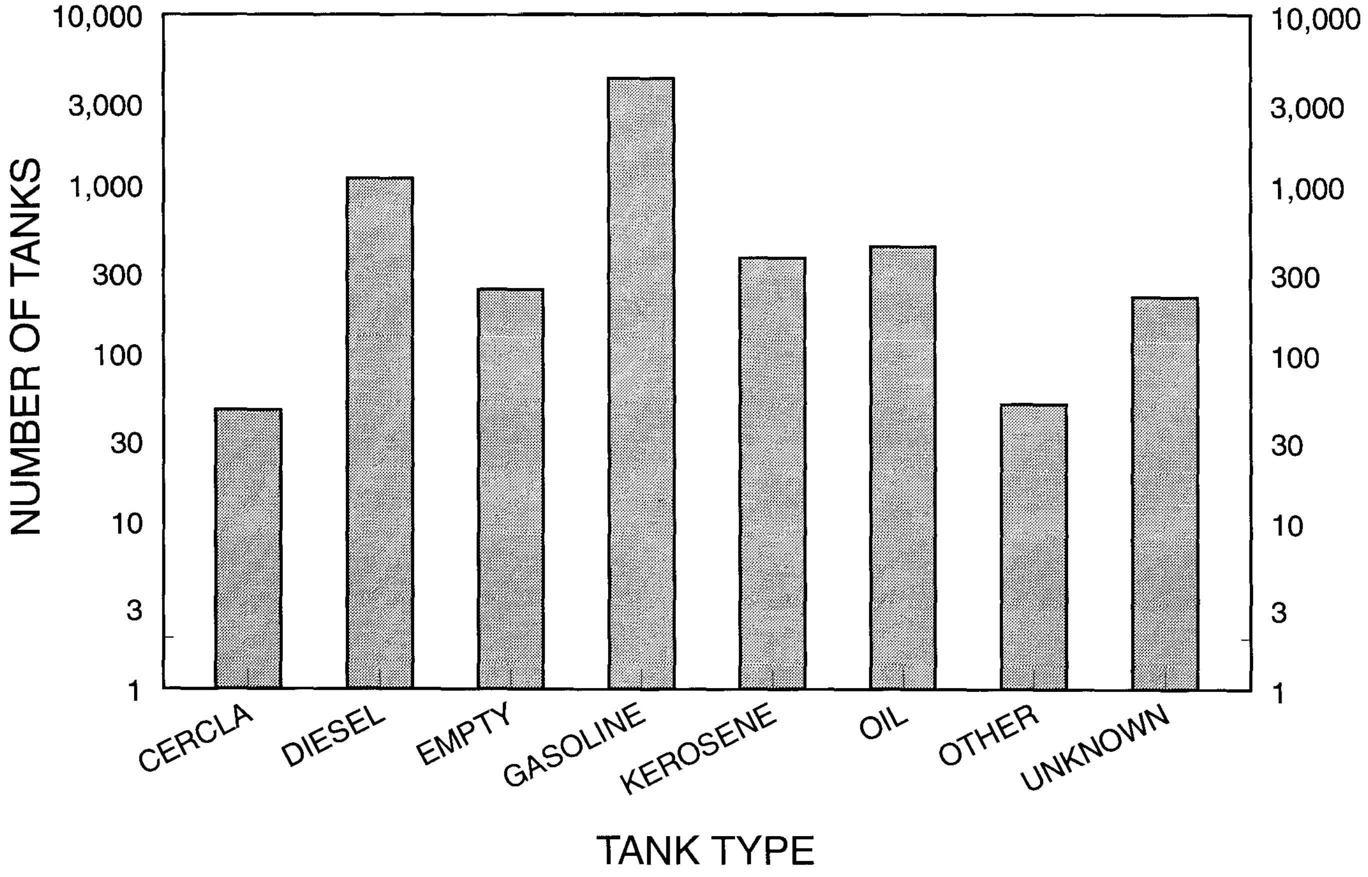


Figure 26. Number of underground storage tanks by type in the Kentucky River Basin.

yields of wells drilled between fracture traces. A study of fracture traces in carbonate rocks of the southern Blue Grass Region of Kentucky concluded that most fracture traces in that region are the result of solution enlarging of joints in bedrock (Hine, 1970). A total of 2,400 apparent fracture traces were mapped in the Bryantsville area over 48 square miles. No formal studies on fracture traces are known in other parts of the State.

Identifying zones with more or larger vertical fractures is being attempted by various techniques. Many practitioners use a combination of aerial photographs, geologic maps, and topographic maps. The aerial photographs have greater detail than maps, and show useful features on a finer scale. Near-vertical fractures expressed at the surface appear as straight or very gently curved linear features that are not manmade. These linear features can appear on maps as straight stream segments, sinkholes that appear in a straight line, and other linear occurrences. Aerial photographs often show additional features such as linear trends in soil color. Geologic maps help to discern whether a linear feature may be due to vertical fractures, or only a contact of two rock types below the soil. Different geologic units also have different magnitudes of development of fracture zones. Other possible explanations for linear features on aerial photographs must be considered, such as old fence rows, overgrown roads, or slumping hillsides.

Fracture traces are generally found on a scale of a thousand or more feet in length to a few miles. Longer linear features that extend for several miles are commonly termed lineaments. Natural linear features of any length found on aerial photographs or other landsurface imagery are also termed lineaments. The term "fracture trace" is used to distinguish a linear feature at the earth's surface that is caused by fracturing of bedrock. The origins of fracture traces are diverse.

Finding wells with better yields than surrounding wells is the often-elusive goal of fracture-trace analysis. Practitioners of fracture-trace analysis often attempt to improve their odds by choosing one or more drilling sites on large properties at the exact intersections of apparent fracture traces. Such techniques can somewhat improve the odds of drilling a larger yield well, but offer no certainty for individual wells. Small plots of land often have no discernible fractures in which to drill.

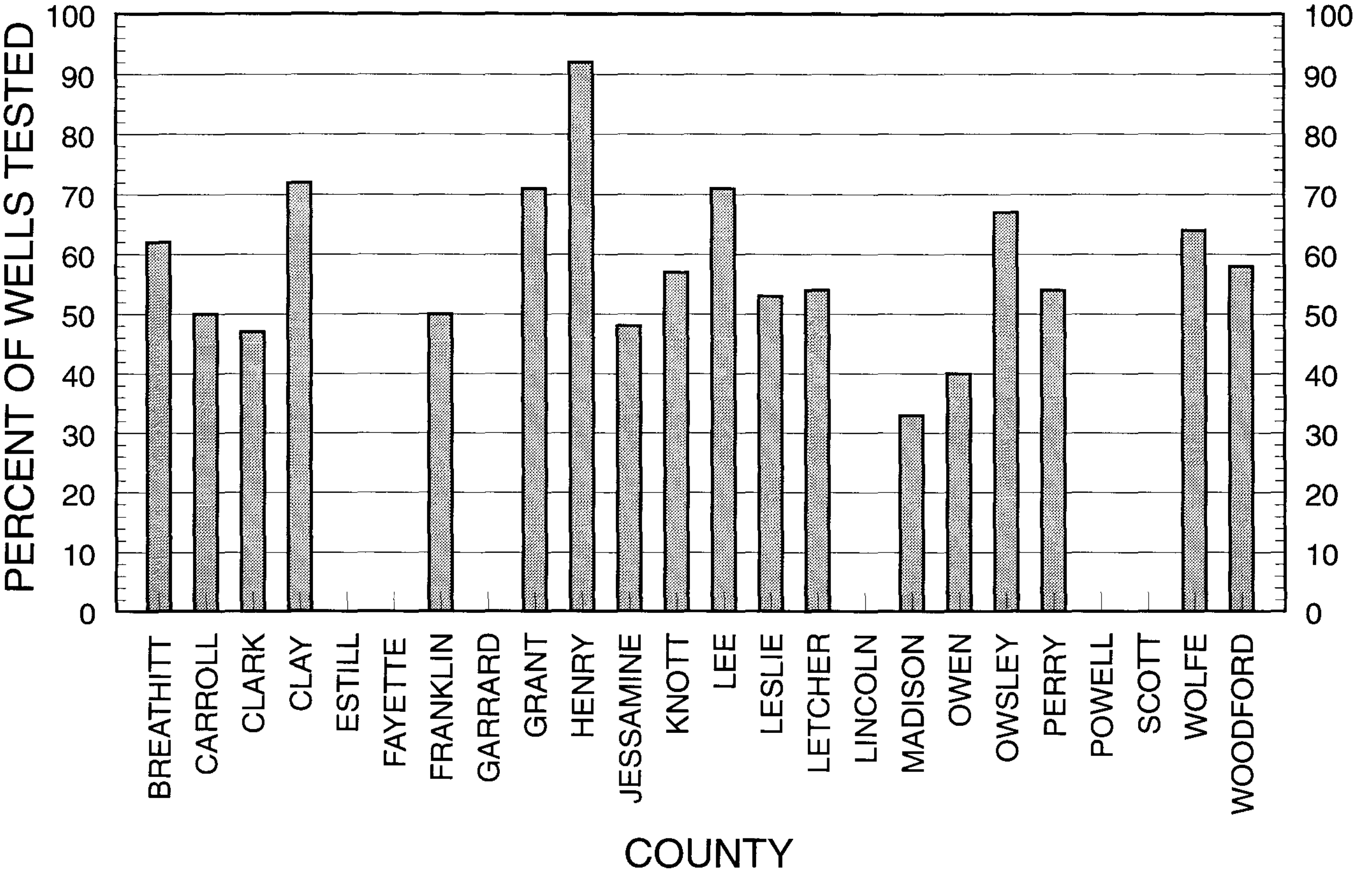


Figure 27. Percentage of wells per county contaminated by fecal coliform bacteria.

Success in using fracture-trace analysis no doubt varies in the different geologic settings of Kentucky. Other factors normally considered for a potential well site, such as an adequate recharge zone, must still be considered with this technique.

Water-Well Drilling at an Angle

A relatively untested method of drilling water wells is drilling at an angle, such as 15 or 20' from vertical. In the Kentucky River watershed the bedrock is relatively impermeable, and most water that recharges wells is from bedding-plane openings and vertical fractures such as joints in the rock. Drilling a bedrock borehole at an angle intersects more near-vertical fractures than with conventional vertical drilling.

Intersecting more near-vertical fractures does not assure greater recharge to a well. At some locations in the Kentucky River Basin, bedding planes may yield as much water as typical near-vertical joints in rock, and in eastern Kentucky, coal beds are often the zone with the highest permeability. Vertical fractures, which are usually spaced a few feet apart, can be closed or may be filled with mineral deposits. However, open vertical fractures generally contribute a significant portion of the ground water to wells throughout the Kentucky River Basin. Drilling 100 feet deep at a 20' angle creates a borehole that extends 34 feet horizontally and 94 feet vertically from the surface. If near-vertical joints in a locality are commonly spaced at 5-foot intervals, then six of the joints should be intersected instead of one. Drilling at an angle is possible by some, but not all, rotary drillers in Kentucky. In general, the greater the angle, the harder it is to handle heavy drilling equipment.

SUMMARY

The ground-water system of the Kentucky River Basin varies dramatically along the course of the river. Most of the ground-water-bearing units tapped by private wells are unconfined or semi-confined bedrock aquifers. These units generally have low primary hydraulic conductivities and low storativity. Zones of high potential yields within the bedrock aquifers are irregularly distributed. The most productive wells are drilled in fractured bedrock, either sandstone or limestone, and in the alluvium along the river's floodplain.

Table 7. Specific capacities after 1 hour of pumping for selected wells in the Kentucky River Basin.*

Well ID Number	*County*	*Total Depth (feet)*	*Well Diameter (inches)*	*Static Water Level Depth (feet)*	*Pumping Rate (gpm)*	*Drawdown Below Static Water Level (ft.)*	*Specific Capacity (gpm/ft.)*	*Producing Formation or Member*
00004387	Anderson	95.0	6	75.00	25.00	70.00	0.36	Tyrone
00001220	Clark	185.0	6	60.00	3.00	85.00	0.04	
00002734	Fayette	68.9		17.52	6.00	11.05	0.54	Grier
00002735	Fayette	65.6		17.74	4.00	19.61	0.20	Grier
00002737	Fayette	82.0		24.86	1.00	18.07	0.06	
00002767	Fayette	121.4		27.49	238.00	7.51	31.69	Grier
00002768	Fayette	98.4		9.18	238.00	6.40	37.19	Grier
00001952	Garrard	69.0	6	15.00	3.00	10.00	0.30	
00001568	Jessamine	150.0	6	106.00	1.00	44.00	0.02	
00004012	Knott	79.0	5 3/16	56.00	4.00	23.00	0.17	
00004013	Knott	59.0	5 3/16	30.00	15.00	10.00	1.50	Breathitt
00001170	Knox	80.0	5 5/8	4.00	22.00	27.00	0.81	
00004903	Leslie	85.0	6	20.00	5.00	65.00	0.08	
00001032	Letcher	150.0		40.00	10.00	50.00	0.20	
00001468	Letcher	325.0	6	150.00	2.00	175.00	0.01	
00002422	Letcher	150.0		30.00	1.00	120.00	0.01	
00004296	Letcher	165.0	6	40.00	14.00	6.00	2.33	Breathitt
00012889	Letcher	46.0	6	12.45	15.00	2.02	7.43	Breathitt
00001132	Lincoln	60.0		30.00	7.00	10.00	0.70	
00002072	Lincoln	40.0	6	23.00	10.00	1.00	10.00	Calloway Creek
00002168	Lincoln	100.0	6	82.00	2.00	5.00	0.40	
00004384	Powell	103.0	6	60.00	3.00	80.00	0.04	
00004937	Powell	55.0	6	40.00	2.00	50.00	0.04	
00003182	Rockcastle	120.0	6	30.00	1.00	90.00	0.01	
00001219	Scott	185.0	6	110.00	10.00	5.00	2.00	Tanglewood
00002779	Scott	98.4		51.96	4.28	3.64	1.18	Grier
00002781	Scott	108.2		72.23	8.40	7.94	1.06	Grier
00002781	Scott	108.2		70.32	6.82	7.81	0.87	Grier
00002784	Scott	55.8		28.67	3.17	4.82	0.66	
00004942	Scott	69.0	6	54.00	25.00	4.00	6.25	Tanglewood
00002789	Woodford	13.1		5.67	4.60	0.16	28.75	Grier
00002790	Woodford	32.8		4.33	7.93	12.40	0.64	

* Wells with zero drawdown were eliminated because water-level measurement was suspected to be inaccurate. Wells with missing drawdown data or pumping rates were also deleted. The accuracy of data reported in this table is contingent upon the reliability of agencies and individuals reporting the data.

Ground water acts as a buffer to peak and low flows in Kentucky River Basin streams. During summer and fall droughts, ground water flows from aquifers along these streams into the channel, maintaining the streamflow. These aquifers are recharged by infiltration from the stream during high flows in the winter and spring, as well as by precipitation. At current withdrawal rates, ground-water usage does not seem to have an adverse impact on the Kentucky River.

Privately owned ground-water sources supply approximately 135,000 people living in the basin--about 19 percent of the total population and 36 percent of the rural population. Over 50 percent of residential water supplies in eastern Kentucky rely on ground water.

If aquifers are protected from pollution by wellhead protection programs, and old wells are retrofitted to prevent direct contamination, then ground water will continue to provide a reliable water supply in many rural areas of the basin. In other areas the quality of domestic supplies should be able to be improved through educational programs. The technology is available to treat most naturally occurring water-quality problems. In practice, however, many homeowners may not be taking full advantage of the available technology.

Without field research, the potential for ground water to supply significant amounts of water will be as uncertain in the future as it is today. Current knowledge of ground-water resources is inadequate for the reliable development of large-capacity wells in the basin. For most of the basin, few wells will have yields adequate to supply a large demand. Furthermore, because the areal distribution and hydraulic properties of basin aquifers are poorly known, siting a well for maximum yield is presently difficult. Ground water from present wells will not provide an adequate supply for communities with a population of over a few thousand.

Most large-demand ground-water-supplied systems in the basin use springs. A group of springs with protected watersheds and a minimum total discharge of 1,000 gpm can supply a community of 8,000 to 10,000 people. Springs are the most significant ground-water source in the Inner Blue Grass. Unfortunately, the recharge areas and drought reliability of most springs are unknown. However, the limited discharge data available for springs and large wells in the basin strongly suggest that the potential for ground water to supplement current supplies should not be ignored. Discharge from well fields and springs could be used to augment surface supplies during drought.

For the citizens of the basin to fully benefit from ground water, its distribution and quality must become better understood, and it must be protected. Mapping and research are needed to identify areas where high yield wells could be drilled, such as in fault zones. Innovative technologies for well drilling and well stimulation need to be examined. The supply potential of the Knox Formation is not completely understood. The identification of the drainage areas of springs is also needed. A better understanding of the distribution and quality of ground-water resources is crucial for the establishment of wellhead protection areas and other pollution prevention programs.

SELECTED REFERENCES

American Water Works Association journal, 1975, Evaluation of state drinking water quality surveillance programs: American Water Works Association journal, v. 67, no. 8, p. 428-432.

Ausness, R.C., 1978, A proposed revision of Kentucky's water rights legislation: University of Kentucky Water Resources Research Institute, Research Report 114, 140 p.

Baker, J.A., and Price, WE., Jr., 1956, Public and industrial water supplies of the Eastern Coal Field region, Kentucky: U.S. Geological Survey Circular 369,63 p.

Beiter, D.P., 1970, Calcite saturation in an eastern Kentucky karst stream: Lexington, University of Kentucky, M.S. Thesis, 74 p.

Bienkowski, L.S., 1990, Delineation and characterization of the aquifers of the Eastern Kentucky Coal Field: Lexington, University of Kentucky, Ph.D. Dissertation, 319 p.

Black, D.F.B., and Haney, D.C., 1975, Selected structural features and associated dolostone occurrences in the vicinity of the Kentucky River Fault System (Roadlog for Geological Society of Kentucky 1975 Field Conference): Kentucky Geological Survey, ser. 10, 27 p.

Bradfield, A.D., and Porter, S.D., 1990, Summary of biological investigations relating to surface-water quality in the Kentucky River Basin, Kentucky: U.S. Geological Survey Water-Resources Investigations Report 90-4051, 63 p.

Brenniman, G.R., Kojola, W.H., Levy, P.S., Carnow, B.W., and Namekata, T., 1979, Health effects of human exposure to barium in drinking water: Chicago, Ill., Illinois University Medical Center, NTIS PB-292-268 A07, Final Report EPA-600/1-79-003, 127 p.

Brice, D.A., 1985, Comparison of textural and hydrogeologic properties of Carboniferous and modern fluvial point bars: Lexington, University of Kentucky, M.S. Thesis, 122 p.

Carey, D.I., 1992, Water quality in the Kentucky River Basin: Kentucky Geological Survey, ser. 11, Information Circular 37, 56 p.

Carey, D.I., Dinger, J.S., Davidson, O.B., Sergeant, R.E., Taraba, J.L., Ilvento, T.W., Coleman, Steve, Boone, Rayetta, and Knoth, L.M., 1993, Quality of domestic well water in Kentucky: Kentucky Geological Survey, ser. 11, Information Circular 44, 155 p.

Corbett, R.G., and Manner, B.M., 1984, Fluoride in the ground water of northeast Ohio: Ground Water, v. 22, no. 1, p. 13-17.

Cordiviola, Steve, Townsend, Margaret, Dugan, Tom, and Gilmore, M.K., 1980, Indirect methods for delineating fresh-water aquifers in areas with limited water-quality information [abs.]: Geological Society of America Abstracts with Programs, v. 12, no. 7, p. 406.

Couch, A.W., 1988, A DRASTIC evaluation for part of the Inner Bluegrass karst region, Kentucky: The Centerville, Georgetown, Lexington East, and Lexington West Quadrangles: Lexington, University of Kentucky, M.S. Thesis, 95 p.

Currens, J.C., 1989, Wellhead protection in rural Kentucky, contamination occurrence, and the implication for future resource development [abs.]: Proceedings, Kentucky Water Resources Symposium, University of Kentucky, Water Resources Research Institute, Lexington, Kentucky, p. 43.

Currens, J.C., Dinger, J.S., and Carey, D.I., 1991, A reconnaissance of the ground-water resources of the Kentucky River Basin: Lexington-Fayette Urban County Government, 29 p.

Davis, S.N., and DeWiest, R.J.M., 1966, Hydrogeology: New York, John Wiley, 463 p.

Dougherty, P.H., 1981, The impact of the agricultural land use cycle on flood surges and runoff in a Kentucky karst region: Proceedings of the International Congress of Speleology, v. 8, p. 267-269.

Dougherty, P.H., 1983, Valley tides; a water balance analysis of land use response floods in a karst region, Sinking Valley, Kentucky: Environmental Karst, GeoSpeleo Publication, p. 25-36.

Elam, A.B., Jr., Haan, C.T., Barfield, B.J., and Bridges, T.C., 1972, Precipitation probabilities for Kentucky: University of Kentucky, College of Agriculture, Agricultural Experiment Station, Progress Report 202, 55 p.

Evaldi, R.D., and Kipp, J.A., 1991, Effects of oil production on water resources in the Kentucky River Basin, Kentucky: U.S. Geological Survey Water-Resources Investigations Report 90-4191, 58 p.

Faust, R.J., 1976, Ground-water resources of the Lexington, Kentucky, area: U.S. Geological Survey Water-Resources Investigation Report WRI 76-0113, 24 p-

Faust, R.J., Banfield, G.R., and Willinger, G.A., 1980, A compilation of ground-water quality data for Kentucky: U.S. Geological Survey Open-File Report 80-0685, 963 p.

Fleischer, Michael, and Robinson, W.O., 1963, Some problems of the geochernistry of fluorine, in Studies in analytical geochemistry: Royal Society of Canada, Special Publication 6, p. 58-75.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Gardner, T.W., 1978, Paleohydrology, paleornorphology and depositional environments of some fluvial sandstones of Pennsylvanian age in eastern Kentucky: Cincinnati, Ohio, University of Cincinnati, Ph.D. Dissertation, 235 p.

Gouzie, D.R., 1986, Carbonate geochemistry and chemical discrimination of groundwater basins in portions of the Inner Bluegrass karst region, Kentucky: Lexington, University of Kentucky, Ph.D. Dissertation, 110 p.

Hall, F.R., and Palmquist, W.N., Jr., 1960a, Availability of ground water in Anderson, Franklin, Shelby, Spencer, and Woodford Counties, Kentucky: U.S. Geological Survey Hydrologic Investigations Atlas HA-24.

Hall, F.R., and Palmquist, W.N., Jr., 1960b, Availability of ground water in Carroll, Gallatin, Henry, Owen, and Trimble Counties, Kentucky: U.S. Geological Survey Hydrologic Investigations Atlas HA-23.

Hall, F.R., and Palmquist, W.N., Jr., 1960c, Availability of ground water in Clark, Estill, Madison, and Powell Counties, Kentucky: U.S. Geological Survey Hydrologic Investigations Atlas HA-19.

Hamilton, D.K., 1950, Areas and principles of groundwater occurrence in the Inner Bluegrass Region ' Kentucky: Kentucky Geological Survey, ser. 9, Bulletin 5, 68 p.

Harmon, R.S., 1979, An isotopic study of groundwater seepage in the central Kentucky karst: Water Resources Research, v. 15, no. 2, p. 476-480.

Harza Engineering Company, 1991, Development of a long range water supply plan: Lexington, Ky., Kentucky River Steering Committee, no pagination.

Hendrickson, G.E., 1958, Summary of occurrence of ground water in Kentucky: U.S. Geological Survey Hydrologic Investigation Atlas HA-10.

Hendrickson ' G.E., and Krieger, R.A., 1964, Geochemistry of natural waters of the Blue Grass Region, Kentucky: U.S. Geological Survey Water-Supply Paper 1700,135 p.

Hess, J.W., 1974, Hydrochernical investigations of the central Kentucky karst aquifer system: University Park, Pennsylvania State University, Ph.D. Dissertation, 218 p.

Hess, J.W., and White, W.B., 1974, Groundwater geochemistry in the central Kentucky karst aquifer [abs.]: Geological Society of America Abstracts with Programs, v. 6, no. 7, p. 792.

Hess, J.W., and White, W.B., 1976, Analysis of karst aquifers from hydrographs of karst springs: Congress of International Speleology, Proceedings, v. 4, no. 6, p. 115-120.

Hess, J.W., and White, W.B., 1988, Storm response of the karstic carbonate aquifer of south-central Kentucky: Journal of Hydrology, v. 99, nos. 3-4, p. 235-252.

Hine, G.T., 1970, Relation of fractures traces, joint, and ground-water occurrence in the area of the Bryantsville Quadrangle, central Kentucky: Kentucky Geological Survey, ser. 10, Thesis Series 10, 27 p.

Hodge, J.M., 1885, Preliminary report on the geology of the Lower North Fork, Middle and South Forks of the Kentucky River: Kentucky Geological Survey, ser. 2, Geological Reports, p. 54-154.

Hodge, J.M., 1908, Summary of report on the region drained by the three forks of the Kentucky River: Kentucky Geological Survey, ser. 3, Progress Report, p. 36-47.

Hopkins, H.T., 1966, Fresh-saline interface map of Kentucky: U.S. Geological Survey, Scale 1 inch-1 mile.

Hopkins, H.T., 1972, Preliminary report on the quality and direction of movement of water within the Knox Dolomite and St. Peter Sandstone: U.S. Geological Survey, unpublished report, 10 p.

Hopper, W.M., Jr., and Thrailkill, John, 1983, The lack of influence of lithology and structure on the development of a karst aquifer [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 4, p. 252.

Jillson, W.R., 1963a, A bibliography of the Kentucky River valley--Citations of printed and manuscript sources touching upon its history, geology, coal, oil, gas, calcite, barite, fluorite, galenite, sphalerite, and mining industries, with annotations: Frankfort, Ky., Roberts Printing Company, 55 p.

Jillson, W.R., 1963b, Delineation of the Mesozoic course of the Kentucky River across the Inner Bluegrass Region of the State: Frankfort, Ky., Roberts Printing Company, 24 p.

Johnson, J.H., and Stapleton, J.M., 1961, Mineral and water resources of Kentucky: Kentucky Department of Economic Development, 35 p.

Johnson, J.T., 1970, Non-parametric analysis of variables influencing limestone groundwater occurrence: Lexington, University of Kentucky, M.S. Thesis, 41 p.

Johnson, J.T., and Thrailkill, John, 1970, Non-parametric analysis of variables influencing limestone groundwater occurrence [abs.]: Geological Society of America, Abstracts with Programs, v. 2, no. 3, p. 221-222.

Johnson, J.T., and Thrailkill, John, 1973, Variables affecting well success in a Kentucky limestone aquifer: Journal of Hydrology, v. 20, no. 4, p. 327-333.

Johnson, M.L., 1981a, Dynamic re-adjustments in a cave system speleogenesis, a result of a base level surface stream abandoning 8 km (5 miles) of a surface meander streambed: Proceedings of the International Congress of Speleology, v. 8, p. 630.

Johnson, M.L., 1981b, Hydrochernical facies, a method to delineate the hydrology of inaccessible features of karst plumbing systems: Proceedings of the International Congress of Speleology, v. 8, p. 627-629.

journal of Hydraulics, 1974, Subsurface environment-Private property or public dornain?: Journal of Hydraulics, v. 100, no. 11, p. 1699-1675.

Kentucky Department of Conservation, Division of Flood Control and Water Usage, 1959, Kentucky Water Resources Commission study: Kentucky Department of Conservation, Division of Flood Control and Water Usage, 109 p.

Kentucky Environmental and Economic Development Policy Project, 1974: (NTIS Report PB-240 766), 56 p.

Kentucky Environmental Quality Commission, 1992, State of Kentucky's environment: A report of progress and problems: Kentucky Environmental Quality Commission, 332 p.

Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water, 1984, Report to Congress on water quality, 159 p.

Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water, 1986, Report to Congress on water quality, 157 p.

Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water, 1988, Report to Congress on water quality, 155 p.

Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water, 1990, Report to Congress on water quality, 187 p.

Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water, 1992, Report to Congress on water quality, 187 p.

Kilburn, Chabot, Price, WE., Jr., and Mull, D.S., 1962, Availability of ground water in Bell, Clay, Jackson, Knox, Laurel, Leslie, McCreary, Owsley, Rockcastle and Whitley Counties, Kentucky: U.S. Geological Survey Hydrologic Investigations Atlas HA-38.

Kipp, J.A., in preparation, The Knox Aquifer: Kentucky Geological Survey.

Kipp, J.A., and Dinger, J.S., 1984, Effects of fractures on ground-water hydrology in eastern Kentucky fabs.]: Geological Society of America Abstracts with Programs, v. 16, no. 3, p. 150.

Kipp, J.A., Lawrence, F.W., and Dinger, J.S., 1983, A conceptual model of ground-water flow in the eastern Kentucky coal field, in Graves, D.H., ed., Symposium on surface mining, hydrology, sedimentology, and reclamation: University of Kentucky, Office of Engineering Services, Bulletin 133, p. 543-548.

Krieger, R.A., Cushman, R.V, and Thomas, N.O., 1969, Water in Kentucky: Kentucky Geological Survey, ser. 10, Special Publication 16,51 p.

Kulp, WK., and Hopkins, H.T., 1960, Public and industrial water supplies of Kentucky: Kentucky Geological Survey, ser. 10, Information Circular 4,102 p.

Lattman, L.H., and Parizek, R.R., 1964, Relationship between fracture traces and the occurrence of ground-water in carbonate rocks: Journal of Hydrology, v. 2, no. 2, p. 73-91.

LeGrand, Harry, 1979, Evaluation techniques of fractured-rock hydrology: Journal of Hydrology, v. 43, nos. 1/4, p. 333-346.

Lovins, E.E., 1988, An evaluation of the drastic system in assessing groundwater pollution potential for parts of Marshall, Fayette, and Madison Counties, Kentucky: Lexington, University of Kentucky, M.S. Thesis, 135 p.

MacQuown, W.C., Jr., 1969, Geological factors controlling aquifer development in the lower Lexington Limestone (Middle Ordovician) of the central Blue Grass Region, Kentucky [abs.]: Geological Society of America, Special Paper 121, p. 454-455.

Matson, G.C., 1909, Water resources of the Blue Grass Region, Kentucky: U.S. Geological Survey WaterSupply Paper 233, 223 p.

McCann, M.R., 1975, Hydrogeology of northeast Woodford County, Kentucky: Lexington, University of Kentucky, M.S. Thesis, 104 p.

Mull, D.S., 1965, Ground-water resources of the Jenkins-Whitesburg area, Kentucky: U.S. Geological Survey Water-Supply Paper 1809-A, 36 p.

Mull, D.S., 1968, The hydrology of the Lexington and Fayette County, Kentucky, area: Lexington and Fayette County Planning Commission, U.S. Geological Survey, 24 p.

Mull, D.S., Cushman, RX, and Lambert, T.W., 1971, Public and industrial water supplies of Kentucky, 1968-69: Kentucky Geological Survey, ser. 10, Information Circular 20,107 p.

Noger, M.C., 1990, Generalized geologic bedrock conditions as related to solid-waste landfills in Kentucky: Map compiled for Kentucky Solid Waste Management Study: Issues and Options, Kiefer, J. D., coord., Kentucky Geological Survey, Scale 1:500,000.

Ohio River Valley Sanitation Commission, 1976, Registry of wells for use in underground injection of wastewater, 1972-1975, a summary of operational characteristics of injection wells in the Ohio Valley region: Ohio River Valley Sanitation Commission, 57

P.

Palmquist, W.N., Jr., and Hall, F.R., 1954, Public and industrial water supplies of the Blue Grass Region, Kentucky: U.S. Geological Survey, Circular 299, 101

P.

Palmquist, W.N., Jr., and Hall, ER., 1960a, Availability of ground water in Boyle, Garrard, Lincoln, and Mercer Counties, Kentucky: U.S. Geological Survey Hydrologic Investigations Atlas HA-20.

Palmquist, W.N., Jr., and Hall, F.R., 1960b, Availability of ground water in Bourbon, Fayette, Jessamine, and Scott Counties, Kentucky: U.S. Geological Survey Hydrologic Investigations Atlas HA-25.

Palmquist, W.N., Jr., and Hall, F.R., 1960c, Availability of ground water in Boone, Campbell, Grant, Kenton, and Pendleton Counties, Kentucky: U.S. Geological Survey, Hydrologic Investigations Atlas HA-15.

Palmquist, W.M., Jr., and Hall, F.R., 1961, Reconnaissance of ground-water resources in the Blue Grass Region, Kentucky: U.S. Geological Survey WaterSupply Paper 1533,39 p.

Pavona, K.V, 1971, Relation of groundwater chemistry to lithology in a Kentucky carbonate aquifer: Lexington, University of Kentucky, M.S. Thesis, 38 p.

Powell, R.L., 1966, Caves-Speleology and karst hydrology, in Natural features of Indiana-Symposium: Indiana Academy of Science, Proceedings, p. 116-130.

Price, W.E., Kilburn, Chabot, and Mull, D.S., 1962a, Availability of ground water in Boyd, Carter, Elliott, Greenup, Johnson, Lawrence, Lee, Menifee, Morgan, and Wolfe Counties, Kentucky: U.S. Geological Survey Hydrologic Investigations Atlas HA-37.

Price, W.E., Kilburn, Chabot, and Mull, D.S., 1962b, Availability of ground water in Breathitt, Floyd, Harlan, Knott, Letcher, Martin, Magoffin, Perry, and Pike Counties, Kentucky: U.S. Geological Survey Hydrologic Investigations Atlas HA-36.

Price, W.E., Mull, D.S., and Kilburn, Chabot, 1962, Reconnaissance of ground-water resources in the Eastern Coal Field region, Kentucky: U.S. Geological Survey Water-Supply Paper 1607,56 p.

Quinlan, J.F., and Ray, J.A., 1983, Procedures for efficient delineation of groundwater basins in karst areas [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 6, p. 666.

Quinones, Ferdinand, 1981, Hydrology of area 14, Eastern Coal Province, Kentucky: U.S. Geological Survey Open-File Report 81-0137,112 p.

Quinones, Ferdinand, Mull, D.S., York, Karen, and Kendall, Victoria, 1981, Hydrology of area 14, Eastern Coal Province, Kentucky: U.S. Geological Survey Water-Resources Investigations Report 81-137, 82 p.

Quinones, Ferdinand, and Plebuch, R.O., 1978, Hydrology of area 34, Interior Coal Province, Eastern Region, Kentucky and Indiana: U.S. Geological Survey Open-File Report 82-0638,126 p.

Rao, A.R., Tho, P.C., and Rukvichai, C., 1980, Characterization and models of watershed storage: Journal of Hydrology, v. 45, nos. 3-4, p. 253-277.

Rauch, H.W., 1984, Use of lineaments as exploratory tools for natural gas and ground water in Martin County, Kentucky: Proceedings of the International Symposium on Remote Sensing of Environment, v. 3, p. 249-250.

Robl, T.L., 1977, Factors controlling the geochernistry of vadose and stream waters in a carbonate terrain: Lexington, University of Kentucky, Ph.D. Dissertation, 216 p.

Robl, T.L., 1978, Factors controlling the geochemistry of stream waters in a carbonate terrain [abs.]: Geological Society of America Abstracts with Programs, v. 10, no. 4, p. 196.

Robl, T.L., 1979, The geochernistry of vadose and soil waters in a limestone terrain [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 504.

Roth, D.K., and Cooper, S.C., 1984, Hydrology of area 11, Eastern Coal Province, Ohio, Kentucky, and West Virginia: U.S. Geological Survey, Open-File Report 84-0233, 66 p.

Scanlon, B.R., 1985, Chemical, physical, and microbiological characteristics of groundwater in wells and springs in the Inner Bluegrass karst region: Lexington, University of Kentucky, Ph.D. Dissertation, 40 P.

Scanlon, B.R., 1989, Physical controls on hydrochemical variability in the Inner Bluegrass karst region of central Kentucky: Ground Water, v. 27, no. 5, p. 639-646.

Smith, M.O., 1966, Geology and successful farm ponds in the Inner Blue Grass Region of Kentucky: Kentucky Geological Survey, ser. 10, Thesis Series 1, 64 P.

Smoot, J.L., Liebermann, T.D., Evaldi, R.D., and White, K.D., 1990, Surface water-quality assessment of the Kentucky River Basin, Kentucky: Analysis of available water-quality data through 1986: U.S. Geological Survey Open-File Report 90-360, 209 p.

Spangler, L.E., 1982, Karst hydrogeology of northern Fayette and southern Scott counties, Kentucky: Lexington, University of Kentucky, M.S. Thesis, 103 p.

Spangler, L.E., Byrd, P.E., and Thrailkill, John, 1984, Use of optical brightener and direct yellow dyes for water tracing in the Inner Bluegrass karst region, Kentucky: National Speleological Society Bulletin, v. 46, no. 2, p. 10-16.

Spangler, L.E., and Thrailkill, John, 1981, Hydrogeology of northern Fayette County and southern Scott County, Kentucky, USA: Proceedings of the International Congress of Speleology, v. 8, p. 553-555.

Sprinkle, C.L., Davis, R.W., and Mull, D.S., 1983, Evaluation of ground-water quality data from KentuckyU.S. Geological Survey Open-File Report 83-0210,16 P.

Strahler, A.N., and Strahler, A.H., 1979, Elements of physical geography (2d ed.): New York, John Wiley, 560 p.

Thrailkill, John, 1969, Solution geochemistry of the water of limestone terraines: University of Kentucky Water Resources Research Institute, Report A-009-KY, 125 p.

Thrailkill, John, 1972a, Carbonate chemistry of aquifer and stream water in Kentucky: Journal of Hydrology, v. 16, no. 2, p. 93-104.

Thrailkill, John, 1972b, Digital computer modeling of limestone groundwater systems: University of Kentucky Water Resources Research Institute, Research Report 50, 71 p.

Thrailkill, John, 1973, Digital computer modeling of limestone groundwater systems [abs.]: Geological Society of America Abstracts with Programs, v, 5, no. 5, p. 445.

Thrailkill, John, 1974, Pipe flow models of a Kentucky limestone aquifer: Ground Water, v. 12, no. 4, p. 202-205.

Thrailkill, John, 1975, Carbonate equilibria in karst waters. Karst hydrology and water resources: Proceedings of the United States-Yugoslavian symposium, v. 2, Karst water resources, p. 745-771.

Thrailkill, John, 1983, The nature of groundwater basins in the Inner Bluegrass karst region, Kentucky [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 2, p. 97.

Thrailkill, John, 1984, Hydrogeology and environmental geology of the Inner Bluegrass karst region, Kentucky (Field guide for the Annual Meeting of the Southeastern and North-Central Sections, Geological Society of America, Lexington, Kentucky, April 4-6, 1984): University of Kentucky, Department of Geological Sciences, 31 p.

Thrailkill, John, 1985a, Flow in a limestone aquifer as determined from water tracing and water levels in wells: Journal of Hydrology, v. 78, nos. 1-2, p. 123-136.

Thrailkill, John, 1985b, The Inner Blue Grass karst region, in Dougherty, P.H., ed., Caves and karst of Kentucky: Kentucky Geological Survey, ser. 11, Special Publication 12, p. 28-62.

Thrailkill, John, Byrd, P.E., Hopper, W.H., Jr., McCann, M.R., Spangler, L.E., Troester, J.W., Gouzie, D.R., and Pogue, K.R., 1981, The Inner Bluegrass karst region, Kentucky, an overview: Eighth International Congress of Speleology, Proceedings, v. 1, p. 336-338.

Thrailkill, John, Byrd, P.E., Sullivan, S.B., Spangler, L.E., Taylor, C.J., Nelson, G.K., and Pogue, K.R., 1983, Studies in dye-tracing techniques of Kentucky: University of Kentucky Water Resources Research Institute, Research Report 140, 89 p.

Thrailkill, John, and Gouzie, D.R., 1984, Discharge and travel time determinations in the Royal Spring groundwater basin, Kentucky: University of Kentucky Water Resources Research Institute, Research Report 149, 43 p.

Thrailkill, John, Osolnik, M.J., and Postley, R.H., 1969, Calcite saturation relationships in a Kentucky limestone aquifer [abs.]: Geological Society of America Abstracts with Programs, v. 1, pt. 6, p. 49.

Thrailkill, John, Spangler, L.E., Hopper, W.M., Jr., McCann, M.R., Troester, J.W., and Gouzie, D.R., 1982, Groundwater in the Inner Bluegrass karst region, Kentucky: University of Kentucky Water Resources Research Institute, Research Report 136, 115 P.

Thrailkill, John, Troester, J.W., Spangler, L.E., and Cordiviola, S.J., 1984, Nature of a groundwater basin divide near Georgetown, Inner Blue Grass karst region, Kentucky: International Contributions to Hydrogeology, v. 1, p. 76-79.

Thrailkill, John, Wiseman, R.F., and Scanlon, B.R., 1985, Investigations of pollution in a karst aquifer utilizing optical brightener: University of Kentucky Water Resources Research Institute, Research Report 158, 39 p.

U.S. Department of Agriculture, 1981, Report for Kentucky River Basin: Economics and Statistics Service, Forest Service, and Soil Conservation Service, in cooperation with Kentucky Soil and Water Conservation Commission, and Kentucky Natural Resources and Environmental Protection Cabinet, 119 P.

U.S. Geological Survey, 1953, Surface water supply of the United States 1953: U.S. Geological Survey Water-Supply Paper 1275, 587 p.

U.S. Geological Survey, 1954, Surface water supply of the United States 1954: U.S. Geological Survey Water-Supply Paper 1335, 607 p.

U.S. Geological Survey, 1982, Water resources data for Kentucky-Water year 1981: U.S. Geological Survey Water Data Report KY-81-1, 685 p.

Waller, R.M., 1988, Ground water and the rural homeowner: U.S. Geological Survey, General Interest Publication, 37 p.

Warrick, David, and Straw, WT., 1985, The Kentucky River, a classic example of rejuvenation [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 3, p. 196.

Water Resources Bulletin, 1974, Family and individual costs of water development: Water Resources Bulletin, v. 10, no. 10, p. 91-101.

Watson, R.A., 1966, Central Kentucky karst hydrology: Limestone hydrology-A symposium with discussion: National Speleological Society Bulletin, v. 28, no. 3, p. 159-166.

Wells, L.G., Ward, A.D., and Phillips, R.E., 1983, Predicting infiltration and surface runoff from reconstructed spoils and soils: University of Kentucky Water Resources Research Institute, Research Report 143, 44 p.

Wells, S.G., 1974, Drainage basin morphology in the sinkhole plain of the central Kentucky karst: Conference on Karst Geological Hydrology, Proceedings, v. 4, p. 91.

Wells, S.G., 1977, Fluvial geomorphic responses to ground water hydrology in low relief karst [abs.]: Geological Society of America Abstracts with Programs, v. 9, no. 7, p. 1220-1221.

Wells, S.G., and Gutierrez, A.A., 1981, Geomorphic adjustments of fluvial systems to groundwater hydrology in semiarid and humid karst: Proceedings of the International Congress of Speleology, v. 8, p. 216.

Werner, Christian, 1972, Channel and ridge networks in drainage basins: Association of American Geographers, Proceedings, v. 4, p. 109-114.

Whitesides, D.V., 1970, Common errors in developing a groundwater aquifer: Ground Water v. 8, no. 4, p. 25-28.

Wright, W.G., 1985, Effects of fracturing on well yields in the coalfield area of Wise and Dickenson Counties, southwestern Virginia: U.S. Geological Survey Water Resources Investigation Report 85-4601, 21 p.

Wunsch, D.R., 1991, High barium concentrations in ground water in eastern Kentucky: Kentucky Geological Survey, ser. 11, Reprint 31, 14 p.

Wunsch, D.R., 1992, Ground-water geochemistry and its relationship to the flow system at an unmined site in the Eastern Kentucky Coal Field: Lexington, University of Kentucky, Ph.D. Dissertation, 268 p.

Wunsch, D.R., 1992, Ground-water geochemistry and its relationship to the flow system at an unmined site in the Eastern Kentucky Coal Field: Kentucky Geological Survey, ser. 11, Thesis Series 5,128 p.

Wyrick, G.G., and Borchers, J.W., 1981, Hydrologic effects of stress-relief fracturing in an Appalachian valley: U.S. Geological Survey Water-Supply Paper 2177,51 p.

GLOSSARY

Aquifer-An underground formation of rock or unconsolidated material that contains and yields water.

Confined aquifer-Aquifer that is overlain and underlain by confining beds and contains water that is under sufficient pressure to rise above the top of the aquifer. Also called artesian aquifer.

Discharge, ground-water-Discharge of water from an aquifer either by natural means such as evapotranspiration and flow from seeps and springs, or by artificial means such as pumping from wells.

Drawdown and recovery-Drawdown is the lowering of the water level in a well as a result of withdrawal of water. Recovery is the rise of the water level after withdrawal of water has ceased. Both are generally measured in feet.

Evapotranspiration-Total discharge of water to the air by direct evaporation and plant transpiration.

Ground water-Water beneath the earth's surface between saturated soil and rock that supplies wells and springs.

Hydraulic conductivity-A coefficient of proportionality describing the rate at which water can move through an aquifer.

Hydrogeology-The science that deals with subsurface waters and related geologic aspects of surface waters: the study of the laws and occurrence of movement of subterranean waters.

Hydrostatic pressure-The pressure exerted by the water at a given point in a body of water at rest.

Lithology-The description of rocks on the basis of such characteristics as color, structure, mineralogic composition, and grain size; the physical character of a rock.

Mineralogy-The study of minerals; their formation and occurrence, properties and composition, and their classification.

Permeability-The capacity of earth material to transmit water under pressure. In general, the larger the connected pore spaces or other openings in the material, the greater the permeability.

Porosity-The ratio of the volume of the openings to the total volume of rock, unconsolidated sediment, or soil. A high porosity does not necessarily indicate a high permeability.

Pressure head-Hydrostatic pressure expressed as the height of a column of water that can be supported by the pressure. It is the height that a column of water rises in a tightly cased well that has no discharge. The pressure head is commonly expressed with reference to the land surface at the well or some other convenient datum.

Recharge, ground-water-Addition of water to an aquifer from all sources; in this region, chiefly from infiltration of precipitation through the soil, seepage from streams or other bodies of surface water, flow of surface water through sinkholes, or flow of ground water from another aquifer.

Specific capacity- The rate of yield of a well per unit of drawdown, generally expressed in gallons per minute per foot of drawdown at the end of a specified period of discharge. It is not an exact quantity, as drawdown increases with time, but it gives an approximate indication of how much water a well can yield.

Specific conductance- A measure of the ability of water to conduct an electrical current; depends on the quantity and types of ionized substances in the water. Freshly distilled water has a conductivity of about 1 microsiemen per centimeter (pS/cm). The conductivity of drinkable waters in the United States ranges from 50 to 1,500 gS/cm. The specific conductance in pS/cm can be multiplied by 0.64 to estimate dissolved-solids concentration in milligrams per liter (mg/L).

Specific yield- The ratio of the volume of water a rock will yield by gravity, after being saturated, to the volume of rock.

Static water level- The water level measured in a well when the water level is unaffected by withdrawals or recharge through the well or nearby wells.

Storativity- The volume of water an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in pressure head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to the specific yield. Also called storage coefficient.

APPENDIX A:

Wells and Springs Reported Used for Large-Demand Purposes in the Kentucky River Basin

ANDERSON COUNTY

Map ID Number	Type of Site	Reported Water Use	Latitude	Longitude	Ground Elevation (ft.)	Well Depth (ft.)	Producing Zone or Aquifer	Producing Formation/Member
00006264	water well	industrial	380222.00	845047.00	540.0	65.0		alluvium

CLARK COUNTY

Map ID Number	Type of Site	Reported Water Use	Latitude	Longitude	Ground Elevation (ft.)	Well Depth (ft.)	Producing Zone or Aquifer	Producing Formation/Member
00005570	water well	irrigation	375652.00	841005.00	900.0	95.0	Lexington Ls.	Tanglewood
00005596	water well	irrigation	375859.00	841230.0	990.0	58.0	Lexington Ls.	Millersburg
00006062	water well	irrigation	375645.00	840836.00	850.00	65.0		
00006057	water well	irrigation	375756.00	840652.00	1000.0	50.0	Lexington Ls.	Millersburg
00006152	water well	irrigation	375510.00	842032.00	700.0	85.0	High Bridge	Camp Nelson

CLAY COUNTY

Map ID Number	Type of Site	Reported Water Use	Latitude	Longitude	Ground Elevation (ft.)	Well Depth (ft.)	Producing Zone or Aquifer	Producing Formation/Member
00006216	water well	municipal	371008.00	844232.00	920.0			Breathitt

ESTILL COUNTY

Map ID Number	Type of Site	Reported Water Use	Latitude	Longitude	Ground Elevation (ft.)	Well Depth (ft.)	Producing Zone or Aquifer	Producing Formation/Member
00006068	water well	irrigation	374152.00	835909.00	630.0	38.0	sand	alluvium

FAYETTE COUNTY

Map ID Number	Type of Site	Reported Water Use	Latitude	Longitude	Ground Elevation (ft.)	Well Depth (ft.)	Producing Zone or Aquifer	Producing Formation/Member
00000679	water well	domestic	380722.00	843224.00	955.0	203.0	Lexington Ls.	Grier
00001069	water well	domestic	380308.00	843624.00	935.0	84.0	Lexington Ls.	Grier
00001196	water well	irrigation	380538.00	843700.00	890.0	103.0	Lexington Ls.	Grier
00001288	water well	irrigation	380845.00	843112.00	850.0	140.0	Lexington Ls.	Grier
00001291	water well	irrigation	380910.00	843128.00	850.0	103.0	Lexington Ls.	Grier
00001395	water well	irrigation	380517.00	842901.00	965.0	207.0		
00001406	water well	irrigation	380436.00	841733.00	1000.0	1107.0	Knox	sand
00001407	water well	irrigation	380429.00	841725.00	1000.0	125.0	Lexington Ls.	Tanglewood
00001408	water well	irrigation	380434.00	841724.00	1010.0	205.0	Lexington Ls.	Tanglewood

FAYETTE COUNTY—Continued

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00001409	water well	irrigation	380433.00	841741.00	990.0	185.0	Lexington Ls.	Tanglewood
00001437	water well	irrigation	380907.00	843128.00	840.0	60.0	Lexington Ls.	Tanglewood
00001476	water well	irrigation	380842.00	843112.00	850.0	153.0	Lexington Ls.	Grier
00001477	water well	irrigation	380845.00	843112.00	860.0	140.0	Lexington Ls.	Grier
00001604	water well	irrigation	380530.00	842856.00	950.0	200.0	Lexington Ls.	Grier
00001615	water well	irrigation	380517.00	842900.00	965.0	1010.0	Knox	
00002710	water well	irrigation	381116.00	842338.00	941.4	68.9	Lexington Ls.	Tanglewood
00002715	water well	irrigation	381116.00	842347.00	921.7		Lexington Ls.	Tanglewood
00002727	water well	irrigation	380812.00	842716.00	908.6	82.0	Lexington Ls.	Grier
00002733	water well	irrigation	380914.00	842408.00	938.1		Lexington Ls.	Tanglewood
00002734	water well	irrigation	380053.00	843831.00	888.9	68.9	Lexington Ls.	Grier
00002753	water well	irrigation	380048.00	843829.50	879.0		Lexington Ls.	Grier
00002758	water well	irrigation	380240.00	843649.00	905.3	82.0	Lexington Ls.	Grier
00002766	water well	irrigation	380316.50	843615.00	898.7	98.4	Lexington Ls.	Grier
00002767	water well	irrigation	380317.00	843619.00	888.9	121.4	Lexington Ls.	Grier
00002768	water well	irrigation	380204.50	843645.00	875.8	98.4	Lexington Ls.	Grier
00005562	water well	irrigation	380707.00	843152.00	950.0	76.0	Lexington Ls.	Tanglewood
00005580	water well	irrigation	380416.00	841921.00	934.0	148.0	Lexington Ls.	Tanglewood
00005592	water well	irrigation	380159.00	842138.00	1000.0	125.0	Lexington Ls.	Tanglewood
00005593	water well	irrigation	380415.00	842401.00	930.0	105.0	Lexington Ls.	
00005637	water well	irrigation	380206.00	843840.00	910.0	125.0	Lexington Ls.	Grier
00005818	water well	irrigation	380148.00	843437.00	990.0	65.0	Lexington Ls.	Tanglewood
00005820	water well	irrigation	380949.00	842843.00	900.0	125.0	Lexington Ls.	Grier
00005822	water well	irrigation	380756.00	843522.00	930.0	85.0	Lexington Ls.	Tanglewood
00005826	water well	irrigation	380949.00	842843.00	900.0	125.0	Lexington Ls.	Grier
00005951	water well	irrigation	380102.00	842301.00	1005.0	105.0	Lexington Ls.	Tanglewood
00005952	water well	irrigation	380103.00	842310.00	1000.0	104.0	Lexington Ls.	Tanglewood
00005953	water well	irrigation	380101.00	842300.00	995.0	104.0	Lexington Ls.	Tanglewood

FAYETTE COUNTY—Continued

Map ID Number	Type of Site	Reported Water Use	Latitude	Longitude	Ground Elevation (ft.)	Well Depth (ft.)	Producing Zone or Aquifer	Producing Formation/Member
00005954	water well	irrigation	380740.00	842223.00	950.0	140.0		
00005955	water well	irrigation	380256.00	842126.00	1000.0	950.0	Knox	sandy limestone
00005957	water well	irrigation	380251.00	842117.00	1025.0	60.0	Lexington Ls.	Millersburg
00005958	water well	irrigation	375716.00	842053.00	900.0	80.0	Lexington Ls.	Grier
00005963	water well	irrigation	380202.00	842247.00	950.0	85.0	Lexington Ls.	Tanglewood
00005967	water well	irrigation	380104.00	842250.00	1000.0	85.0	Lexington Ls.	Tanglewood
00006059	water well	irrigation	380138.00	842207.00	980.0	125.0	Lexington Ls.	Tanglewood
00006060	water well	irrigation	380138.00	842200.00	1000.0	100.0	Lexington Ls.	Tanglewood
00006061	water well	irrigation	380713.00	843151.00	950.0	45.0	Lexington Ls.	Tanglewood
00006217	water well	irrigation	380211.00	843128.00	930.0		Lexington Ls.	Grier
00006218	water well	irrigation	380730.00	843230.00	940.0		Lexington Ls.	
00007878	water well	irrigation	380432.00	842001.00	934.0	78.0	Lexington Ls.	Tanglewood

FRANKLIN COUNTY

Map ID Number	Type of Site	Reported Water Use	Latitude	Longitude	Ground Elevation (ft.)	Well Depth (ft.)	Producing Zone or Aquifer	Producing Formation/Member
00000814	water well	industrial	380915.00	845127.00	500.0		coarse gravel	alluvium
00000815	water well	industrial	380915.00	845127.00	500.0		coarse gravel	alluvium
00000816	water well	industrial	380915.00	845127.00	500.0		coarse gravel	alluvium
00000817	water well	industrial	380915.00	845127.00	500.0		coarse gravel	alluvium
00000818	water well	industrial	380915.00	845127.00	500.0		coarse gravel	alluvium
00001195	water well	irrigation	381328.00	844939.00	755.0	128.0	Lexington Ls.	Tanglewood
00005582	water well	irrigation	381113.00	844936.00	690.0	350.0	Lexington Ls	Grier
00005634	water well	irrigation	381219.00	844840.00	700.0	85.0	Lexington Ls.	Grier

GARRARD COUNTY

Map ID Number	Type of Site	Reported Water Use	Latitude	Longitude	Ground Elevation (ft.)	Well Depth (ft.)	Producing Zone or Aquifer	Producing Formation/Member
00006056	water well	irrigation	373906.00	843226.00	860.0	140.0		
00012885	water well	municipal	373655.00	843511.00	940.0	128.0		Garrard

JESSAMINE COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00000697	water well	irrigation	375344.00	843555.00	890.0	886.0	Knox	
00001313	water well	irrigation	375741.00	843529.00	1010.0	153.0		
00001343	water well	irrigation	375811.00	843743.00	964.0	153.0	Lexington Ls.	Grier
00001345	water well	irrigation	375813.00	843753.00	950.0	105.0	Lexington Ls.	Grier
00001346	water well	irrigation	375812.00	843757.00	953.0	153.0	Lexington Ls.	Grier
00001347	water well	irrigation	375828.00	843750.00	946.0	78.0	Lexington Ls.	Grier
00001348	water well	irrigation	375832.00	843756.00	945.0	153.0	Lexington Ls.	Grier
00001584	water well	irrigation	375811.00	843755.00	956.0	203.0	Lexington Ls.	Grier
00001585	water well	irrigation	375810.00	843759.00	950.0	153.0	Lexington Ls.	Grier
00001586	water well	irrigation	375811.00	843804.00	960.0	178.0	Lexington Ls.	Grier
00001587	water well	irrigation	375816.00	843806.00	990.0	203.0	Lexington Ls.	Grier
00004143	spring	irrigation	375832.62	843746.83	925.0		Lexington Ls.	Grier
00004148	water well	irrigation	375834.11	843748.07	935.0	255.0	Lexington Ls.	Grier
00004806	spring	irrigation	375814.00	843436.00	930.0		Lexington Ls.	Grier
00005816	water well	irrigation	375537.00	843235.00	950.0	125.0	Lexington Ls.	Grier
00006055	water well	irrigation	375649.00	843603.00	990.0	85.0	Lexington Ls.	Grier
00006265	water well	municipal	375309.00	843345.00	1020.0		Lexington Ls.	
00006392	water well	industrial	374612.00	843704.00	580.0	125.0	High Bridge	Camp Nelson
00006393	water well	industrial	374613.00	843653.00	580.0	200.0	High Bridge	Camp Nelson

KNOTT COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00004411	water well	public	371557.00	830542.00	1230.0	61.0	coal	Breathitt
00004955	water well	public	372024.00	825841.00	1340.0	164.0	coal & siltstone	Breathitt
00005714	water well	public	372009.00	825857.00	1100.0	200.0		
00005918	water well	public	371706.00	825608.00	1300.0	280.0		
00006219	water well	municipal	372003.00	825825.00	1035.0			Breathitt

LESLIE COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00002557	water well	public	370016.00	832003.00	1140.0	61.0	siltstone	Breathitt
00002558	water well	public	370010.00	832011.00	1220.0	82.0	coal	Breathitt

LETCHER COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00002421	water well	industrial	371153.00	824135.00	1354.0	100.0	coal	Breathitt
00006014	water well	public	371017.00	824057.00	1720.0	164.0		
00006022	water well	industrial	370829.00	830108.00	900.0	100.0	sandstone	Breathitt
00006221	water well	municipal	371238.00	823950.00	1580.0			Breathitt
00006222	water well	municipal	371305.00	824111.00	1600.0			Breathitt
00006223	water well	municipal	371112.00	824150.00	1360.0			Breathitt
00012848	water well	public	371047.00	824105.00	1420.0	54.0		Breathitt
00012868	water well	public	370700.00	824918.00	1160.0	180.0		Breathitt
00012871	water well	industrial	371122.00	824255.00	1280.0	75.0	sandstone & coal	Breathitt
00012875	water well	public	371032.00	824459.00	1300.0	220.0		Breathitt
00012880	water well	industrial	371413.50	824713.00	1245.0	300.0		Breathitt
00012881	water well	industrial	371418.50	824649.00	1260.0	285.0		Breathitt
00012882	water well	industrial	371411.50	824716.00	1250.0	325.0		Breathitt
00012883	water well	industrial	371420.00	824643.00	1270.0	303.0		Breathitt
00012884	water well	industrial	371416.00	824706.00	1250.0	325.0		Breathitt

LINCOLN COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00004145	spring	municipal	373253.00	844029.00	935.0			Boyle
00005406	water well	irrigation	372734.00	843021.00	938.0	62.0		Boyle

MERCER COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00005576	water well	irrigation	375118.00	844131.00	650.0	125.0	High Bridge	Camp Nelson
00006391	water well	municipal	374505.00	844614.00	880.0	25.0	Lexington Ls.	Grier

OWEN COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00006144	water well	irrigation	382458.00	845039.00	560.0	40.0	Lexington Ls.	Grier
00006146	water well	irrigation	382239.00	844941.00	600.0	105.0		

OWSLEY COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00005905	water well	public	372432.00	834932.00	1100.0	55.0		

PERRY COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00000003	water well	institution	372053.39	832832.19	760.0	93.0	sandstone	Breathitt
00000005	water well	institution	372119.28	832007.43	820.0	110.0		Breathitt
00000249	water well	municipal	371530.00	831514.00	860.0	60.0		
00002503	water well	public	371017.00	830628.00	1040.0	102.0		
00003892	water well	industrial	371822.00	831052.00	1240.0	200.0		
00003940	water well	public	371424.00	831135.00	1360.0	123.0		

POWELL COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00006394	water well	municipal	375102.00	835140.00	660.0	150.0		alluvium

SCOTT COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
0002786	water well	irrigation	381016.00	843215.00	839.7	52.5	Lexington Ls.	Tanglewood
00002787	water well	irrigation	380958.00	843201.00	852.8	65.6	Lexington Ls.	Tanglewood

SCOTT COUNTY—Continued

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00005780	water well	public	381231.00	843344.00	840.0	42.0	Lexington Ls.	Grier
00005781	water well	public	381233.00	843342.00	840.0	62.0	Lexington Ls.	Grier
00005862	water well	irrigation	381042.00	844011.00	800.0	185.0	Lexington Ls.	Grier
00005863	water well	irrigation	381144.00	843407.00	880.0	145.0	Lexington Ls.	Tanglewood
00005866	water well	irrigation	381113.00	843024.00	850.0	85.0	Lexington Ls.	Grier
00006067	water well	irrigation	381139.00	844033.00	850.0	249.0		
00006069	water well	irrigation	381022.00	843541.00	880.0	185.0	Lexington Ls.	
00006241	spring	municipal	381230.00	843344.00	810.0		Lexington Ls.	Grier
00006269	water well	institution	381317.00	843405.00	850.0	120.0	Lexington Ls.	Tanglewood
00006270	water well	institution	381319.00	843407.00	850.0	130.0	Lexington Ls.	Tanglewood

WOODFORD COUNTY

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00001293	water well	irrigation	380447.00	844158.00	870.0	148.0	Lexington Ls.	Grier
00001294	water well	irrigation	380444.00	844234.00	892.0	170.0	Lexington Ls.	Grier
00001295	water well	irrigation	380508.00	844257.00	873.0	100.0	Lexington Ls.	Grier
00001296	water well	irrigation	380541.00	844255.00	886.0	128.0	Lexington Ls.	Grier
00001297	water well	irrigation	380534.00	844225.00	843.0	100.0	Lexington Ls.	Grier
00001300	water well	irrigation	380456.00	844317.00	885.0	153.0	Lexington Ls.	Grier
00001302	water well	irrigation	380457.00	844200.00	868.0	138.0	Lexington Ls.	Grier
00001303	water well	irrigation	380459.00	844207.00	869.0	128.0	Lexington Ls.	Grier
00001304	water well	irrigation	380450.00	844208.00	880.0	150.0	Lexington Ls.	Grier
00001305	water well	irrigation	380450.00	844157.00	870.0	153.0	Lexington Ls.	Grier
00001306	water well	irrigation	380645.00	843832.00	855.0	129.0	Lexington Ls.	Grier
00001307	water well	irrigation	380628.00	843844.00	870.0	179.0	Lexington Ls.	Grier
00001308	water well	irrigation	380626.00	843850.00	850.0	104.0	Lexington Ls.	Grier
00001580	water well	stock	380715.00	844613.00	882.0	200.0	Lexington Ls.	
00001581	water well	stock	380718.00	844613.00	880.0	200.0	Lexington Ls.	

WOODFORD COUNTY—Continued

Map ID Number	*Type of Site*	*Reported Water Use*	*Latitude*	*Longitude*	*Ground Elevation (ft.)*	*Well Depth (ft.)*	*Producing Zone or Aquifer*	*Producing Formation/Member*
00002789	water well	domestic	380323.00	843919.00	875.8	13.1	Lexington Ls.	Grier
00004139	spring	irrigation	375937.00	843958.00	850.0		Lexington Ls.	Grier
00005812	water well	irrigation	380739.00	844313.00	890.0	205.0		
00005823	water well	irrigation	380409.00	844103.00	930.0	145.0		
00005860	water well	irrigation	380554.00	844034.00	880.0	165.0		
00005964	water well	irrigation	380841.00	844112.00	800.0	105.0	Lexington Ls.	Grier
00006268	water well	industrial	380641.00	844853.00	680.0	105.0	Lexington Ls.	Grier
00012821	water well	industrial	380647.00	844835.00	695.0	86.0	Lexington Ls.	Grier
00012822	water well	industrial	380647.00	844837.00	695.0	62.0	Lexington Ls.	Grier
00012823	water well	industrial	380643.50	844848.00	690.0	92.5	Lexington Ls.	Grier
00012824	water well	industrial	380650.00	844837.00	700.0	89.0	Lexington Ls.	Grier
00012825	water well	industrial	380907.00	844051.00	795.0	160.0	Lexington Ls.	Grier
00012826	water well	industrial	380901.00	844055.00	805.0	90.0	Lexington Ls.	Grier
00012827	water well	municipal	380848.00	844050.00	815.0	120.0	Lexington Ls.	Grier
00012832	water well	irrigation	381007.00	844432.00	803.6	98.4	Lexington Ls.	Grier
00012839	water well	irrigation	380618.00	843822.00	833.1	68.9	Lexington Ls.	Grier
00012892	spring	municipal	380313.00	844329.00	930.0	180.0	Lexington Ls.	Tanglewood

APPENDIX B:
Underground Storage Tank Data
Kentucky River Basin

UNDERGROUND STORAGE TANKS KENTUCKY RIVER BASIN

Basin Total: 6,691	Status: All Basin	Count	Percent
	Active	2,905	43.4
	Removed/Verified	1,403	21.0
	Closed in place	15	0.2
	Temporarily closed	141	2.1
	Exempt	154	2.3
	Removed/Unverified	493	7.4
	Not verified	1,571	23.5
	Unknown	9	0.1

Substance	Count	Status	Count	Percent
CERCLA	46			
	0.7%	Active	5	10.9
		Removed/Verified	4	8.7
		Closed in place	0	0.0
		Temporarily closed	0	0.0
		Exempt	8	17.4
		Removed/Unverified	3	6.5
		Not verified	26	56.5
		Unknown	0	0.0
Diesel	1,086			
	16.2%	Active	468	43.1
		Removed/Verified	251	23.1
		Closed in place	0	0.0
		Temporarily closed	19	1.7
		Exempt	27	2.5
		Removed/Unverified	56	5.2
		Not verified	264	24.3
		Unknown	1	0.1
Empty	239			
	3.6%	Active	49	20.5
		Removed/Verified	46	19.2
		Closed in place	1	0.4
		Temporarily closed	26	10.9
		Exempt	4	1.7
		Removed/Unverified	46	19.2
		Not verified	62	25.9
		Unknown	5	2.1

Substance	Count	Status	Count	Percent
Gasoline	4,253			
	63.6%	Active	1,945	45.7
		Removed/Verified	882	20.7
		Closed in place	7	0.2
		Temporarily closed	76	1.8
		Exempt	30	0.7
		Removed/Unverified	303	7.1
		Not verified	1,009	23.7
		Unknown	1	0.0
Jet	25			
	0.4%	Active	12	48.0
		Removed/Verified	3	12.0
		Closed in place	0	0.0
		Temporarily closed	0	0.0
		Exempt	0	0.0
		Removed/Unverified	1	4.0
		Not verified	9	36.0
		Unknown	0	0.0
Kerosene	368			
	5.5%	Active	167	45.4
		Removed/Verified	56	15.2
		Closed in place	1	0.3
		Temporarily closed	5	1.4
		Exempt	54	14.7
		Removed/Unverified	10	2.7
		Not verified	75	20.4
		Unknown	0	0.0
Oil	432			
	6.5%	Active	163	37.7
		Removed/Verified	126	29.2
		Closed in place	1	0.2
		Temporarily closed	11	2.5
		Exempt	13	3.0
		Removed/Unverified	38	8.8
		Not verified	79	18.3
		Unknown	1	0.2
Other	25			
	0.4%	Active	11	44.0
		Removed/Verified	4	16.0
		Closed in place	0	0.0
		Temporarily closed	0	0.0
		Exempt	7	28.0
		Removed/Unverified	1	4.0
		Not verified	2	8.0

Substance	Count	Status	Count	Percent
		Unknown	0	0.0
Unknown	217			
	3.2%	Active	85	39.2
		Removed/Verified	31	14.3
		Closed in place	5	2.3
		Temporarily closed	4	1.8
		Exempt	11	5.1
		Removed/Unverified	35	16.1
		Not verified	45	20.7
		Unknown	1	0.5

UNDERGROUND STORAGE TANKS BY COUNTY

Breathitt: 183

Substance	*Count*	*Status*	*Count*
Diesel	34		
		Active	8
Not verified	13		
		Removed/Verified	7
		Removed/Unverified	6
Empty	3		
		Not verified	3
Gasoline	122		
		Active	46
		Exempt	1
		Not verified	45
		Removed/Verified	15
		Temporarily closed	7
		Removed/Unverified	8
Jet	3		
		Active	1
		Not verified	1
		Removed/Unverified	1
Kerosene	7		
		Active	5
		Not verified	1
		Exempt	1
Oil	6		
		Active	4
		Removed/Unverified	1
		Removed/Verified	1
Other	1		
		Exempt	1
Unknown	7		
		Active	5
		Not verified	2

Carroll: 160

Substance	*Count*	*Status*	*Count*
Diesel	24		
		Active	9
		Removed/Verified	13
		Removed/Unverified	2
Empty	5		
		Removed/Verified	4
		Removed/Unverified	1
Gasoline	100		
		Active	44
		Exempt	1
		Not verified	16
		Removed/Verified	28
		Temporarily closed	1
		Removed/Unverified	10
Kerosene	13		
		Active	4
		Exempt	7
		Removed/Verified	2
Oil	7		
		Active	4
		Removed/Verified	1
		Removed/Unverified	2
Other	2		
		Active	1
		Not verified	1
Unknown	9		
		Not verified	5
		Removed/Verified	3
		Removed/Unverified	1

Clark: 283

Substance	*Count*	*Status*	*Count*
Diesel	60		
		Exempt	7
		Not verified	13
		Removed/Verified	17
		Removed/Unverified	7
Empty	6		
		Active	2
		Removed/Verified	4
Gasoline	169		
		Active	58
		Exempt	1
		Not verified	36
		Removed/Verified	59
		Temporarily closed	1
		Removed/Unverified	14
CERCLA	1		
		Removed/Verified	1

Kerosene	14		
		Active	6
		Exempt	1
		Not verified	2
		Removed/Verified	5
Oil	27		
		Active	7
		Not verified	7
		Removed/Verified	12
		Removed/Unverified	1
Unknown	6		
		Not verified	3
		Removed/Verified	3

Clay: 168

Substance	*Count*	*Status*	*Count*
Diesel	23		
		Active	7
		Exempt	2
		Not verified	7
		Removed/Verified	5
		Temporarily closed	2
Empty	2		
		Active	2
Gasoline	128		
		Active	40
		Not verified	50
		Removed/Verified	26
		Temporarily closed	6
		Removed/Unverified	6
Kerosene	6		
		Active	3
		Removed/Verified	2
		Temporarily closed	1
Oil	3		
		Active	1
		Not verified	1
		Removed/Unverified	1
Unknown	6		
		Active	5
		Not verified	1

Estill: 176

Substance	*Count*	*Status*	*Count*
Diesel	20		
		Active	10
		Exempt	1
		Not verified	6
		Removed/Verified	3
Empty	7		
		Not verified	2
		Removed/Verified	3
		Temporarily closed	2
Gasoline	132		
		Active	45
		Exempt	4
		Not verified	59
		Removed/Verified	16
		Removed/Unverified	8
CERCLA	2		
		Active	2
Jet	3		
		Active	3
Kerosene	9		
		Active	5
		Not verified	4
Oil	3		
		Active	3

Fayette: 1,705

Substance	*Count*	*Status*	*Count*
Diesel	317		
		Active	116
		Exempt	8
		Not verified	70
		Unknown	1
		Removed/Verified	109
		Temporarily closed	1
		Removed/Unverified	12
Empty	59		
		Active	8
		Exempt	1
		Not verified	20
		Removed/Verified	14
		Temporarily closed	6
		Removed/Unverified	10
Gasoline	926		
		Active	410
		Closed in place	2
		Exempt	7
		Not verified	182
		Unknown	1
		Removed/Verified	249
		Temporarily closed	7
		Removed/Unverified	68

CERCLA	36		
		Active	2
		Exempt	6
		Not verified	25
		Removed/Verified	3
Jet	11		
		Active	1
		Not verified	8
		Removed/Verified	2
Kerosene	96		
		Active	32
		Closed in place	1
		Exempt	16
		Not verified	23
		Removed/Verified	18
		Temporarily closed	1
		Removed/Unverified	5
Oil	189		
		Unknown	1
		Active	69
		Exempt	2
		Not verified	35
		Removed/Verified	63
		Temporarily closed	8
		Removed/Unverified	11
Other	3		
		Active	1
		Exempt	2
Unknown	68		
		Active	20
		Closed in place	2
		Exempt	8
		Not verified	9
		Removed/Verified	16
		Removed/Unverified	13

Franklin: 489

Substance	*Count*	*Status*	*Count*
Diesel	47		
		Active	16
		Exempt	3
		Not verified	14
		Removed/Verified	13
		Removed/Unverified	1
Empty	20		
		Active	5
		Not verified	3
		Removed/Verified	5
		Temporarily closed	2
		Removed/Unverified	5
Gasoline	317		
		Active	124
		Exempt	2
		Not verified	66
		Removed/Verified	85
		Temporarily closed	6
		Removed/Unverified	34
Jet	4		
		Active	4
Kerosene	37		
		Active	16
		Exempt	11
		Not verified	6
		Removed/Verified	3
		Temporarily closed	1
Oil	42		
		Active	11
		Exempt	1
		Not verified	10
		Removed/Verified	14
		Removed/Unverified	6
Other	3		
		Exempt	2
		Removed/Unverified	1
Unknown	19		
		Active	2
		Exempt	1
		Not verified	5
		Removed/Verified	4
		Removed/Unverified	7

Garrard: 150

Substance	*Count*	*Status*	*Count*
Diesel	24		
		Active	5
		Not verified	13
		Removed/Verified	4
		Removed/Unverified	2
Empty	11		
		Active	2
		Not verified	4
		Removed/Verified	4
		Removed/Unverified	1
Gasoline	102		
		Active	30
		Not verified	33
		Removed/Verified	33
		Removed/Unverified	6

Kerosene	5		
		Active	4
		Not verified	1
Oil	2		
		Active	1
		Removed/Verified	1
Unknown	6		
		Active	6

Grant: 192

Substance	*Count*	*Status*	*Count*
Diesel	24		
		Active	11
		Not verified	10
		Temporarily closed	2
		Removed/Unverified	1
Empty	11		
		Active	7
		Closed in place	1
		Not verified	3
Gasoline	126		
		Active	31
		Closed in place	1
		Not verified	55
		Removed/Verified	21
		Temporarily closed	4
		Removed/Unverified	14
Kerosene	16		
		Active	5
		Exempt	2
		Not verified	8
		Removed/Verified	1
Oil	13		
		Active	1
		Closed in place	1
		Exempt	2
		Not verified	6
		Removed/Verified	2
		Removed/Unverified	1
Other	1		
		Exempt	1
Unknown	1		
		Active	1

Henry: 218

Substance	*Count*	*Status*	*Count*
Diesel	42		
		Active	21
		Not verified	15
		Removed/Verified	4
		Temporarily closed	1
		Removed/Unverified	1
Empty	13		
		Active	2
		Not verified	6
		Removed/Verified	2
		Temporarily closed	3
Gasoline	136		
		Active	58
		Not verified	41
		Removed/Verified	28
		Temporarily closed	3
		Removed/Unverified	6
Kerosene	17		
		Active	8
		Not verified	7
		Removed/Verified	2
Oil	5		
		Active	1
		Exempt	1
		Not verified	2
		Removed/Verified	1
Unknown	5		
		Closed in place	3
		Not verified	2

Jessamine: 223

Substance	*Count*	*Status*	*Count*
Diesel	42		
		Active	14
		Exempt	1
		Not verified	10
		Removed/Verified	16
		Removed/Unverified	1
Empty	4		
		Active	1
		Unknown	2
		Temporarily closed	1

Gasoline	152		
		Active	71
		Exempt	1
		Not verified	29
		Removed/Verified	40
		Removed/Unverified	11
Kerosene	9		
		Active	4
		Not verified	4
		Removed/Verified	1
Oil	13		
		Active	7
		Not verified	3
		Removed/Verified	2
		Removed/Unverified	1
Other	2		
		Removed/Verified	2
Unknown	1		
		Active	1

Knott: 130

Substance	*Count*	*Status*	*Count*
Diesel	21		
		Active	18
		Temporarily closed	1
		Removed/Unverified	2
Empty	3		
		Active	1
		Removed/Unverified	2
Gasoline	88		
		Active	65
		Not verified	3
		Removed/Verified	15
		Temporarily closed	1
		Removed/Unverified	4
Kerosene	9		
		Active	8
		Temporarily closed	1
Oil	3		
		Active	1
		Temporarily closed	1
		Removed/Unverified	1
Unknown	6		
		Active	4
		Temporarily closed	2

Lee: 103

Substance	*Count*	*Status*	*Count*
Diesel	19		
		Active	8
		Exempt	1
		Not verified	2
		Removed/Verified	3
		Removed/Unverified	5
Empty	1		
		Removed/Unverified	1
Gasoline	67		
		Active	48
		Not verified	9
		Removed/Verified	5
		Removed/Unverified	5
Kerosene	4		
		Active	2
		Removed/Verified	2
Oil	3		
		Active	1
		Exempt	1
		Removed/Verified	1
Other	1		
		Not verified	1
Unknown	8		
		Active	2
		Removed/Verified	2
		Removed/Unverified	4

Leslie: 96

Substance	*Count*	*Status*	*Count*
Diesel	12		
		Active	9
		Not verified	1
		Removed/Verified	1
		Removed/Unverified	1
Empty	1		
		Active	1
Gasoline	69		
		Active	45
		Closed in place	2
		Not verified	15
		Removed/Verified	2
		Removed/Unverified	5
Kerosene	4		
		Active	3
		Not verified	1

Oil	3		
		Active	2
		Removed/Verified	1
Unknown	7		
		Active	6
		Removed/Unverified	1

Letcher 254

Substance	*Count*	*Status*	*Count*
Diesel	42		
		Active	25
		Exempt	1
		Removed/Verified	5
		Temporarily closed	8
		Removed/Unverified	3
Empty	10		
		Removed/Verified	2
		Temporarily closed	3
		Removed/Unverified	5
Gasoline	164		
		Active	126
		Removed/Verified	12
		Temporarily closed	6
		Removed/Unverified	20
Kerosene	12		
		Active	11
		Removed/Unverified	1
Oil	13		
		Active	4
		Removed/Verified	5
		Temporarily closed	1
		Removed/Unverified	3
Other	7		
		Active	7
Unknown	6		
		Active	2
		Removed/Verified	1
		Temporarily closed	2
		Removed/Unverified	1

Lincoln 237

Substance	*Count*	*Status*	*Count*
Diesel	29		
		Active	21
		Not verified	5
		Removed/Verified	1
		Temporarily closed	1
		Removed/Unverified	1
Empty	18		
		Active	3
		Exempt	3
		Removed/Verified	3
		Temporarily closed	1
		Removed/Unverified	8
Gasoline	171		
		Active	100
		Closed in place	2
		Exempt	2
		Not verified	28
		Removed/Verified	21
		Temporarily closed	7
		Removed/Unverified	11
CERCLA	1		
		Active	1
Kerosene	7		
		Active	3
		Exempt	1
		Not verified	3
Unknown	11		
		Active	5
		Not verified	6

Madison 558

Substance	*Count*	*Status*	*Count*
Diesel	91		
		Active	41
		Exempt	1
		Not verified	30
		Removed/Verified	14
		Temporarily closed	1
		Removed/Unverified	4
Empty	13		
		Not verified	6
		Removed/Verified	1
		Temporarily closed	5
		Removed/Unverified	1
Gasoline	358		
		Active	171
		Exempt	2
		Not verified	79
		Removed/Verified	84
		Temporarily closed	3
		Removed/Unverified	19
CERCLA	3		
		Exempt	2
		Not verified	1
Jet	1		
		Active	1

Kerosene	42		
		Active	16
		Exempt	7
		Not verified	6
		Removed/Verified	11
		Removed/Unverified	2
Oil	33		
		Active	8
		Exempt	6
		Not verified	5
		Removed/Verified	9
		Removed/Unverified	5
Other	3		
		Active	2
		Exempt	1
Unknown	14		
		Active	6
		Not verified	3
		Removed/Verified	1
		Removed/Unverified	4

Owen: 73

Substance	*Count*	*Status*	*Count*
Diesel	9		
		Active	5
		Not verified	4
Empty	3		
		Not verified	2
		Removed/Verified	1
Gasoline	56		
		Active	16
		Exempt	1
		Not verified	27
		Removed/Verified	9
		Temporarily closed	3
Kerosene	3		
		Exempt	3
Unknown	2		
		Not verified	2

Owsley: 72

Substance	*Count*	*Status*	*Count*
Diesel	11		
		Active	5
		Not verified	3
		Removed/Verified	2
		Removed/Unverified	1
Empty	4		
		Not verified	4
Gasoline	55		
		Active	15
		Not verified	36
		Removed/Verified	1
		Removed/Unverified	3
Kerosene	2		
		Active	1
		Removed/Unverified	1

Perry: 536

Substance	*Count*	*Status*	*Count*
Diesel	91		
		Active	44
		Exempt	1
		Not verified	30
		Removed/Verified	13
		Temporarily closed	2
		Removed/Unverified	1
Empty	20		
		Active	5
		Not verified	4
		Temporarily closed	3
		Removed/Unverified	8
Gasoline	363		
		Active	154
		Not verified	126
		Removed/Verified	51
		Temporarily closed	8
		Removed/Unverified	24
Jet	2		
		Active	2
Kerosene	14		
		Active	9
		Not verified	4
		Temporarily closed	1
Oil	28		
		Active	20
		Not verified	8
Unknown	18		
		Active	8
		Exempt	2
		Not verified	6
		Removed/Unverified	2

Powell: 131

Substance	*Count*	*Status*	*Count*
Diesel	18		
		Active	11
		Not verified	6
		Removed/Verified	1

Empty	3		
		Active	1
		Not verified	2
Gasoline	101		
		Active	48
		Not verified	31
		Removed/Verified	9
		Temporarily closed	2
		Removed/Unverified	11
Jet	1		
		Removed/Verified	1
Kerosene	4		
		Active	3
		Not verified	1
Oil	3		
		Active	2
		Removed/Unverified	1
Unknown	1		
		Active	1

Scott: 251

Substance	*Count*	*Status*	*Count*
Diesel	36		
		Active	18
		Not verified	8
		Removed/Verified	8
		Removed/Unverified	2
Empty	11		
		Active	5
		Not verified	1
Unknown	3		
		Removed/Verified	1
		Removed/Unverified	1
Gasoline	153		
		Active	70
		Exempt	3
		Not verified	27
		Removed/Verified	37
		Temporarily closed	6
		Removed/Unverified	10
Kerosene	19		
		Active	6
		Exempt	4
		Not verified	1
		Removed/Verified	7
		Removed/Unverified	1
Oil	20		
		Active	10
		Not verified	1
		Removed/Verified	5
		Temporarily closed	1
		Removed/Unverified	3
Other	2		
		Removed/Verified	2
Unknown	10		
		Active	7
		Not verified	1
		Removed/Verified	1
		Removed/Unverified	1

Wolfe: 106

Substance	*Count*	*Status*	*Count*
Diesel	15		
		Active	11
		Removed/Verified	3
		Removed/Unverified	1
Empty	2		
		Removed/Unverified	2
Gasoline	75		
		Active	64
		Exempt	1
		Removed/Verified	5
		Temporarily closed	3
		Removed/Unverified	2
Kerosene	7		
		Active	6
		Exempt	1
Oil	3		
		Active	2
		Removed/Verified	1
Unknown	4		
		Active	3
		Removed/Unverified	1

Woodford: 197

Substance	*Count*	*Status*	*Count*
Diesel	35		
		Active	19
		Exempt	1
		Not verified	4
		Removed/Verified	9
		Removed/Unverified	2

Empty	9		
		Active	4
		Not verified	2
		Removed/Verified	2
		Removed/Unverified	1
Gasoline	123		
		Active	66
		Exempt	4
		Not verified	16
		Removed/Verified	31
		Temporarily closed	2
		Removed/Unverified	4
CERCLA	3		
		Removed/Unverified	3
Kerosene	12		
		Active	7
		Not verified	3
		Removed/Verified	2
Oil	13		
		Active	4
		Not verified	1
		Removed/Verified	7
		Removed/Unverified	1
Unknown	2		
		Active	1
		Unknown	1

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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 non-technical reports and maps, as well as providing information through open-file reports and public data bases.

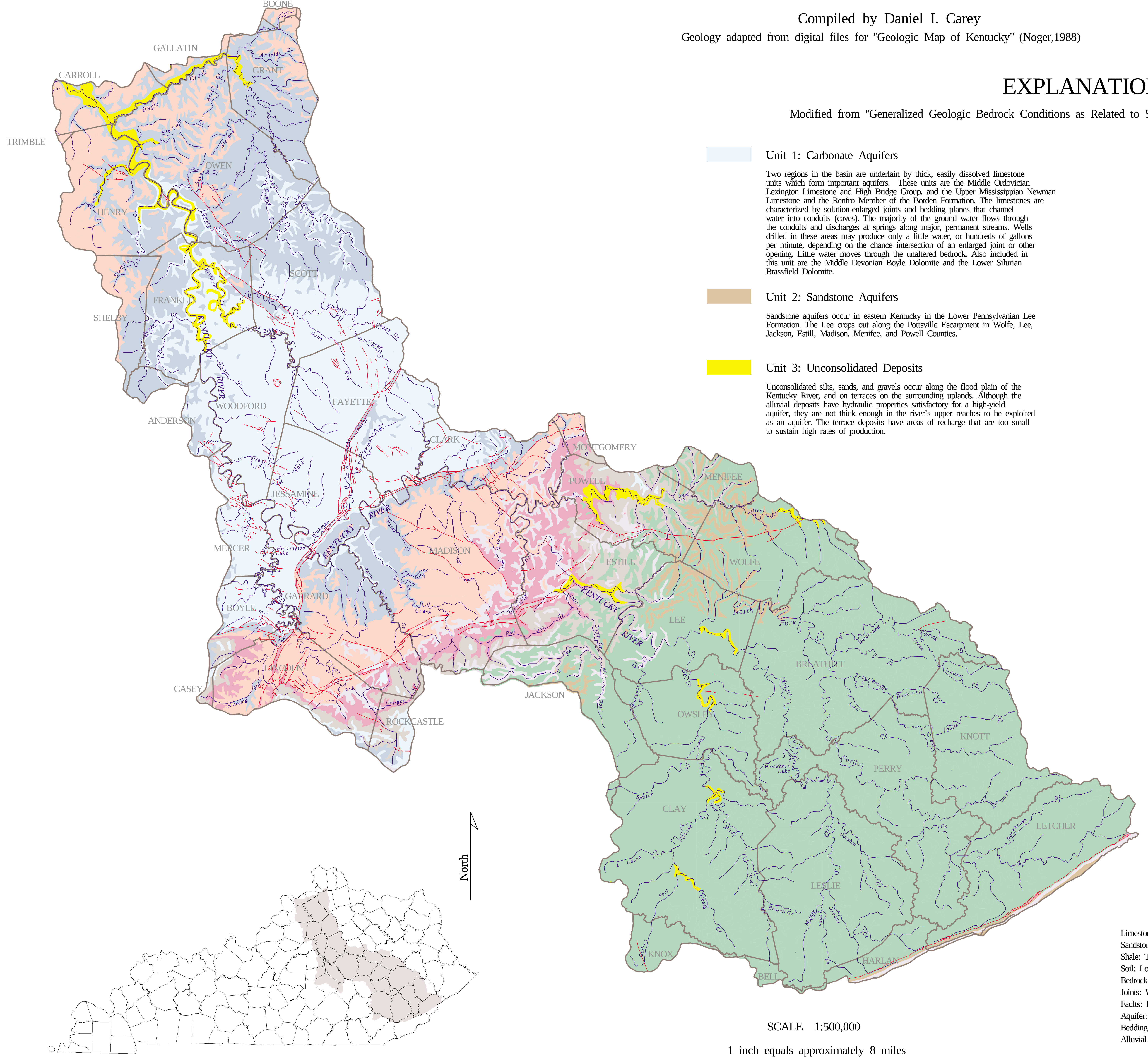
KENTUCKY GEOLOGICAL SURVEY
Donald C. Haney, State Geologist and Director
UNIVERSITY OF KENTUCKY, LEXINGTON

PLATE 1
INFORMATION CIRCULAR 52

GENERALIZED HYDROGEOLOGIC MAP OF THE KENTUCKY RIVER BASIN

Compiled by Daniel I. Carey

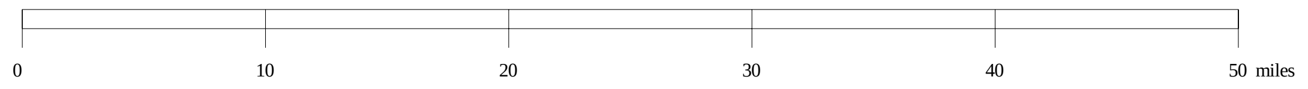
Geology adapted from digital files for "Geologic Map of Kentucky" (Noger,1988)



Location Map - Kentucky River Basin

SCALE 1:500,000

1 inch equals approximately 8 miles



1994

EXPLANATION

Modified from "Generalized Geologic Bedrock Conditions as Related to Solid-Waste Landfills in Kentucky" (Noger, 1990)

Unit 1: Carbonate Aquifers

Two regions in the basin are underlain by thick, easily dissolved limestone units which form important aquifers. These units are the Middle Ordovician Lexington Limestone and High Bridge Group, and the Upper Mississippian Newman Limestone and the Renfro Member of the Borden Formation. The limestones are characterized by solution-enlarged joints and bedding planes that channel water into conduits (caves). The majority of the ground water flows through the conduits and discharges at springs along major, permanent streams. Wells drilled in these areas may produce only a little water, or hundreds of gallons per minute, depending on the chance intersection of an enlarged joint or other opening. Little water moves through the unaltered bedrock. Also included in this unit are the Middle Devonian Boyle Dolomite and the Lower Silurian Brassfield Dolomite.

Unit 2: Sandstone Aquifers

Sandstone aquifers occur in eastern Kentucky in the Lower Pennsylvanian Lee Formation. The Lee crops out along the Pottsville Escarpment in Wolfe, Lee, Jackson, Estill, Madison, Menifee, and Powell Counties.

Unit 3: Unconsolidated Deposits

Unconsolidated silts, sands, and gravels occur along the flood plain of the Kentucky River, and on terraces on the surrounding uplands. Although the alluvial deposits have hydraulic properties satisfactory for a high-yield aquifer, they are not thick enough in the river's upper reaches to be exploited as an aquifer. The terrace deposits have areas of recharge that are too small to sustain high rates of production.

Unit 4: Fractured Shales

Although the jointing and bedding planes in these brittle shales allow ground-water movement, there is little storage in the unfractured material. This unit is composed primarily of the New Albany-Ohio black shales. Wells in these units typically produce little water.

Unit 5: Clay Shales

These shales are easily weathered and produce a highly plastic weathered zone. This unit is composed of the Lower Silurian Crab Orchard Formation and the Upper Mississippian Pennington Formation. Joints and bedding planes tend to heal or become clogged, and although clay minerals have large intergranular storage of water, there is little or no permeability to allow its movement. Wells in these units are generally dry.

Unit 6: Interbedded Shales and Limestones

Limestone makes up about 20 percent of the unit. This unit consists of the Upper Ordovician Drakes, Kope, Ashlock, and Fairview Formations, and the Calloway Creek and Grant Lake Limestones. These formations have some limited potential as aquifers, but the high clay content generally blocks small conduits in the limestone. Wells in these units are generally dry.

Unit 7: Interbedded Clay Shales and Siltstones

This unit is represented principally by the Lower Mississippian Borden Formation. The Garrard Siltstone is also included in this unit. Where clay shales are dominant, successful water wells are difficult to obtain. In areas where the unit is sandy, wells more commonly yield sufficient water for domestic supplies.

Unit 8: Interbedded Limestones and Shales

This unit, which consists of the Upper Ordovician Clays Ferry Formation and the Upper Member of the Newman Limestone along Pine Mountain, contains more than 20 percent limestone. Where limestone exceeds 60 percent, wells may yield adequate water for a domestic supply.

Unit 9: Coals, Sandstones, and Shales

This unit represents the Middle Pennsylvanian Breathitt Formation. Wells that penetrate sections composed of more than 50 percent sandstone have better than average yields, and almost all wells will produce enough water for domestic supplies. Many wells will produce sufficient supplies for small industries. Wells completed in coals, or obtaining flow from coals, are highly productive, but may be of marginal or poor water quality. Wells completed in shales are commonly adequate for domestic supplies, depending upon the occurrence of weathered fractures in the shale. Wells completed in fractured sandstones along Pine Mountain have some of the highest production capacities in the basin.

Faults

The presence of faults is very important to the success of large-capacity wells in the Kentucky River Basin. In general, faulting enhances the permeability of bedrock aquifers because the bedrock is broken and pulverized along a zone bordering the fault plane. This is especially true in the limestone areas where fracturing is enhanced by subsequent solution. High-capacity wells in both central and eastern Kentucky are commonly located in fault zones.

DEFINITIONS

Limestone: Layered rock composed of grains of calcite cemented together; may contain fossils.
Sandstone: Layered rock composed of grains of sand cemented together.
Shale: Thin-layered rock composed of clay minerals.
Soil: Loose materials occurring between the ground surface and underlying bedrock.
Bedrock: Solid rock underlying soils and unconsolidated materials.
Joints: Widely spaced vertical cracks in the bedrock.
Faults: Fractures in the earth's crust along which displacement has occurred.
Aquifer: Stratum or zone below the surface of the earth capable of producing water, as from a well.
Bedding plane: The division planes which separate the individual layers, beds, or strata.
Alluvial deposits: Stream sediment deposits of comparatively recent time.

References

Noger, M.C., comp., 1988, Geologic map of Kentucky: U.S. Geological Survey, scale 1:500,000.
Noger, M.C., comp., 1990, Generalized geologic bedrock conditions as related to solid-waste landfills in Kentucky: Kentucky Geological Survey, scale 1:500,000.

GENERALIZED STRATIGRAPHIC COLUMN

SYSTEM	SERIES	FORMATION OR UNIT
QUATERNARY	Holocene	Alluvium
	Pleistocene	Terrace deposits
PENNSYLVANIAN	Middle	Breathitt Formation
	Lower	Lee Formation
MISSISSIPPIAN	Upper	Pennington Formation Newman Limestone
	Lower	Borden Formation
DEVONIAN	Upper	New Albany Shale (Ohio Shale)
	Middle	Boyle Dolomite
SILURIAN	Lower	Crab Orchard Formation
		Brassfield Dolomite
ORDOVICIAN	Upper	Drakes Formation
		Ashlock Formation (Grant Lake Limestone)
		Calloway Creek Limestone (Fairview Formation)
		Garrard Siltstone Kope Formation (Clays Ferry Formation) Lexington Limestone
		High Bridge Group

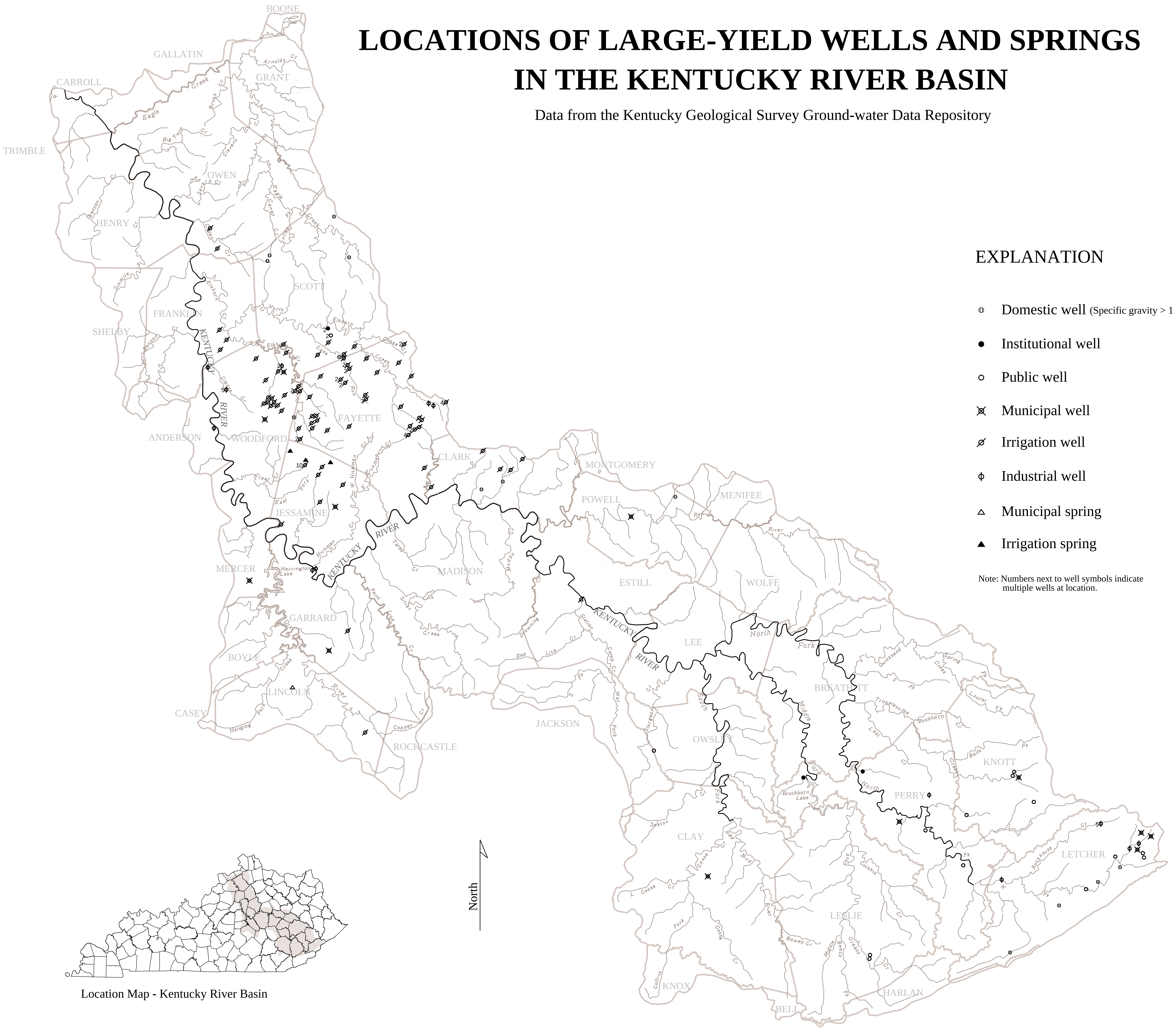
Note: Parentheses indicate different name used for equivalent stratigraphic unit in another area.

Cartography directed by Terry D. Hounshell

KENTUCKY GEOLOGICAL SURVEY
Donald C. Haney, State Geologist and Director
UNIVERSITY OF KENTUCKY, LEXINGTON

LOCATIONS OF LARGE-YIELD WELLS AND SPRINGS IN THE KENTUCKY RIVER BASIN

Data from the Kentucky Geological Survey Ground-water Data Repository



EXPLANATION

- o Domestic well (Specific gravity > 1 gpm/ft)
- ● Institutional well
- ○ Public well
- ⊗ Municipal well
- ø Irrigation well
- ϕ Industrial well
- △ Municipal spring
- ▲ Irrigation spring

Note: Numbers next to well symbols indicate multiple wells at location.

Location Map - Kentucky River Basin

SCALE 1:500,000

1 inch equals approximately 8 miles

0 10 20 30 40 50 miles

1994

Cartography directed by Terry D. Hounshell