Results

Water Properties

pH. The property pH (negative base-10 logarithm of hydrogen ion activity in moles per liter) is one of the most fundamental water-quality parameters. It is easily measured, indicates whether water will be corrosive or will precipitate scale, determines the solubility and mobility of most dissolved constituents, and provides a good indication of the types of minerals groundwater has reacted with as it flows from recharge to discharge area or sample site.

The pH of neutral (neither acidic nor basic) water varies with temperature. For example, the neutral pH of pure water at 25°C (77°F) is 7.0. The neutral pH of pure water at 30°C (86°F) and 0°C (32°F) is 6.9 and 7.5, respectively (Hem, 1985). Solutes, including dissolved gases, also affect pH. Rain that has equilibrated with atmospheric carbon dioxide has a pH of about 5.6 (Hem, 1985). Streams and lakes in humid regions such as Kentucky typically have pH values between 6.5 and 8. Soil water in contact with decaying organic material can have values as low as 4, and the pH of water that has reacted with iron sulfide minerals in coal or shale can be even lower. In the absence of iron sulfide minerals, the pH of groundwater typically ranges from about 6.0 to 8.5, depending on the type of soil and rock contacted. Reactions between groundwater and sandstones result in pH values between about 6.5 and 7.5, whereas groundwater flowing through carbonate strata can have values as high as 8.5.

There are no health-based drinking water standards for pH. However, pH values outside of the range 6.5 to 8.5 can lead to high dissolved concentrations of some metals for which there are drinking water standards and associated health effects. The U.S. Environmental Protection Agency has established a secondary standard (SMCL) for pH of 6.5 to 8.5. Water with a pH value higher than 8.5 or lower than 6.5 can produce staining, etching, or scaling of equipment.

The data repository contained 2,589 pH values from 434 sites in BMU 3 (Table 4). The median pH value (6.9) is near neutral and the interquartile range is only 1.1 pH units. Few sites have pH values greater than 8.5, but many sites have pH values less than 6.5. Measured values follow a normal distribution between about 5.5 and 9.0 (Fig. 2).

There is a high density of sample sites in the Eastern Kentucky Coal Field portion of the Upper Cumberland River watershed, the eastern portion of the Lower Cumberland River watershed, and in the northern portion of the Tennessee River watershed (Fig. 3). Physiographic regions and the underlying rock types strongly influence pH values. Values range from less than 6.5 to greater than 8.5 in the geologically heterogeneous Eastern Kentucky Coal Field, are generally near neutral in the carbonate terrain of the Eastern and Western Pennyroyal Regions, and are commonly less than 6.5 in the sandy Jackson Purchase Region.

Table 4. Summary of pH values (standard pH units).

Measurements	2,589
Maximum	9.5
75th percentile	7.4
Median	6.9
25th percentile	6.3
Minimum	1.7
Interquartile range	6.3–7.4
Sites	434
SMCL	6.5–8.5
Sites > 8.5	9
Sites < 6.5	188

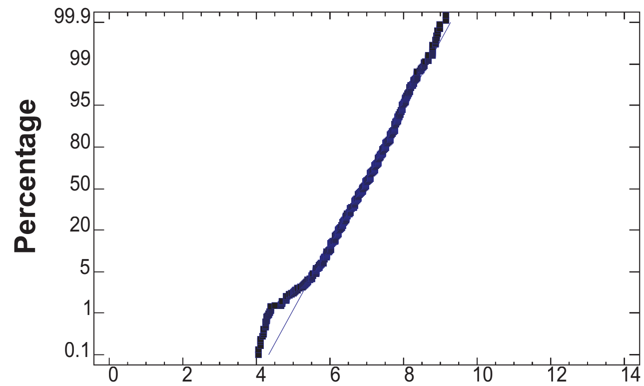

Figure 2. Cumulative plot of pH values. The highest and lowest 0.1 percent of values are omitted so that the central 99.8 percent of the data can be presented more clearly.

Comparing values within physiographic regions (Fig. 4) and major watersheds (Fig. 5) shows that bedrock geology, as represented by physiographic regions, is the primary control on groundwater pH. The Upper Cumberland River watershed includes parts of the Eastern Kentucky Coal Field and Eastern Pennyroyal Region. The highest and lowest pH values are found in the Eastern Kentucky Coal Field portion of the Upper Cumberland watershed, whereas samples from the Eastern Pennyroyal Region of the Upper Cumberland watershed have a smaller range of pH values and a higher median value than samples from the Eastern Kentucky Coal Field. Samples from the Lower Cumberland watershed (entirely within the Western Pennyroyal Region) and the Ohio and Mississippi watersheds (entirely within the Jackson Purchase Region) have a relatively small range of values, reflecting the geologic

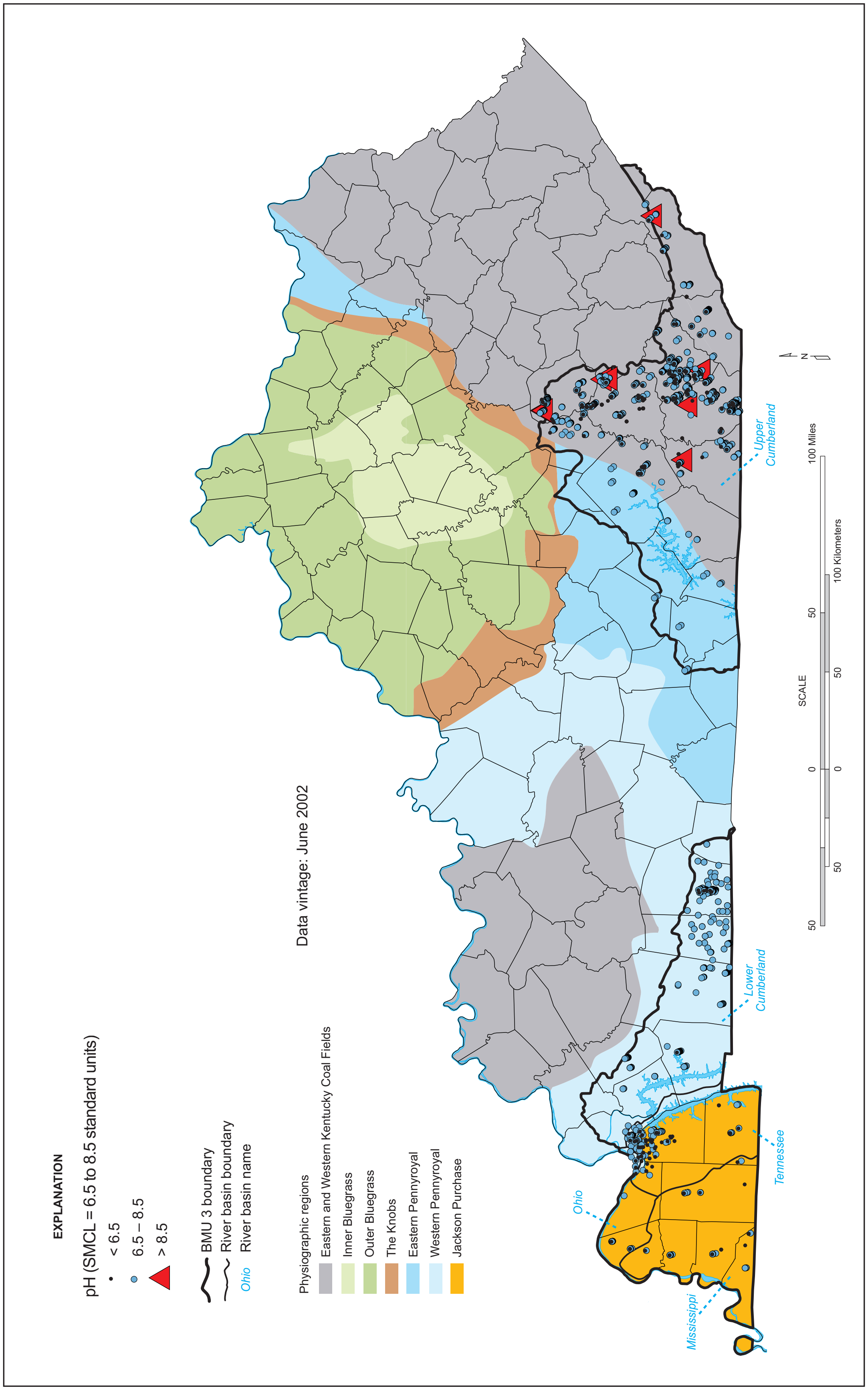

Figure 3. Sampled sites and ranges of pH values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

similarity within regions. Samples from the Tennessee River watershed have an interquartile range nearly as large as samples from the Upper Cumberland River watershed, because the Tennessee River watershed includes both the carbonate Western Pennyroyal Region and the sandy Jackson Purchase Region.

The interquartile range of pH values for both wells and springs is about one pH unit, although the total range of values is greater in wells than in springs (Fig. 6). The median pH value from springs is slightly higher than that from wells, because most springs are in carbonate terrain. Shallow wells have greater variability in pH than wells deeper than about 100 ft (Fig. 7).

In summary, groundwater pH values and ranges of values are more closely related to physiographic region than to major watershed. There is no unequivocal evidence of widespread nonpoint-source contamination. Groundwater in the predominantly carbonate-rich geology of the Eastern and Western Pennyroyal Regions is nearly neutral, and pH values show relatively little variability. In the Eastern Kentucky Coal Field, where bedrock lithology is more heterogeneous, groundwater pH shows a much wider range of values. Groundwater in the sandy Jackson Purchase, where carbonate minerals are scarce, is generally slightly acidic. The pH of springs and shallow wells is much more variable than the pH of water from intermediate and deep wells. The decrease in variability of pH with sample depth shows that groundwater in intermediate and deep flow systems has equilibrated with bedrock to a greater extent than groundwater in springs and shallow wells.

A statewide summary of pH data (Fisher, 2002b) can be viewed on the Kentucky Geological Survey Web site (www.uky.edu/KGS/water/gnet/gnet.htm).

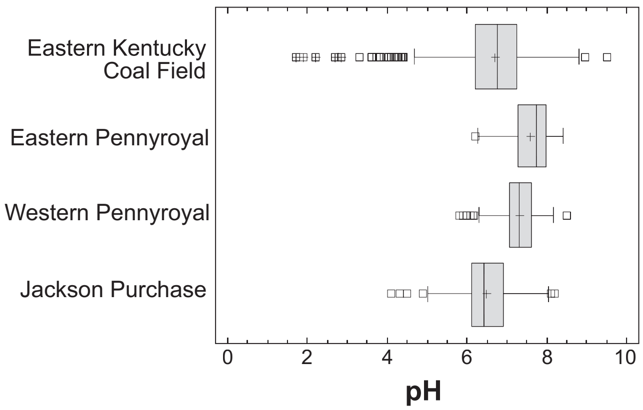

Figure 4. Summary of pH values grouped by physiographic region.

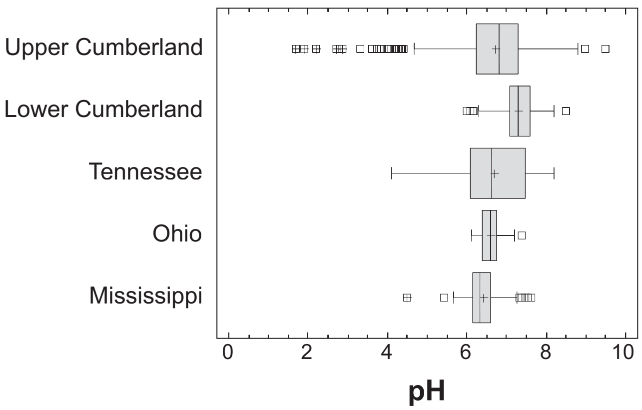

Figure 5. Summary of pH values grouped by major watershed.

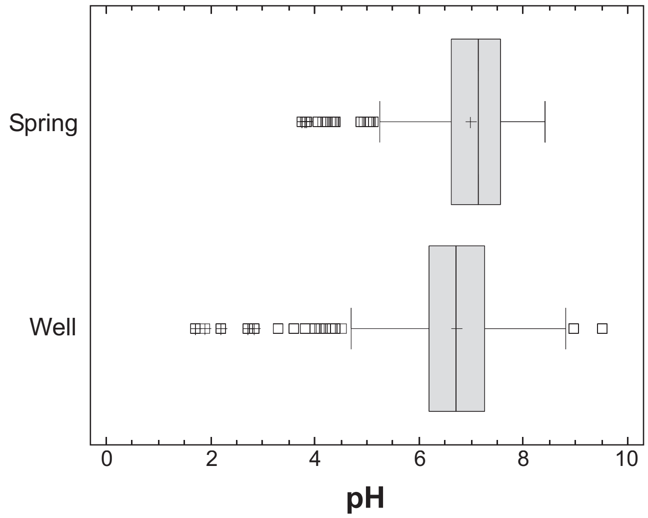

Figure 6. Comparison of pH values from wells and springs.

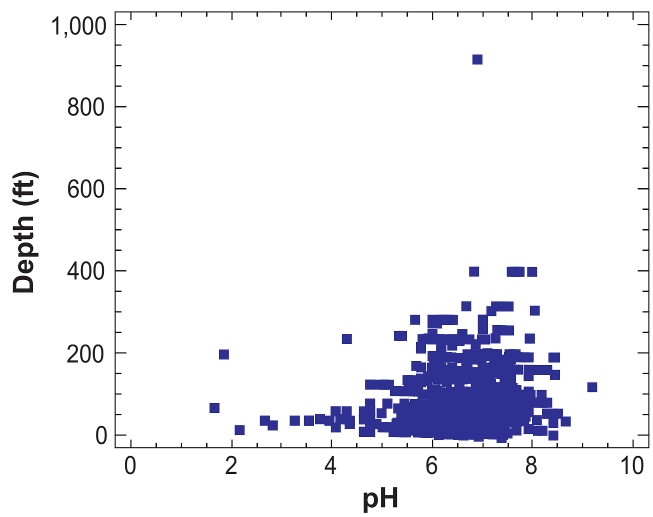

Figure 7. Plot of pH values versus well depth.

Total Dissolved Solids. Total dissolved solids is reported as the sum of all dissolved chemicals in water expressed as mg/L. TDS can be calculated by adding all the solute concentrations from a complete chemical analysis or measured as the weight of the residue remaining after a known volume of water has been evaporated to dryness.

TDS values are a general indicator of the suitability of groundwater for various uses (Mazor, 1991, p. 94–95):

Potable water: up to 500 mg/L TDS

Slightly saline water: adequate for drinking and irrigation (500 to 1,000 mg/L TDS)

Medium saline water: potable only in cases of need; may be used for some crops and aquiculture (1,000 to 2,500 mg/L TDS)

Saline water: adequate for aquiculture and industrial use (2,500 to 5,000 mg/L TDS)

Brackish water: 5,000 to 35,000 mg/L TDS (the salinity of seawater)

Brine: TDS greater than 35,000 mg/L

The EPA has set an SMCL of 500 mg/L TDS. Water having values greater than 500 mg/L has an unpleasant taste and may stain objects or precipitate scale in containers, plumbing, or water heaters.

The Kentucky Groundwater Data Repository contained 632 reports of TDS at 150 sites in BMU 3. Total dissolved solids measurements are summarized in terms of suitability for various uses (Table 5). Nearly all samples and sites yielded potable water. Only three measurements exceeded 2,500 mg/L; no measurements exceeded 5,000 mg/L. A cumulative data plot (Fig. 8) shows that TDS values below about 400 mg/L follow a normal distribution.

TDS values were reported at relatively few sites, and those locations are evenly distributed throughout the project area (Fig. 9). Potable water is present throughout the area. A summary of data grouped by physiographic region (Fig. 10) shows that groundwater in the Eastern Pennyroyal has the smallest range of values, whereas samples from the Western Pennyroyal have the greatest variability of TDS values. The highest values occur in the Lower Cumberland River watershed, whereas sites in the Tennessee River watershed have the smallest range of values (Fig. 11).

Although springs and wells have approximately the same median TDS value and a similar interquartile range (Fig. 12), the highest TDS values are found in wells. Deeper wells have somewhat lower TDS values than shallow wells (Fig. 13).

In summary, nearly 95 percent of the reported TDS values in the project area are less than 500 mg/L. Values greater than 500 mg/L are found in all major watersheds and all regions except the Eastern Pennyroyal. Some high TDS values in the Eastern Kentucky Coal Field may represent groundwater discharge from deep, regional flow systems (Wunsch, 1993). High TDS values in the Western Pennyroyal Region may be naturally occurring (Hopkins, 1966) or caused by brines from nearby oil and gas production wells. Slightly saline to medium saline groundwater in the Jackson Purchase Region probably indicates that samples came from deeper wells than the potable water.

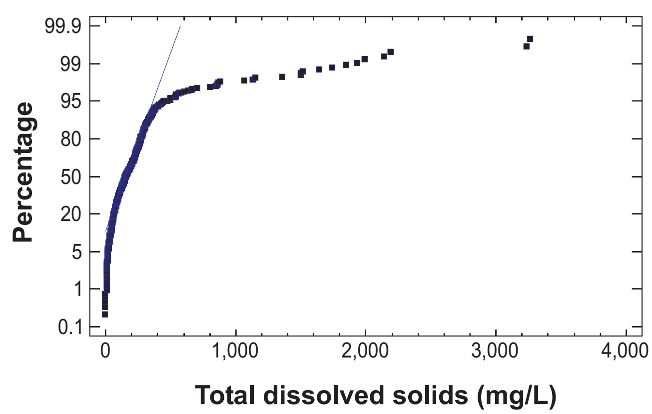

Figure 8. Cumulative plot of total dissolved solids values. The highest and lowest 0.1 percent of values are omitted so that the central 99.8 percent of the data can be presented more clearly.

Table 5. Summary of total dissolved solids values (mg/L).

Total Dissolved Solids (mg/L)	Percentage of Analyses	Percentage of Analyses
Potable water (0–500)	94	87
Slightly saline (501–1,000)	3	7
Medium saline (1,001–2,500)	3	5
Saline: (2,501–5,000)	< 1	< 1
Brackish: (5,001–35,000)	0	0
Brine: (> 35,000)	0	0

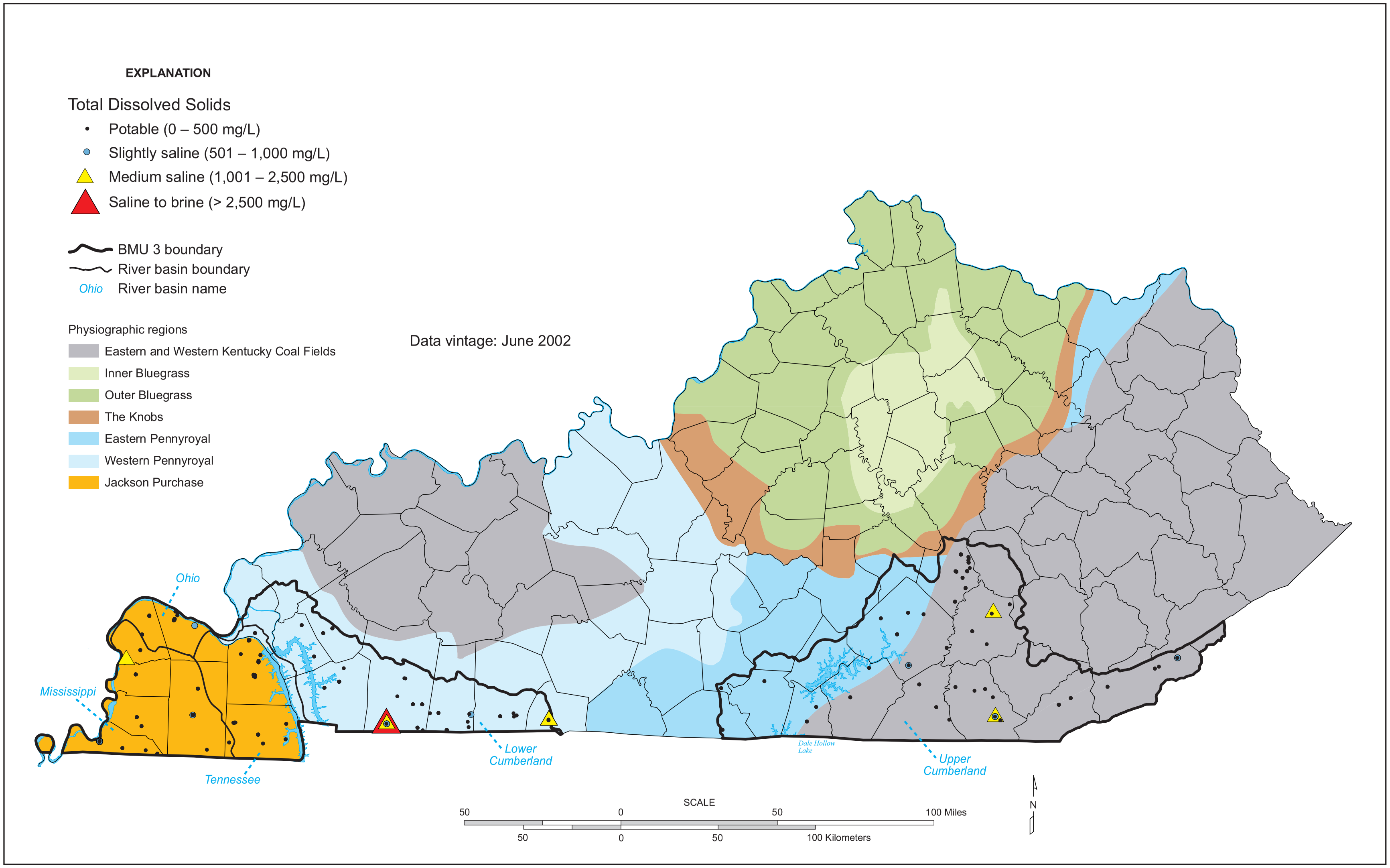

Figure 9. Sample sites and ranges of total dissolved solids values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

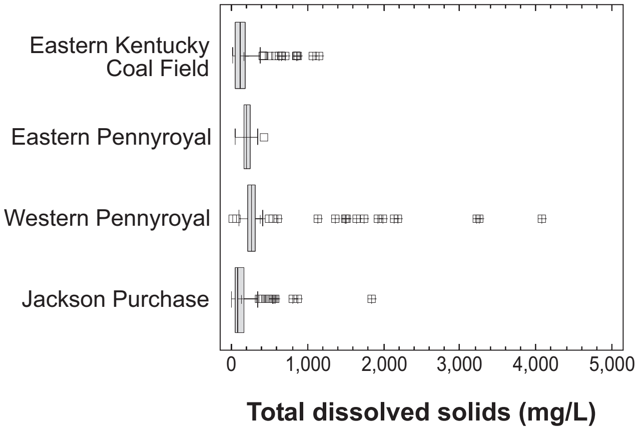

Figure 10. Summary of total dissolved solids values grouped by physiographic region.

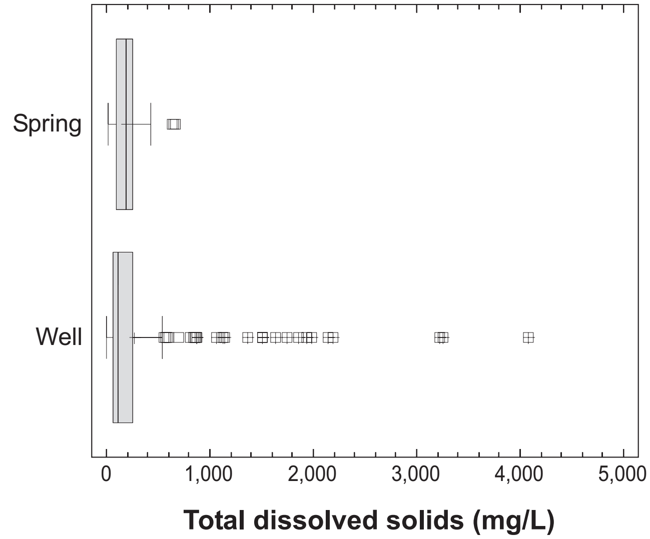

Figure 12. Comparison of total dissolved solids values from wells and springs.

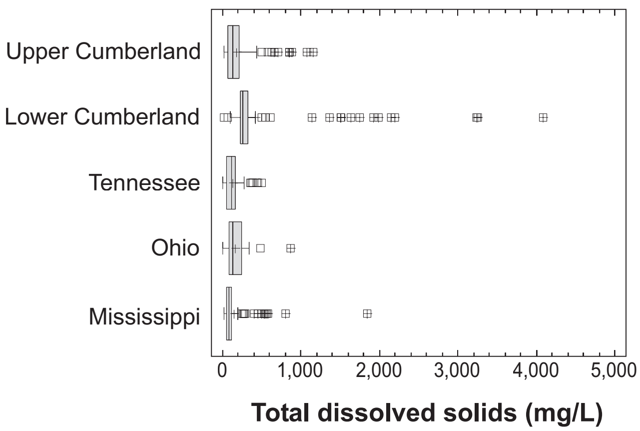

Figure 11. Summary of total dissolved solids values grouped by major watershed.

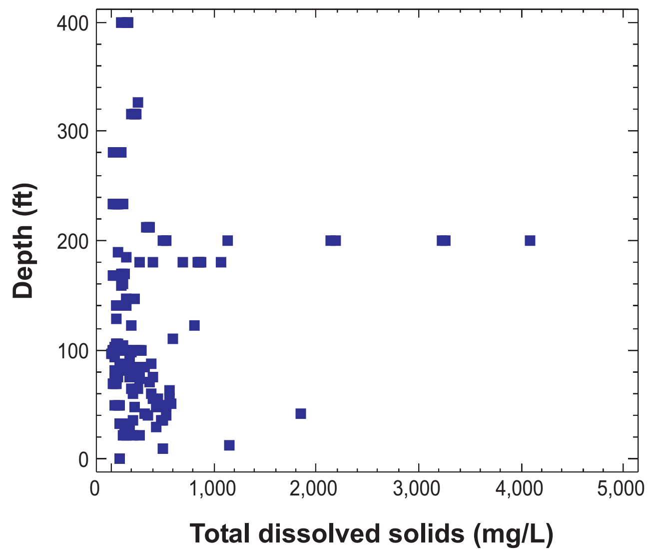

Figure 13. Total dissolved solids values versus well depth.

Specific Electrical Conductance. Specific electrical conductance, also referred to as conductivity, is a measure of the ability of water to conduct an electrical current. It is proportional to total dissolved solids concentrations and therefore an indirect measure of water quality. Specific electrical conductance is a quick and simple measurement to make in the field, and provides a relative comparison of water quality if the samples being compared have nearly the same temperature and predominant cations and anions (for example, sodium and chloride or calcium and bicarbonate).

Conductance is reported in micromhos per centimeter at 25°C, or the numerically equivalent microSiemens per centimeter (µS/cm) in the International System of Units (Hem, 1985). Because conductance does not directly indicate water quality, there are no health or water-use standards based on this parameter.

The data repository contained a large number of conductance measurements in BMU 3 as a result of the extensive sampling program associated with the National Uranium Resource Evaluation project (Smith, 2001). Well depths range to 4,100 ft. Samples from depths greater than 730 ft were collected and reported as part of a USGS program that surveyed water quality in accessible wells throughout Kentucky. Although identified as water wells, samples from such depths do not represent the part of the groundwater system that would be used by private citizens. The deepest sample reported by the Division of Water and identified as a water well was 730 ft. Therefore, to exclude data from exploration wells or oil and gas wells that were incorrectly labeled water wells, we excluded conductance values from depths greater than 730 ft from this summary. The resulting data set is summarized in Table 6 and Figure 14. Less then 5 percent of the measurements exceeded 500 µS/cm; however, values as high as 178,000 µS/cm have been reported.

Table 6. Summary of conductance values (µ/cm).

Measurements	5,308
Maximum	178,000
75th percentile	410
Median	269
25th percentile	128
Minimum	3.4
Interquartile range	128–410
Sites	3,430

Sample coverage is dense throughout BMU 3 (Fig. 15) and a general absence of values greater than 10,000 µS/cm in the Lower Cumberland, Tennessee, Ohio, and Mississippi River watersheds. Most conductance values greater than 10,000 µS/cm are found at sites in the southwestern part of the Upper Cumberland River watershed.

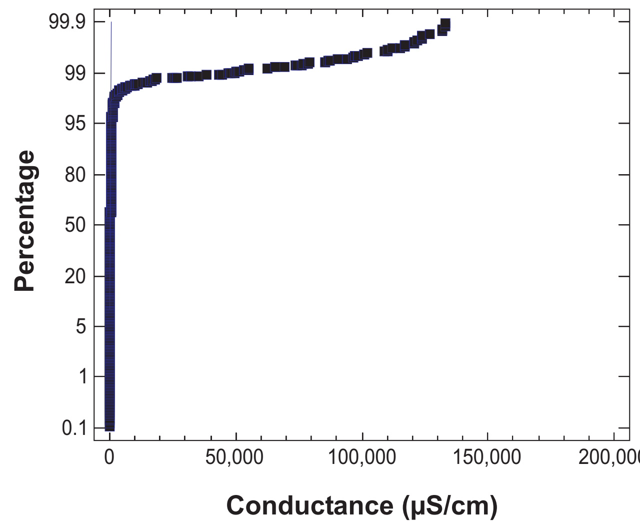

Figure 14. Cumulative plot of conductance values. The highest and lowest 0.1 percent of values are omitted so that the central 99.8 percent of the data can be presented more clearly.

Grouping the data by physiographic region (Fig. 16) and by major river watershed (Fig. 17) shows that, with only one exception, values exceeding 10,000 µS/cm are from sites in the Eastern Kentucky Coal Field and Eastern Pennyroyal Regions of the Upper Cumberland River watershed. The exception is one measured value from a site in the Western Pennyroyal Region of the Lower Cumberland River watershed.

The highest values are found in wells rather than springs (Fig. 18).

Although there are many outlier values, conductance generally decreases with well depth (Fig. 19).

In summary, more than 95 percent of the reported conductance values are less than 500 µS/cm. Values higher than 10,000 µS/cm are found in groundwater from wells in the Eastern Kentucky Coal Field and Eastern Pennyroyal Regions of the Upper Cumberland watershed. Nearly all of these high conductance values were reported as part of a regional groundwater-quality survey conducted by the U.S. Geological Survey during the 1960's and 1970. Few well depths were reported; however, four wells having depths less than 100 ft yielded groundwater with conductance above 10,000 µS/cm. Although there is no way to confirm the very high conductance values, there is also no reason to assume they do not accurately represent the sampled sites. Some high values in the Eastern Kentucky Coal Field may represent discharge of deep, naturally brackish groundwater, and some high values in the Eastern Pennyroyal may represent nonpoint-source contamination from abandoned oil and gas wells.

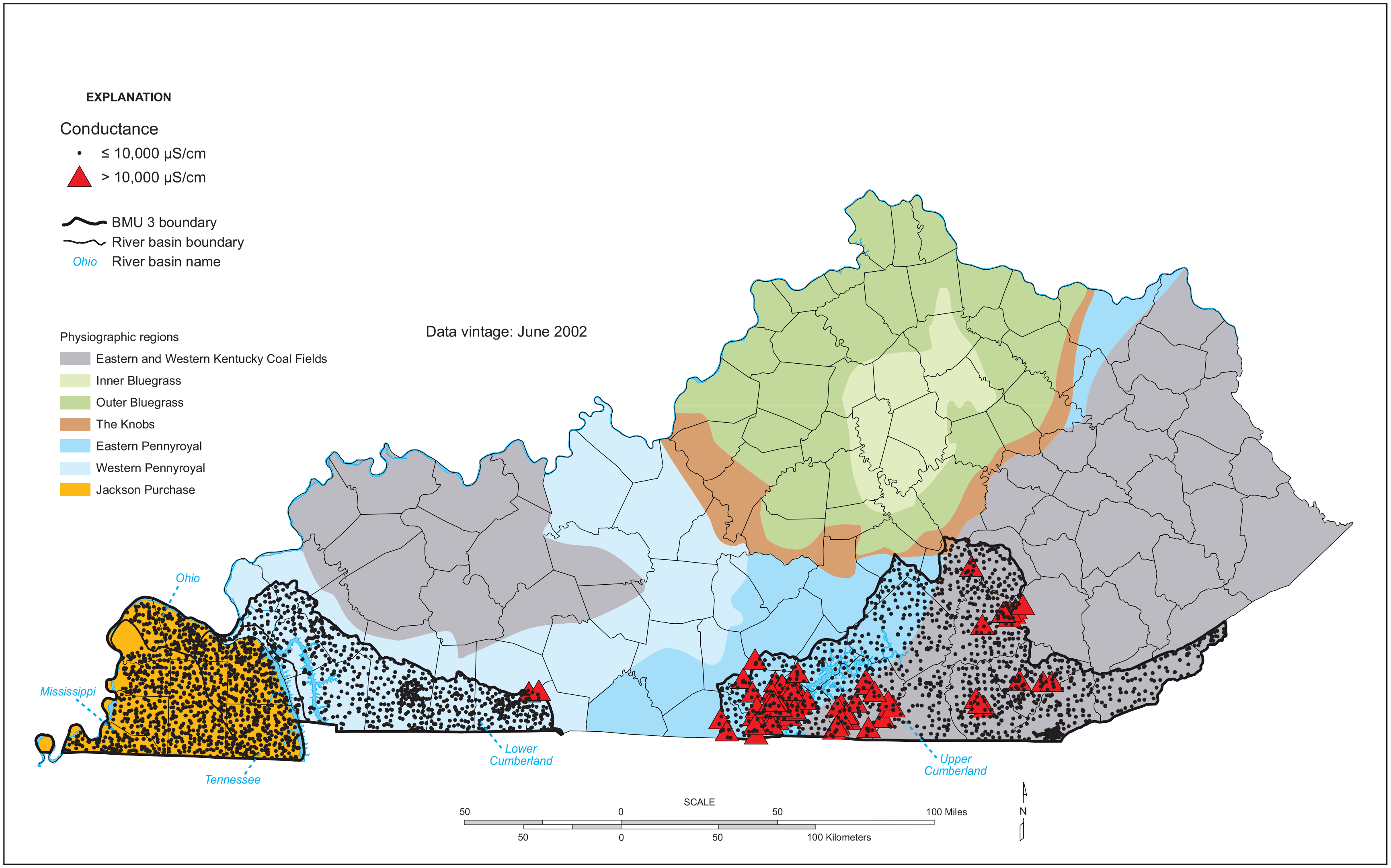

Figure 15. Sample sites and ranges of conductance values.

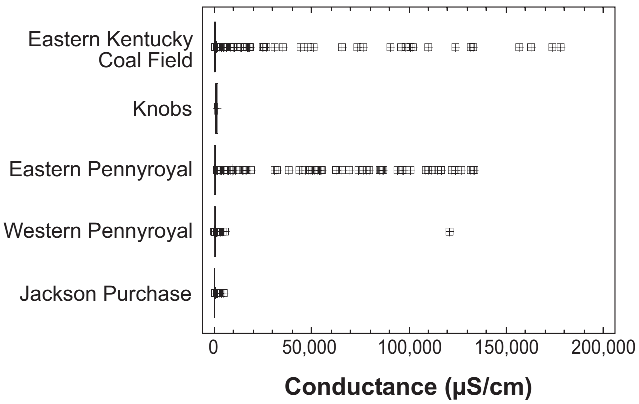

Figure 16. Summary of conductance values grouped by physiographic region

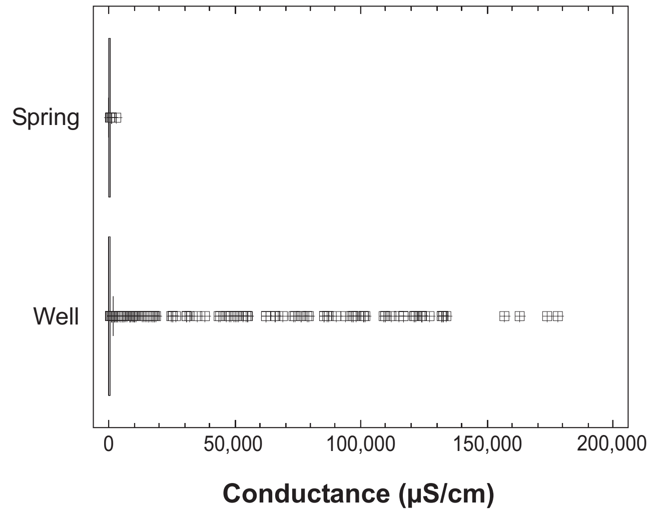

Figure 18. Comparison of conductance values from wells and springs.

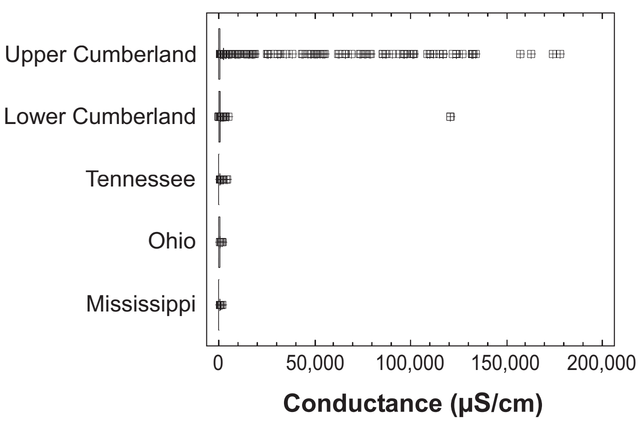

Figure 17. Summary of conductance values grouped by major river watershed.

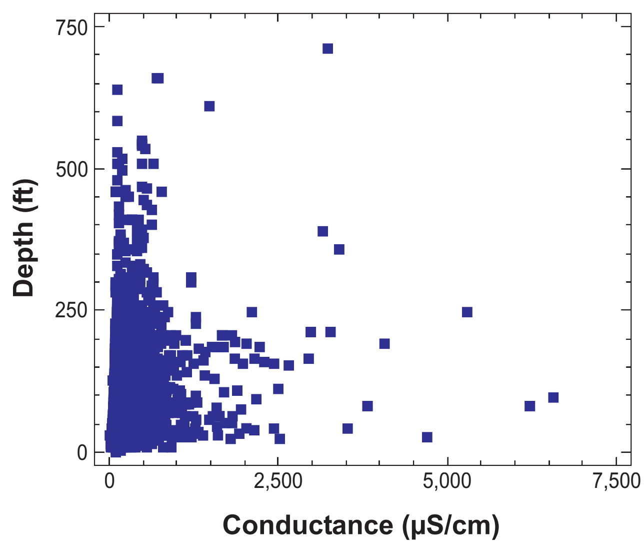

Figure 19. Conductance versus well depth. Higher conductance values have been omitted to better show the main trend of data.

Hardness. Hardness refers to the tendency of water to precipitate an insoluble residue when soap is used, and to form a scale on containers when water evaporates. Hard water reduces the ability of soap and detergents to clean clothes; leaves a sticky film on skin, clothes, and hair; and deposits scale in water heaters, boilers, and industrial equipment.

Because calcium and magnesium are largely responsible for the behavior of soap in water, hardness is usually defined as the concentrations of calcium and magnesium expressed as an equivalent amount of calcium carbonate:

Hardness (mg/L calcium carbonate equivalent) = 2.5 Ca (mg/L) + 4.1 Mg (mg/L).

A frequently used classification of hardness in water supplies is shown in Table 7 (U.S. Geological Survey, 2006).

Table 7. Hardness classification of water supplies.

Hardness Category	Concentration (mg/L)
Soft	0–17
Slightly hard	18–60
Moderately hard	61–120
Hard	121–180
Very hard	> 180

Calcium and magnesium concentrations from the data repository were combined according to the above equation to produce 1,942 groundwater hardness values at 649 sites in BMU 3 (Table 8). Less than 50 percent of the values represent soft to moderately hard water, whereas 44 percent of the samples represent very hard water.

Table 8. Summary of hardness values (mg/L).

Measurements	1,942
Maximum	130,072
75th percentile	242
Median	131
25th percentile	40
Minimum	0.3
Sites	649
Sites < 17 (soft water)	78
Sites 18–60 (slightly hard water)	130
Sites 61–120 (moderately hard water)	73
Sites 121–180 (hard water)	81
Sites > 180 (very hard water)	287

The lower 85 percent of values follows a normal distribution, with excursions to very high values in the remaining 15 percent (Fig. 20).

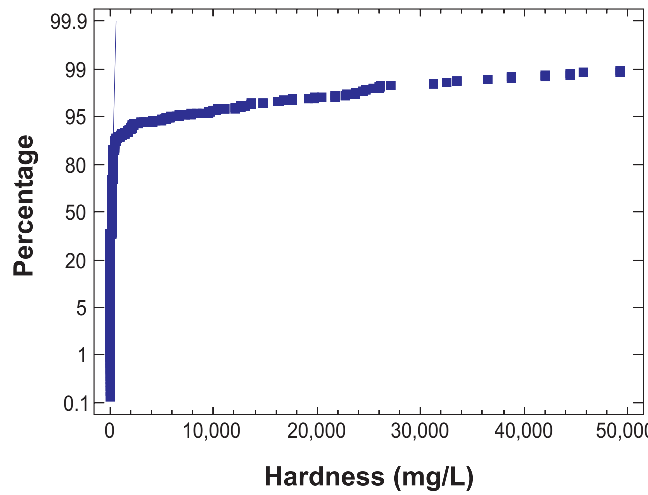

Figure 20. Cumulative plot of hardness values. Values greater than 50,000 mg/L have been omitted to better show the majority of the data.

Sample distribution is dense in all areas except the northern part of the Upper Cumberland River watershed (Fig. 21). Water is soft to moderately hard in the Jackson Purchase Region, hard to very hard in the Eastern and Western Pennyroyal Regions, and highly variable in the Eastern Kentucky Coal Field (Figs. 21–22).

Samples from the Lower Cumberland, Tennessee, Ohio, and Mississippi River watersheds have a small range of values (Fig. 23) because sites in those watersheds are in geologically homogeneous terrain. Samples from the Upper Cumberland watershed have a very large range of values because of the geologic heterogeneity of the Eastern Kentucky Coal Field.

The highest hardness values are found in groundwater from wells rather than from springs (Fig. 24). There is a general trend of decreasing hardness with depth in water wells (Fig. 25).

In summary, hard to very hard groundwater is predominant throughout the project area, with the exception of water from wells in the sandy Jackson Purchase Region. In both the Eastern Kentucky Coal Field and the Eastern Pennyroyal carbonate terrain, dissolved calcium and magnesium supplied by calcite and dolomite produce hard water. These minerals are absent or present only in low abundance in the gravels, sands, silts, and clays of the Jackson Purchase Region. Very high hardness values in the Eastern Kentucky Coal Field may be the result of acidic groundwater dissolving carbonate minerals and producing high calcium and magnesium concentrations.

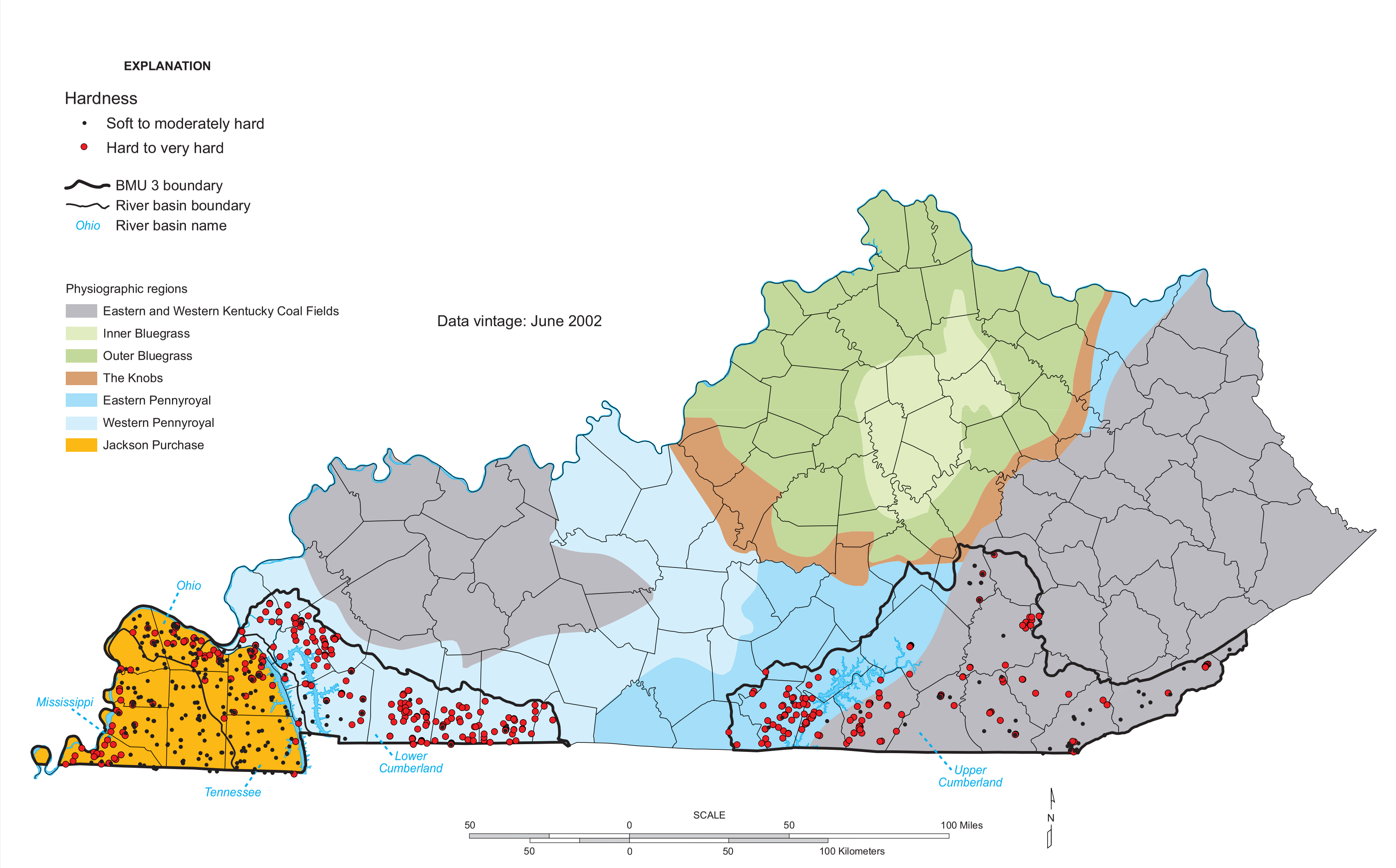

Figure 21. Sample sites and ranges of hardness values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

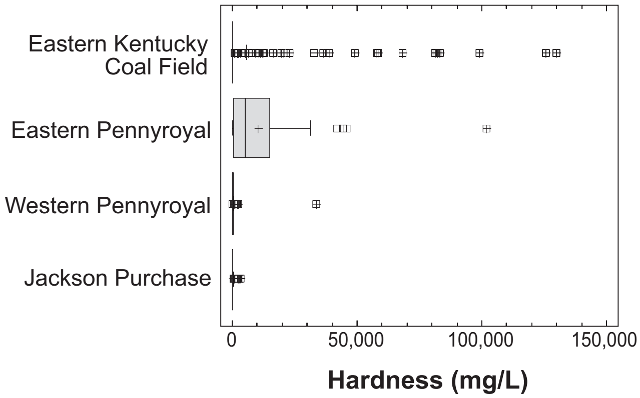

Figure 22. Summary of hardness values grouped by physiographic region.

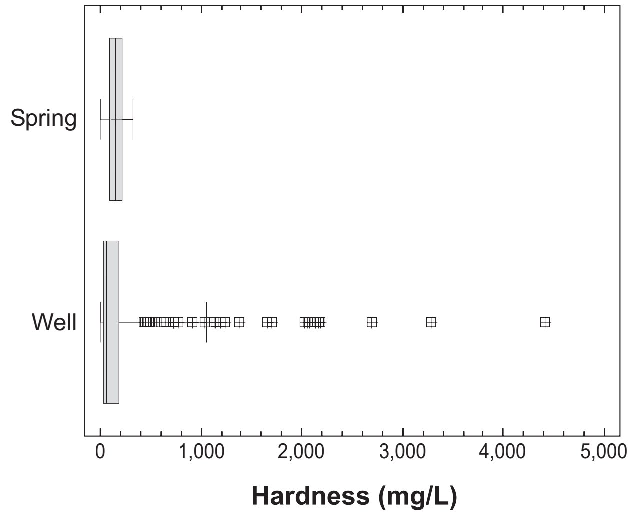

Figure 24. Comparison of hardness values from wells and springs. Higher values were omitted to better show the similarity in interquartile ranges.

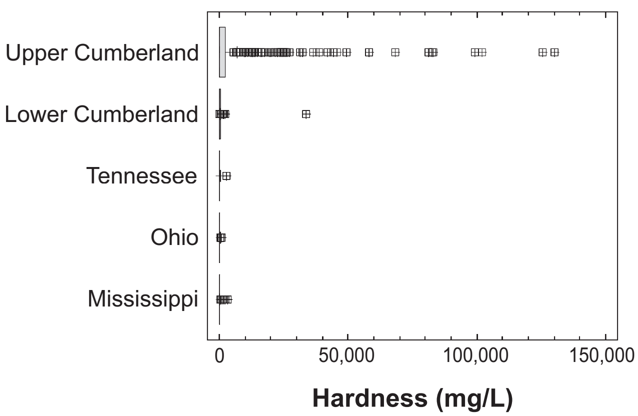

Figure 23. Summary of hardness values grouped by major river watershed.

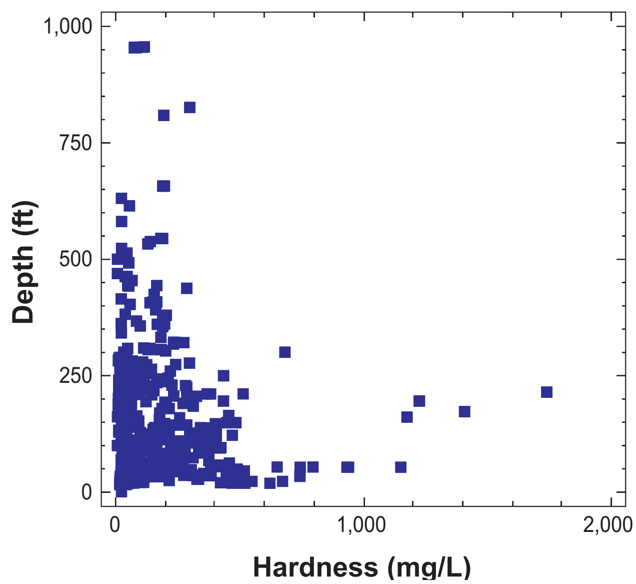

Figure 25. Hardness values versus well depth. Higher values were omitted to better show the majority of the data points.

Total Suspended Solids. Suspended particulate material is reported as total suspended solids. TSS values are typically higher in samples from karst springs or wells in fractured aquifers, where turbulent flow can transport fine material such as clays and particulate organic material, and from uncased wells that have been vigorously stirred during purging prior to sample collection than in water from wells in granular bedrock. TSS measurements also include any precipitate that formed in the sample bottle after collection.

There are no health or cosmetic standards for total suspended solids in water. Some metals and pesticides are preferentially sorbed onto or included in the matrix of suspended material, however, so water high in total suspended solids may also contain significant amounts of metals that may have health or safety implications. Also, high amounts of suspended material can clog plumbing systems and stain clothing and water containers. The Kentucky Pollution Discharge Elimination System recommends that total suspended solids levels be less than 35 mg/L.

In BMU 3 there are 622 measurements of total suspended solids from 109 sites. The values range from 0 to 442 mg/L (Table 9). Despite the high maximum value, the median and interquartile range of total suspended solids values are very low. Eighty percent of the total suspended solids measurements are less than 10 mg/L and 90 percent are less than 20 mg/L (Fig. 26).

Table 9. Summary of total suspended solids values (mg/L).

Measurements	622
Maximum	442
75th percentile	4
Median	3
25th percentile	3
Minimum	0
Interquartile range	3–4
Sites	109
DOW recommended value	35
Sites > 35	14

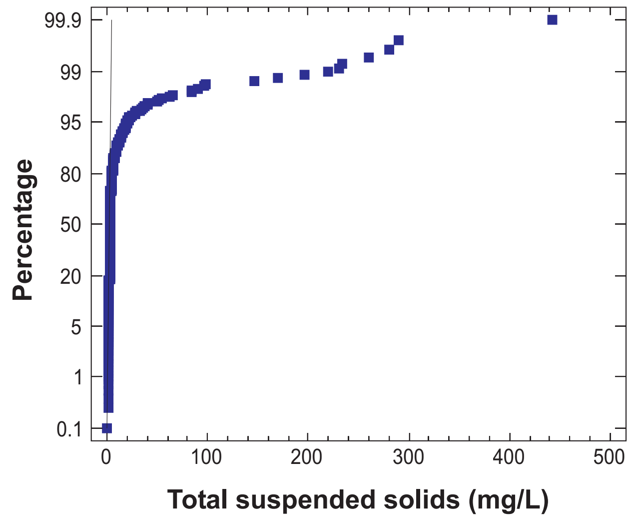

Figure 26. Cumulative plot of total suspended solids values.

Sample site distribution is rather uniform throughout the project area (Fig. 27).

The highest total suspended solids values are found In the Ohio and Tennessee River watersheds in the Jackson Purchase Region (Figs. 28–29). Although many high values are reported from the Jackson Purchase (Fig. 28), they are from only two sites (Fig. 27). Values from sites in the Mississippi River watershed are uniformly low (Fig. 29).

The highest total suspended solids values are reported from wells rather than springs (Fig. 30); wells less than 100 ft deep have the highest total suspended solids values (Fig. 31).

In summary, suspended solids may be locally derived as a result of vigorous well purging before sampling or may be transported by turbulent groundwater flow. Total suspended solids concentrations can be significant because suspended clays and organic material preferentially carry some potentially toxic metals and synthetic organic chemicals. The distribution of the highest total suspended solids values suggests that springs in the Western Pennyroyal Region carry significant amounts of suspended material, and that suspended sediment concentrations are also high in a few wells in the generally unconsolidated to poorly consolidated sands, silts, and clays in the Jackson Purchase Region.

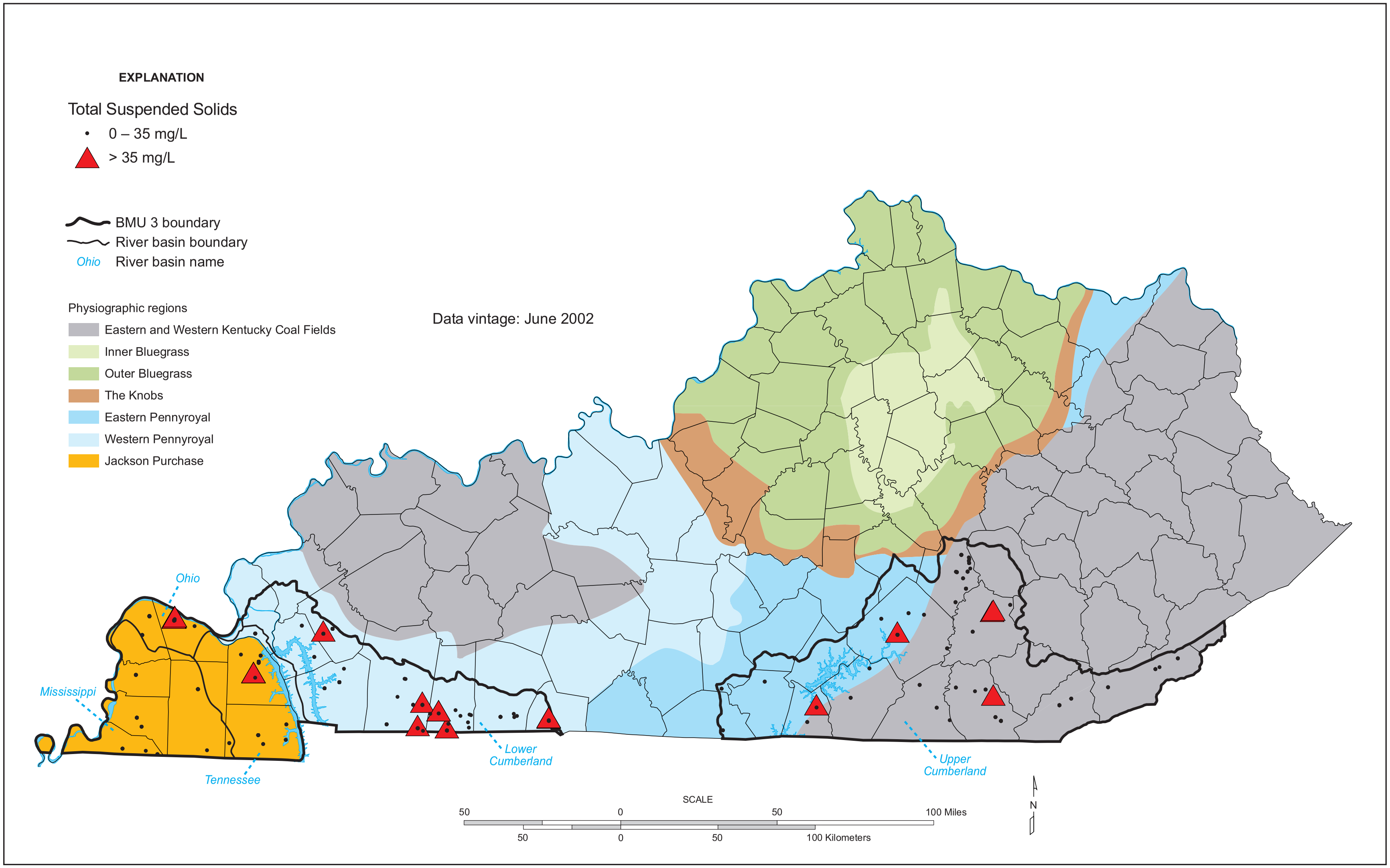

Figure 27. Sample sites and ranges of total suspended solids values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

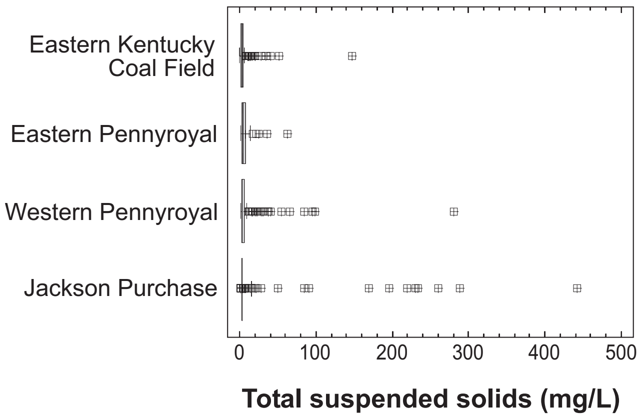

Figure 28. Summary of total suspended solids values grouped by physiographic region.

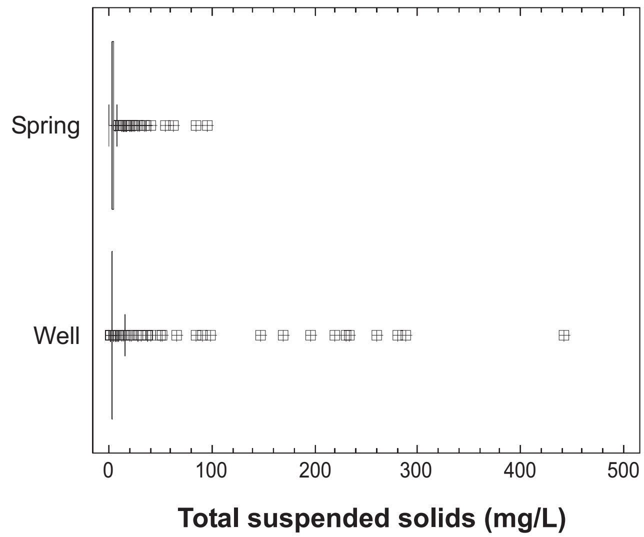

Figure 30. Comparison of total suspended solids values from wells and springs.

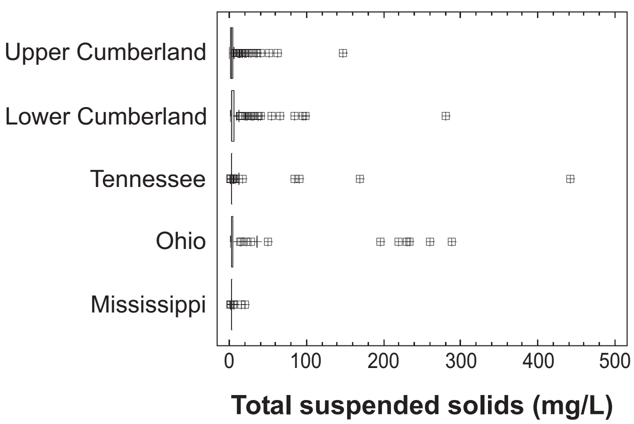

Figure 29. Summary of total suspended solids values grouped by major watershed.

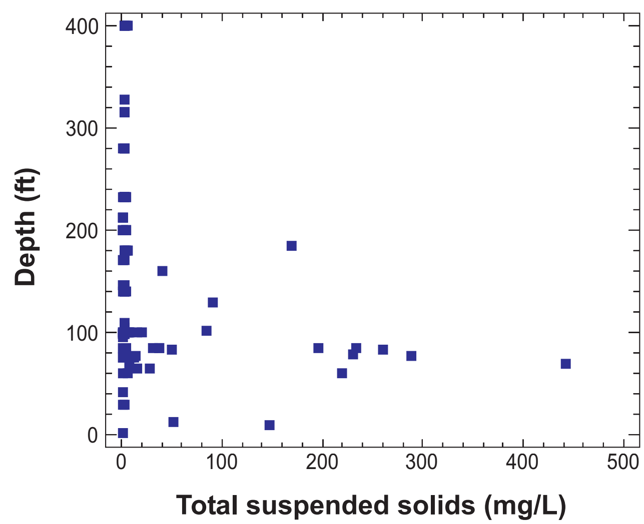

Figure 31. Total suspended solids values versus well depth.