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. For these reasons it is one of the most important parameters that describe groundwater quality.

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 coal and associated 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 8.4.

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

The data repository contained 4,388 pH values from 828 sites in the study area (Table 4). The pH data are generally similar in BMU's 1, 2, and 5. The median values in each basin management unit are within 0.5 pH unit of each other, and the interquartile ranges are similar. Minimum pH values are also similar, but the maximum values are quite different.

Cumulative data plots (Figs. 4–6) show some differences between basin management units. BMU 1 has many values less than 6.5 and greater than 8.5 (Fig. 4), whereas samples from BMU 2 and BMU 5 show many values less than 6.5 but very few values greater than 8.5 (Figs. 5–6). The pH values from BMU 2 are more tightly clustered about the median than values from the other basin management units (Fig. 5).

Distribution of sampled sites through the project area is very uneven (Fig. 7). The Eastern Kentucky Coal Field and Western Pennyroyal Regions are more densely sampled than the other regions. This sample-site distribution in part reflects differences in groundwater use throughout the area. The map also shows that pH values vary considerably in the Eastern Kentucky Coal Field but are more uniform in the carbonate settings of the Inner Bluegrass, Outer Bluegrass, and Western Pennyroyal Regions. Values less than 6.5 are restricted to the Eastern Kentucky Coal Field and Knobs Regions; pH values greater than 8.5 are rare outside the Eastern Kentucky Coal Field.

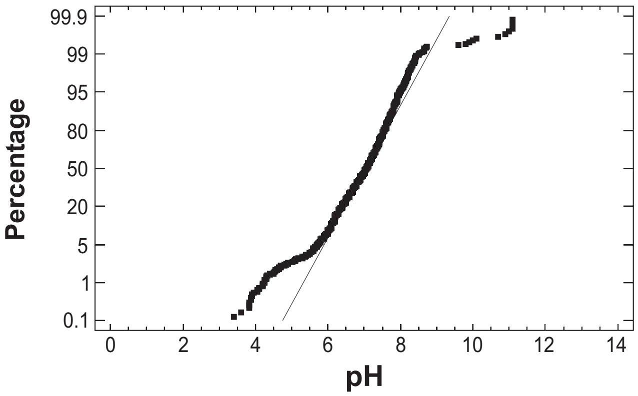

Figure 4. Cumulative plot of pH values from BMU 1.

Table 4. Summary of pH values (standard pH units). SMCL: 6.5 to 8.5.

	BMU 1	BMU 2	BMU 5
Values	2,005	778	1,605
Maximum	11.6	8.6	10.4
75th percentile	7.5	7.7	7.4
Median	7.1	7.4	6.9
25th percentile	6.5	7.2	6.4
Minimum	2.3	2.8	2.6
Interquartile range	1.0	0.5	1.0
Sites	288	278	262
Sites < 6.5	112	35	87
Sites > 8.5	8	2	2

Grouping pH values by physiographic region (Fig. 8) shows the variability within the Eastern Kentucky Coal Field relative to the other regions.

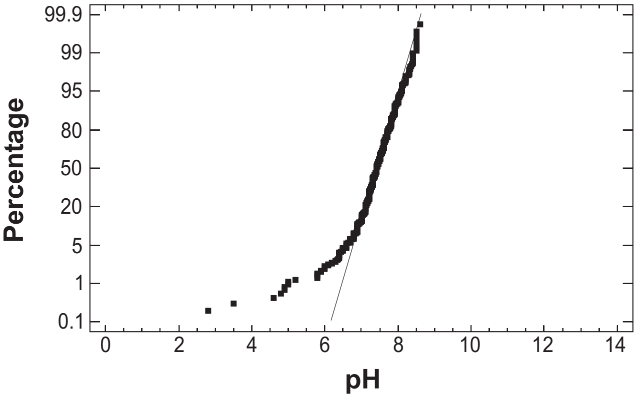

Figure 5. Cumulative plot of pH values from BMU 2.

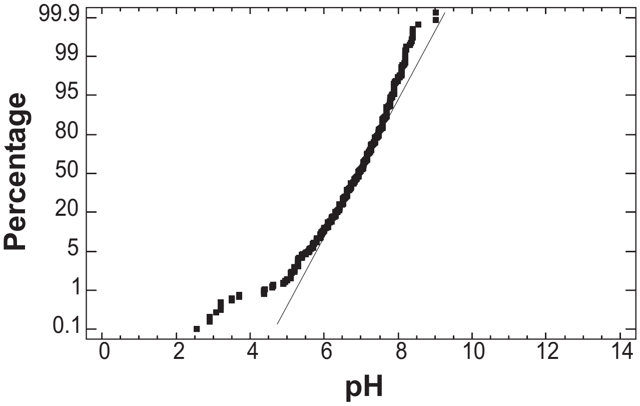

Figure 6. Cumulative plot of pH values from BMU 5.

Samples from the Eastern Kentucky Coal Field produce the highest and lowest pH values reported and the greatest range of pH values. Also, the interquartile range of values is greater for groundwater from the Eastern Kentucky Coal Field than for water from other regions. This pattern is probably the result of the lithologic heterogeneity in the coal fields, whereas bedrock type in the other regions is less variable. The lithologically similar Inner and Outer Bluegrass and Eastern and Western Pennyroyal Regions have similar interquartile ranges.

Group pH values by major watershed (Fig. 9) shows the greatest variability in the Kentucky River watershed, which drains the Eastern Kentucky Coal Field, Knobs, and Inner and Outer Bluegrass Regions.

Groundwater from wells generally has somewhat lower and more variable pH values than groundwater from springs (Fig. 10). Wells also show more pH values greater than 8.5 than springs, probably because wells are more common in the lithologically heterogeneous Eastern Kentucky Coal Field, whereas springs are more common in the carbonate Bluegrass and Pennyroyal Regions.

Shallow wells show a greater range of pH values than deeper wells (Fig. 11), suggesting that groundwater in intermediate and deep flow systems has equilibrated with bedrock, whereas shallower groundwater systems have not.

In summary, sample-site distribution for pH is not uniform throughout the project area. The Eastern Kentucky Coal Field and Western Pennyroyal Regions are relatively well sampled, whereas large parts of the Inner and Outer Bluegrass have not been sampled. Groundwater pH values and ranges of values are more closely related to physiographic region and underlying bedrock lithology than to basin management unit or watershed. Groundwater in the predominantly carbonate regions is nearly neutral, and pH values show relatively little scatter. In the Eastern Kentucky Coal Field, where bedrock lithology is more heterogeneous, most groundwater is near neutral to slightly acidic, but there is a much wider range of values. In general, pH values reflect bedrock geology rather than nonpoint-source effects. The pH of springs and shallow wells is much more variable than the pH observed in 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 KGS Web site (kgsweb.uky.edu/olops/pub/kgs/ic06_12.pdf).

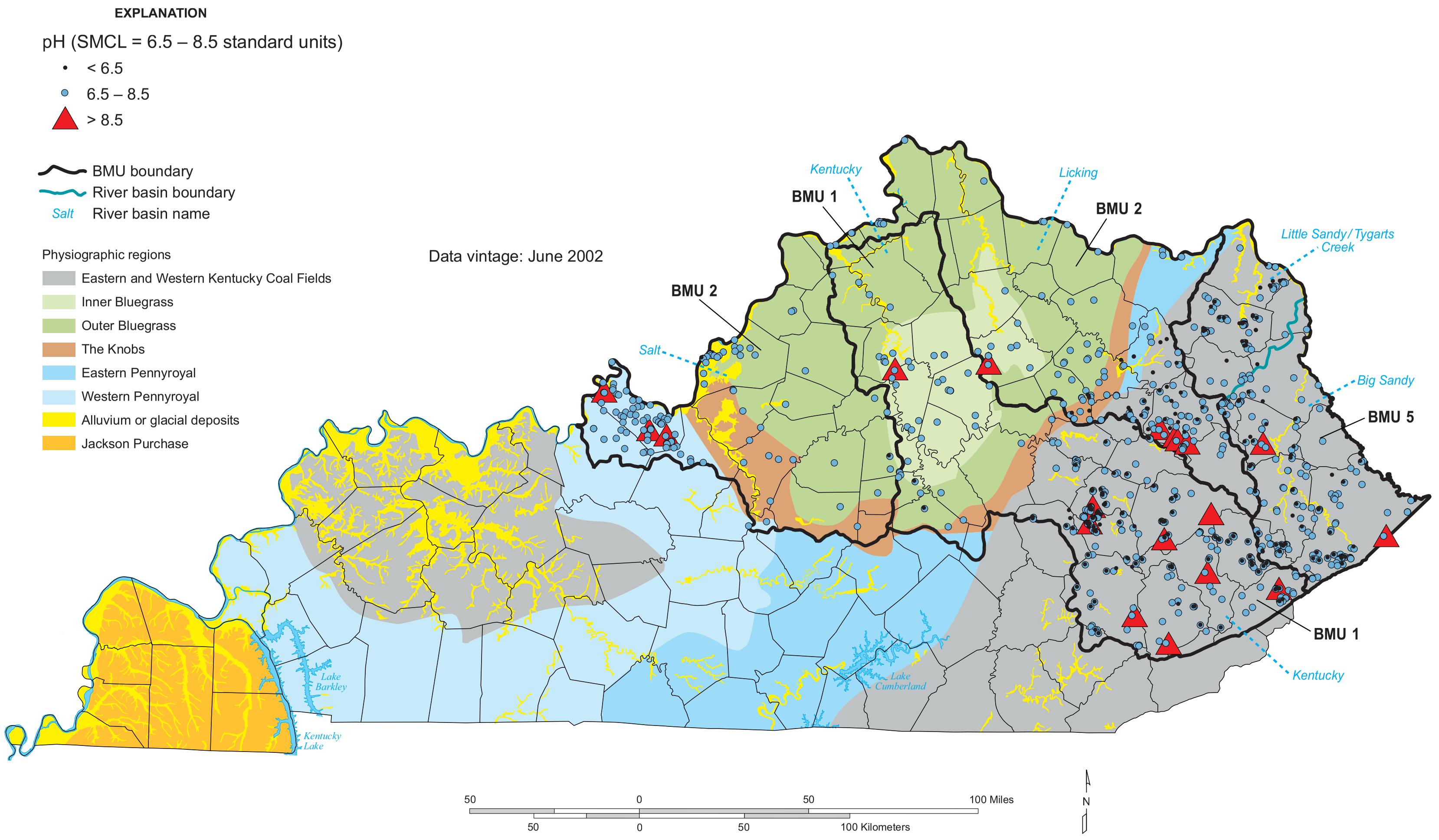

Figure 7. Locations of sampled sites and ranges of pH values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

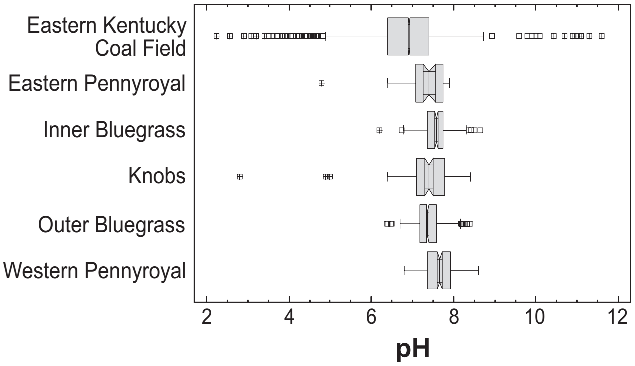

Figure 8. Summary of pH values grouped by physiographic region.

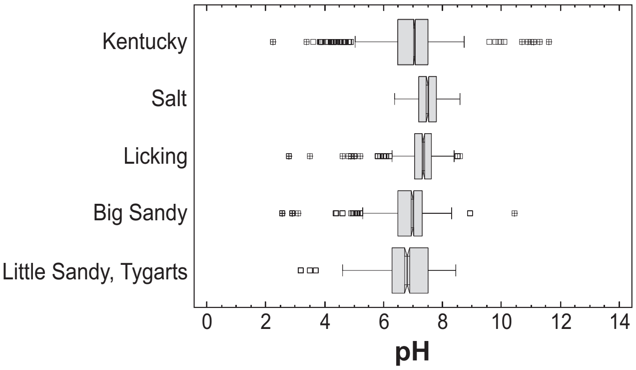

Figure 9. Summary of pH values grouped by major watershed.

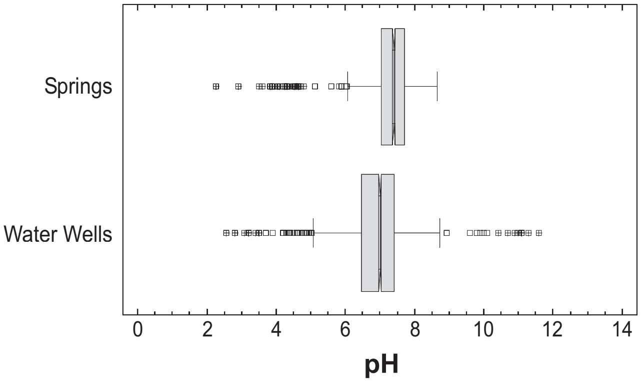

Figure 10. Comparison of pH values from wells and springs.

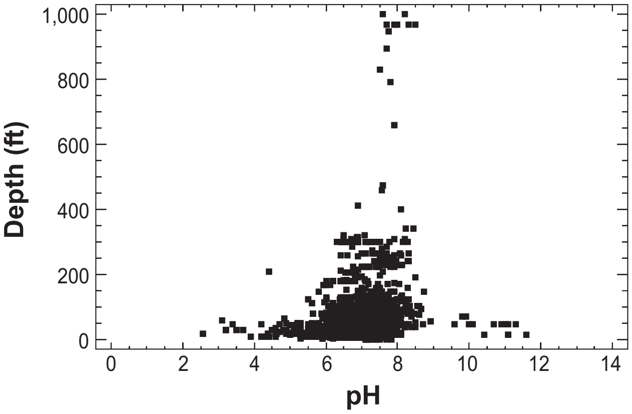

Figure 11. Plot of pH values versus well depth.

Total Dissolved Solids. Total dissolved solids is 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 typically increases with sample depth or the distance that groundwater has traveled from recharge area to sample site.

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 for total dissolved solids. Water having values greater than 500 mg/L has an unpleasant taste and may stain objects or precipitate scale.

The Kentucky Groundwater Data Repository contained 1,185 reports of total dissolved solids at 230 sites in the project area (Table 5). Nearly all samples and sites yielded potable water; the 75th percentile value

Table 5. Summary of total dissolved solids values (mg/L). SMCL: 500 mg/L.

	BMU 1	**BMU 2**	**BMU 5**
Values	599	441	145
Maximum	60,364	18,000	2,880
75th percentile	406	442	414
Median	320	358	298
25th percentile	254	234	222
Minimum	0	10	60
Interquartile range	152	208	192
Sites	82	86	62
Sites > 500 mg/L	24	16	19

for each basin management unit is less than 500 mg/L. Only 59 of 230 sites (26 percent) yielded groundwater with more than 500 mg/L total dissolved solids.

Cumulative data plots (Figs. 12–14) show some differences between the basin management units. A break in slope at about 100 mg/L suggests two different populations of data in BMU 1 (Fig. 12). More than 95 percent of the values from BMU 2 follow a normal distribution, whereas values from BMU 5 show a distribution typical of a positively skewed data set.

The distribution of sampled sites is densest in the Eastern Kentucky Coal Field and Inner Bluegrass, and least dense in the Outer Bluegrass (Fig. 15), a consequence of variations in groundwater use in the project area.

Groundwater from the Eastern Kentucky Coal Field has the highest TDS values, the greatest number of values greater than 1,000 mg/L, and the largest spread in the central 50 percent of the data (Fig. 16). Samples from the Eastern and Western Pennyroyal and the Inner Bluegrass Regions have the smallest spread in the central 50 percent of the reported values.

Grouping total dissolved solids values by major watershed (Fig. 17) shows that all watersheds have about the same range and magnitude of values for the central 50 percent of the data. There are many more values greater than 1,000 mg/L reported from the Kentucky River watershed than from any other major river basin, however.

Groundwater from wells has a somewhat higher median value of total dissolved solids than groundwater from springs (Fig. 18), although the ranges are quite similar.

With the exception of a few high-TDS reports from shallow wells, there is no systematic trend of total dissolved solids with well depth (Fig. 19).

In summary, more than 75 percent of the groundwater sampled in the project area is potable in terms of TDS, although there are exceptions in each basin management unit, physiographic region, and major watershed. Saline to brackish groundwater is most likely to be encountered in the Eastern Kentucky Coal Field. Total dissolved solids values are generally similar in each basin management unit and each major river watershed. There are systematic differences in the data for each physiographic region, however. This indicates that total dissolved solids values are controlled more by the bedrock geologic differences between physiographic regions than by the geographic differences between basin management units or major watersheds. There is no clear evidence that nonpoint-source chemicals are influencing regional trends in total dissolved solids values.

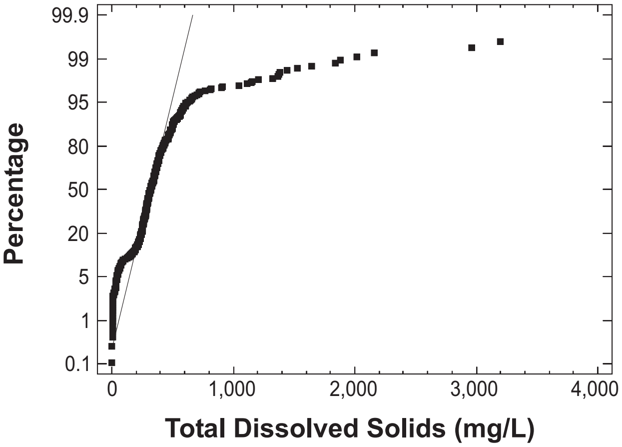

Figure 12. Cumulative plot of total dissolved solids values from BMU 1. Two values greater than 4,000 mg/L were omitted for clarity.

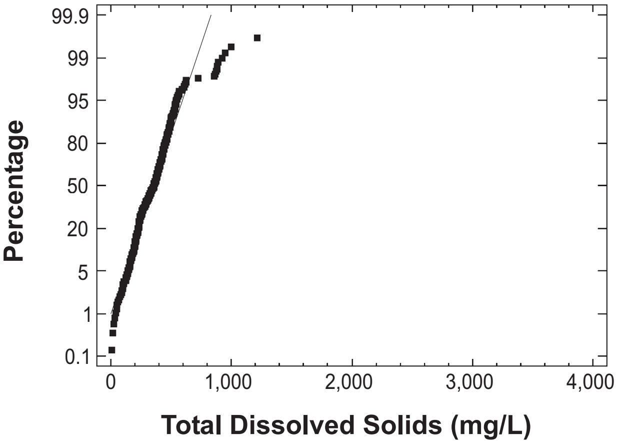

Figure 13. Cumulative plot of total dissolved solids values from BMU 2. One value greater than 4,000 mg/L was omitted for clarity.

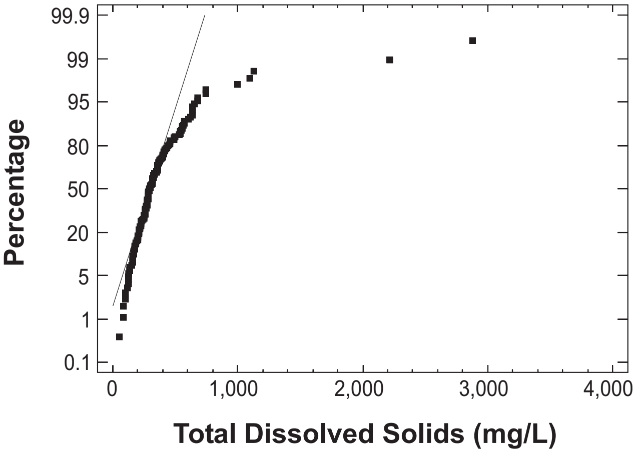

Figure 14. Cumulative plot of total dissolved solids values from BMU 5. No values exceeded 4,000 mg/L.

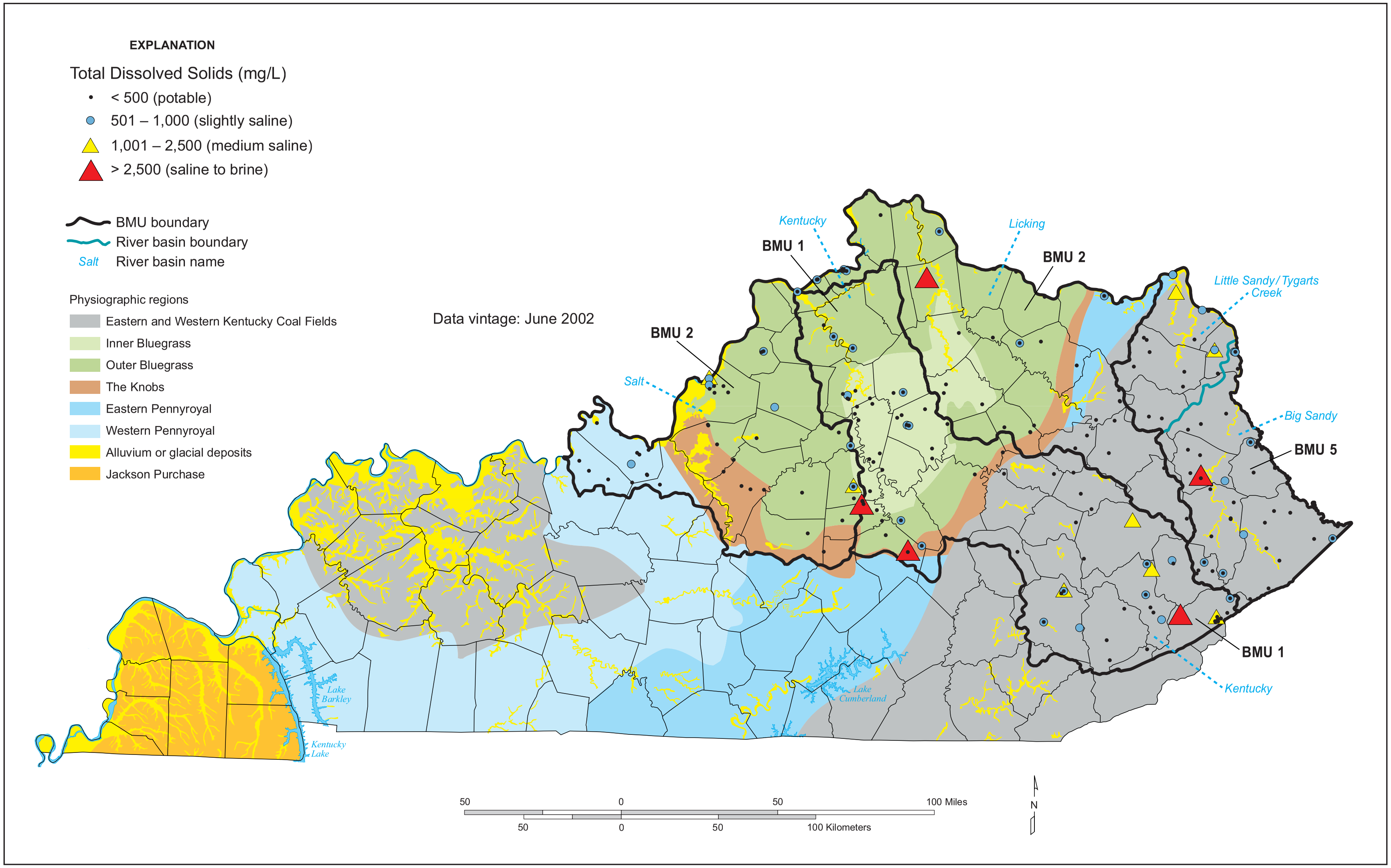

Figure 15. Locations of sampled sites and ranges of total dissolved solids values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

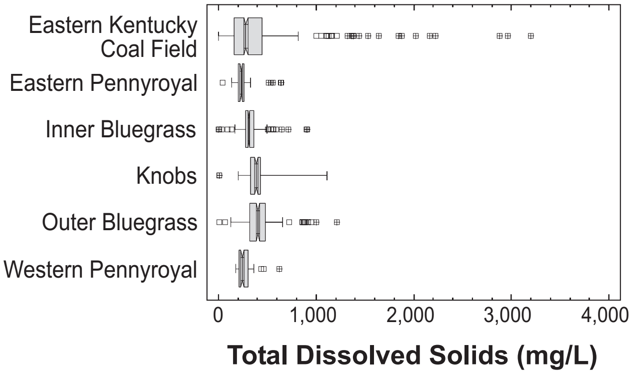

Figure 16. Summary of total dissolved solids values grouped by physiographic region.

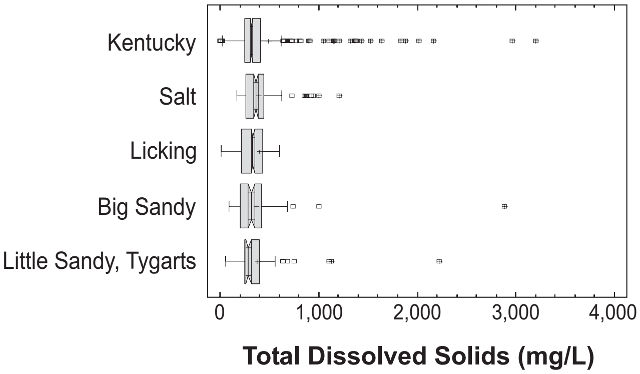

Figure 17. Summary of total dissolved solids values grouped by major watershed.

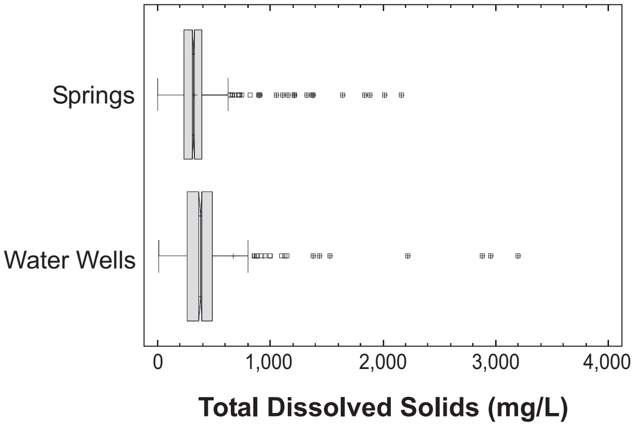

Figure 18. Comparison of total dissolved solids values from wells and springs.

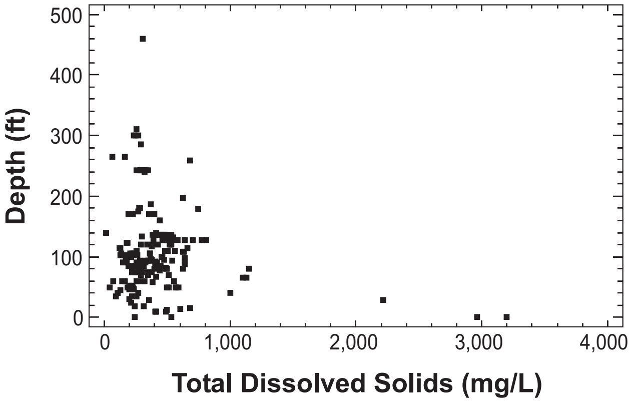

Figure 19. Plot of total dissolved solids values versus well depth.

Specific Electrical Conductance. Specific electrical conductance, also referred to as conductivity, is a measure of the ease with which water conducts an electrical current. It is an indirect measure of water quality and is proportional to total dissolved solids concentrations. 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 10,874 conductance measurements from 4,628 sites in the project area (Table 6). This large number of measurements is the result of the extensive field sampling program associated with the National Uranium Resource Evaluation project (Smith, 2001). Values range from 0 to 205,000 µS/cm. Groundwater from BMU 2 has higher 75th percentile, median, and 25th percentile conductance values and a larger interquartile range than groundwater from the rest of the project area.

The data distributions for the lowest 95 percent of the measured values are similar for the three basin management units (Figs. 20–22). Few groundwater samples from BMU 2 have conductance values greater than 50,000 µS/cm, whereas such values are more common in BMU 1 and BMU 5. The data distribution for BMU 2 (Fig. 21) has a distinct break in slope at about 20,000 µS/cm, which suggests that two different populations are included in the data set.

There are many more sampled sites in the southern half of the project area, below approximately 38°N latitude, than in the northern half (Fig. 23), because sampling for the National Uranium Resource Evaluation program did not extend north of this line. Sites where conductance exceeded 10,000 µS/cm are more common in the Eastern Kentucky Coal Field than in the other regions.

The median conductance value and interquartile range of values is higher for measurements from sites in the Knobs Region than in any other region (Fig. 24). This is because 10 sites in the Knobs Region have yielded high-conductance samples on 48 occasions; the number of high conductance values is large, but the number of sites producing that water is small. Samples from the Eastern Kentucky Coal Field have the lowest median value, whereas samples from the Inner Bluegrass and Western Pennyroyal Regions have the smallest interquartile range. Nearly all of the conductance values are less than 4,000 µS/cm.

Grouping the measurements by major river basin (Fig. 25) shows the Licking River watershed to have the highest median, interquartile range, and 75th percentile values. Nearly all of the conductance values in the project area are less than 4,000 µS/cm, however.

Groundwater from wells has higher median values and interquartile range than groundwater from springs (Fig. 26), as well as many more reported values greater than 4,000 µS/cm.

The vast majority of the conductance values from wells are less than 10,000 µS/cm, and within that group there is a general trend toward lower values with increasing well depth (Fig. 27). There is considerable scatter in the data, however.

In summary, conductance is an indirect indicator of groundwater quality, related to salinity or total dissolved solids, but not a direct measure of either. There are no health-based standards or aesthetic effects associated with high conductance values. Conductance values are as high as 205,000 µS/cm in the project area. There is little systematic regional variation, however. More than 97 percent of the reported values are less than 5,000 µS/cm, and more than 98 percent of the reported values are less than 10,000 µS/cm. The highest conductance values reported in the project area are from wells deeper than 600 ft. There are no clear indications of nonpoint-source effects on conductance values in the project area.

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

	BMU 1	**BMU 2**	**BMU 5**
Values	3,601	5,119	2,154
Maximum	142,000	172,000	205,000
75th percentile	530	1,480	580
Median	350	710	325
25th percentile	195	450	195
Minimum	0	0	0
Interquartile range	335	1,030	385
Sites	1,753	1,827	1,04

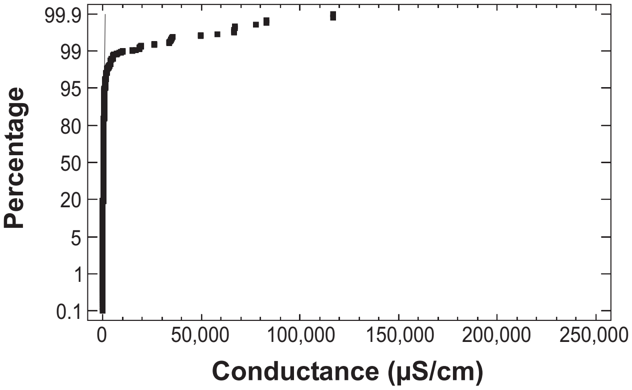

Figure 20. Cumulative plot of conductance values from BMU 1. The highest 0.1 percent of values is omitted so that the central 99.8 percent of the data can be presented more clearly.

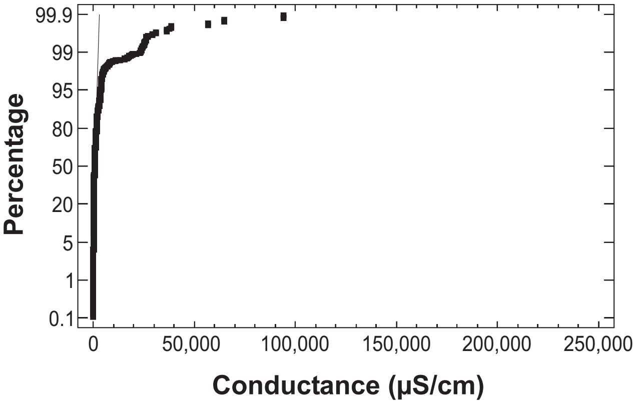

Figure 21. Cumulative plot of conductance values from BMU 2. The highest 0.1 percent of values is omitted so that the central 99.8 percent of the data can be presented more clearly.

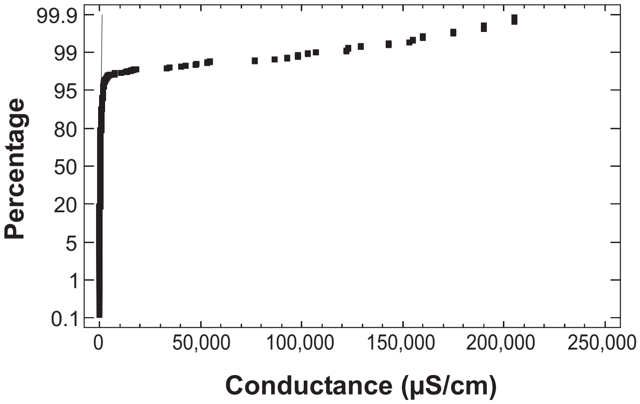

Figure 22. Cumulative plot of conductance values from BMU 5. The highest 0.1 percent of values is omitted so that the central 99.8 percent of the data can be presented more clearly.

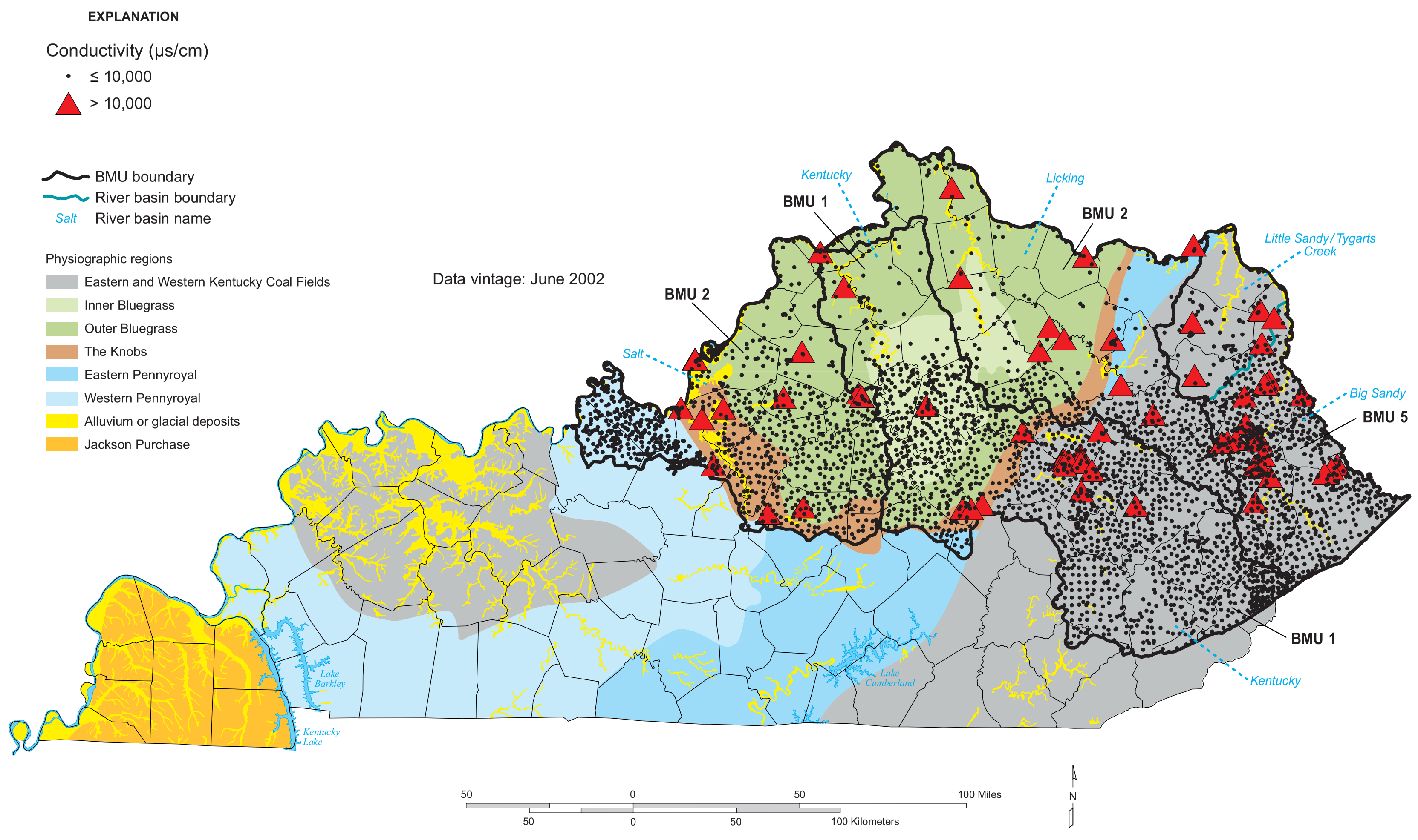

Figure 23. Locations of sampled sites and ranges of conductance values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

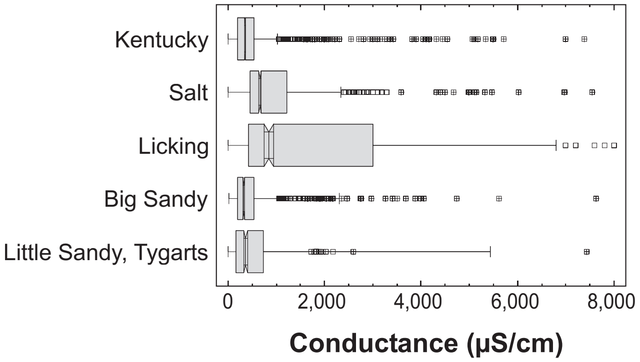

Figure 24. Summary of conductance values grouped by physiographic region. Higher values have been omitted to better show the majority of the data.

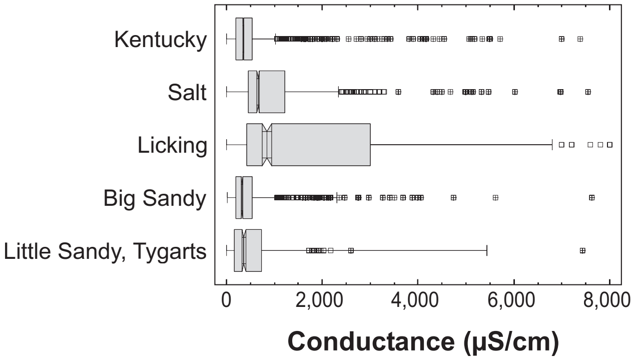

Figure 25. Summary of conductance values grouped by major river watershed. Higher values have been omitted to better show the majority of the data.

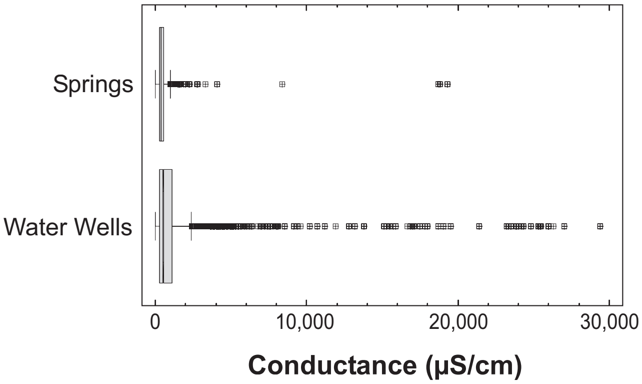

Figure 26. Comparison of conductance values from wells and springs. Higher values have been omitted to better show the majority of the data.

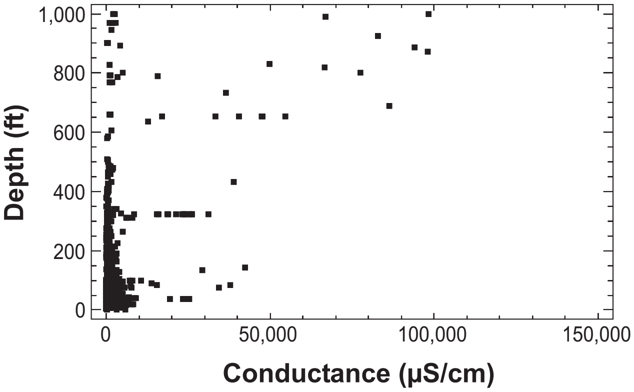

Figure 27. Plot of conductance values versus well depth.

Hardness. Hardness is the capacity 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:

$$\text{Hardness (mg/L calcium carbonate equivalent)} = 2.5\ \text{Ca (mg/L)} + 4.1\ \text{Mg (mg/L)}$$

Table 7 shows a frequently used classification of hardness in water supplies (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 a total of 1,550 groundwater hardness values at 436 sites in the project area. Because most sites were sampled and analyzed more than once, the calculated hardness values for individual samples at a site were averaged to give the number of sites meeting various water-quality criteria (Table 8). Hard to very hard water is predominant in each basin management unit. Soft to moderately hard water is uncommon, except in BMU 5, where 69 of 137 sites produced such water.

Cumulative data plots (Figs. 28–30) show that hardness values greater than 10,000 mg/L are present in each BMU. More than 95 percent of the values are less than 1,000 mg/L, however. Basin management

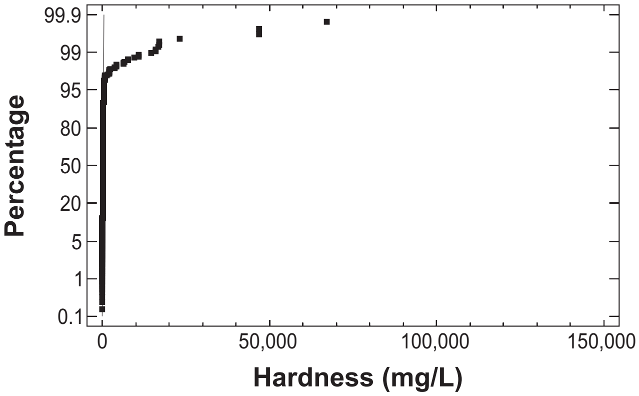

Figure 28. Cumulative plot of hardness values from BMU 1.

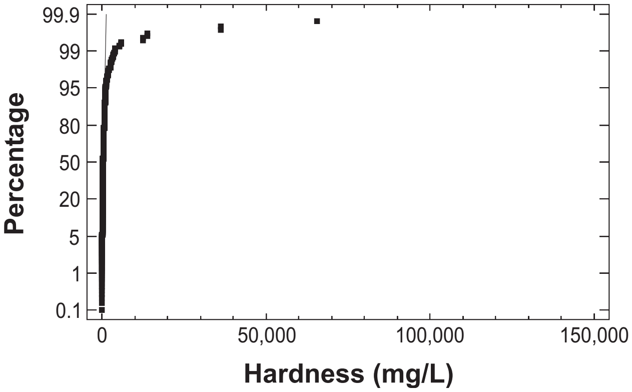

Figure 29. Cumulative plot of hardness values from BMU 2.

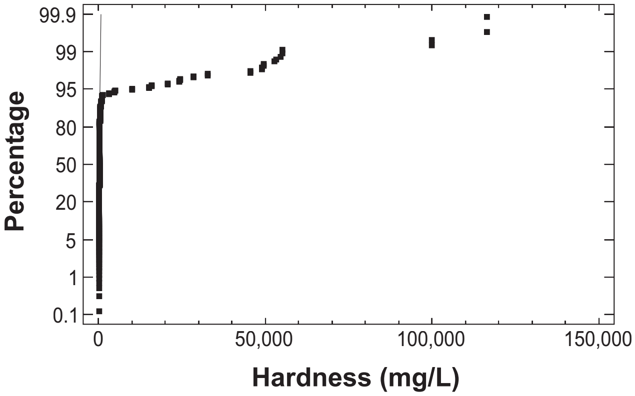

Figure 30. Cumulative plot of hardness values from BMU 5.

Table 8. Summary of the number of sites in various hardness categories.

	BMU 1	BMU 2	BMU 5
Values	339	937	274
Sites	100	199	137
Sites with soft water	2	1	3
Sites with slightly hard water	13	4	23
Sites with moderately hard water	10	8	43
Sites with hard water	13	6	25
Sites with very hard water	62	180	43

unit 5 has the hardest water and the greatest number of values that exceed 10,000 mg/L.

The distribution of sampled sites is extremely uneven throughout the project area (Fig. 31). In the Licking River watershed, the northeastern half of basin management unit 2, 72 sites are located mostly in the Ohio River alluvium and the Inner Bluegrass Region; very few sites in the interior of the watershed have been sampled. The eastern part of the Eastern Kentucky Coal Field and the northern parts of the Salt and Kentucky River watersheds are also more densely sampled than the other parts of the project area. Hard to very hard water is found throughout, but soft to moderately hard water is rare outside of the Eastern Kentucky Coal Field.

The Outer Bluegrass Region has the highest median hardness value and the largest interquartile range (Fig. 32). The Eastern Kentucky Coal Field has the lowest (softest) median value, whereas the Inner Bluegrass Region has the smallest interquartile range.

Grouping the hardness values by major watershed (Fig. 33) shows that samples from the Salt River Basin have the highest median value and largest interquartile range, whereas samples from the Kentucky River watershed have the smallest interquartile range (least variability within the central 50 percent of the data). Groundwater from the Big Sandy River watershed has the lowest median value.

Groundwater from wells has higher median hardness, larger spread of the central 50 percent of values, and more very high hardness values than water from springs (Fig. 34).

The hardest water is reported from wells deeper than 600 ft (Fig. 35). The trend of the majority of reported values is to decrease with well depth, however.

In summary, the distribution of sites at which water hardness could be calculated is very uneven throughout the project area. Water hardness is strongly related to bedrock geology, however, and so can be predicted in areas where there has been no sampling. Groundwater in the Inner Bluegrass and Western Pennyroyal Regions, which are underlain by limestone strata, is typically hard to very hard. Groundwater in the lithologically heterogeneous Eastern Kentucky Coal Field has highly variable hardness. Hard to very hard water occurs at more than 75 percent of the sites in the project area. Although groundwater is typically hard to very hard throughout the project area, few sites have hardness values greater than 1,000 mg/L. For such sites, water softeners can remove much of the calcium and magnesium that cause hardness problems. No significant effect of nonpoint-source chemicals is indicated because water hardness values correspond closely with bedrock geology.

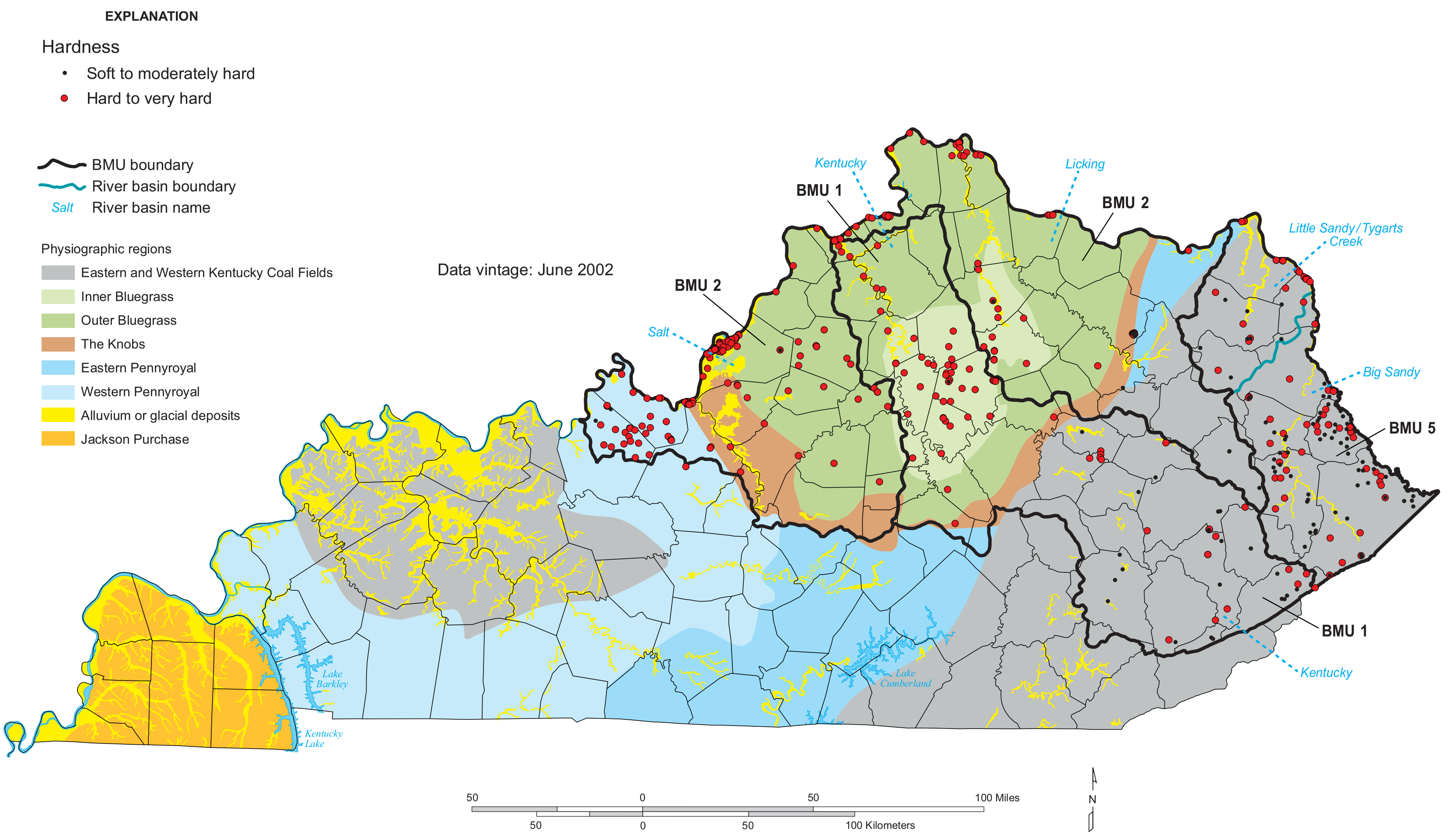

Figure 31. Locations of sampled sites and ranges of hardness values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

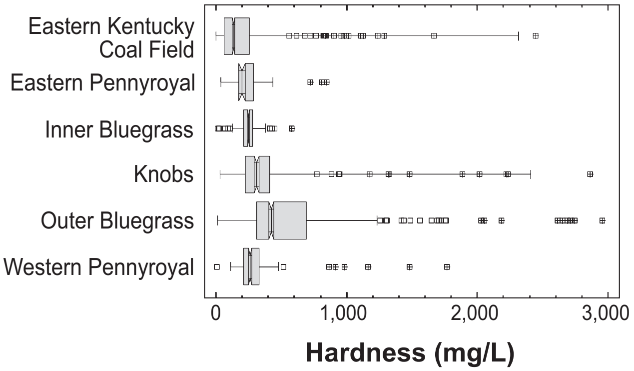

Figure 32. Summary of hardness values grouped by physiographic region. Higher values have been omitted to better show the majority of the data.

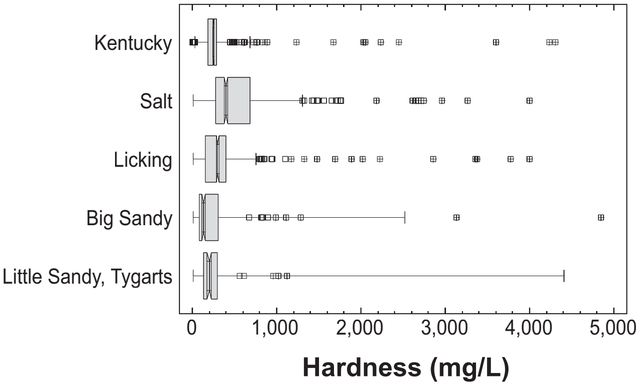

Figure 33. Summary of hardness values grouped by major watershed. Higher values have been omitted to better show the majority of the data.

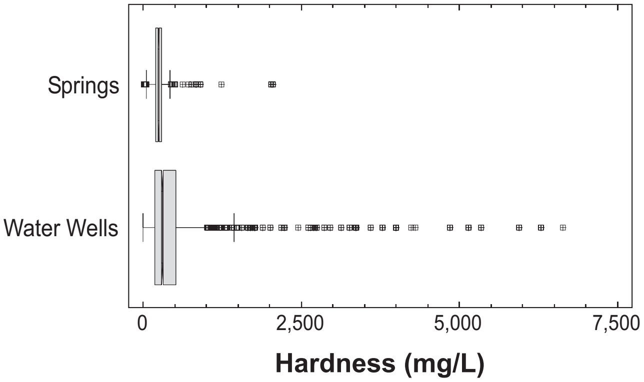

Figure 34. Comparison of hardness values from wells and springs. Higher values have been omitted to better show the majority of the data.

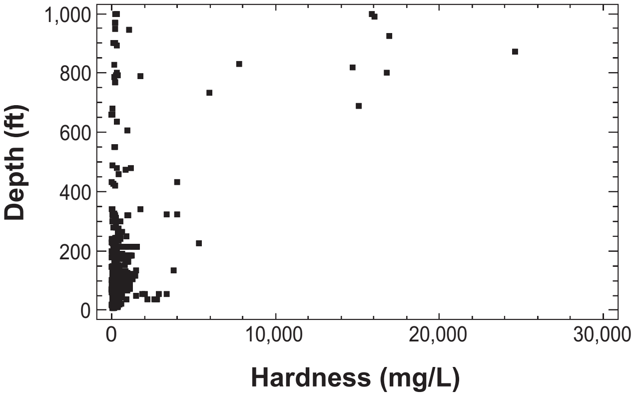

Figure 35. Plot of hardness values versus well depth.

Table 9. Summary of total suspended solids values (mg/L). KPDES recommendation: < 35 mg/L.

	BMU 1	BMU 2	BMU 5
Values	599	439	185
Maximum	1,520	680	125
75th percentile	6	5	5
Median	3	3	3
25th percentile	3	3	1
Minimum	0	< 1	< 1
Interquartile range	3	2	4
Sites	81	82	82
Sites > 35 mg/L	15	10	3

< means analytical result reported as less than the stated analytical detection limit

Total Suspended Solids. Particulate material is reported as total suspended solids. TSS values are typically higher in groundwater samples from karst springs, where turbulent water flow can transport fine material such as clays and particulate organic material; from uncased wells that have been vigorously stirred during purging prior to sample collection; or from wells that intercept a fracture or karst conduit, where turbulent flow may occur. 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 important amounts of metals, which 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 TSS levels be less than 35 mg/L.

The project area contains 1,223 reports of total suspended solids from 245 sites (Table 9). Maximum values in each basin management unit are quite high. Only 40 total suspended solids values from 28 sites exceed 35 mg/L, however.

Cumulative data distribution curves for the three basin management units are very similar (Figs. 36–38).

Site distribution is sparse and uneven throughout the project area (Fig. 39). This is probably because total suspended solids is not considered a critical parameter in determining groundwater quality.

In no physiographic region (Fig. 40) or major watershed (Fig. 41) does the 75th percentile of values exceed 10 mg/L. The largest interquartile range is found in the Salt River watershed of the Western Pennyroyal Region.

Groundwater from springs is more likely to produce turbid water (high TSS) than groundwater from wells (Fig. 42). Of the 28 sites that produce water

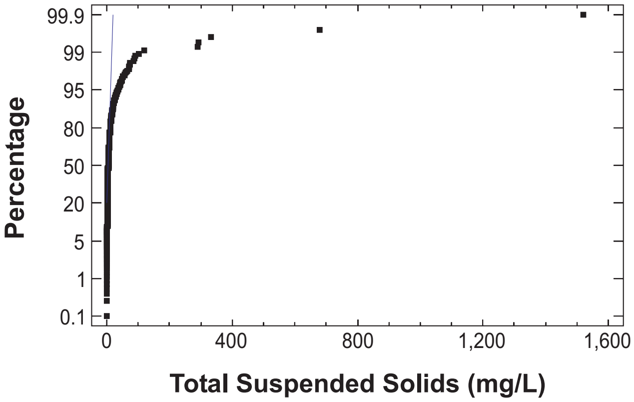

Figure 36. Cumulative plot of total suspended solids values from BMU 1.

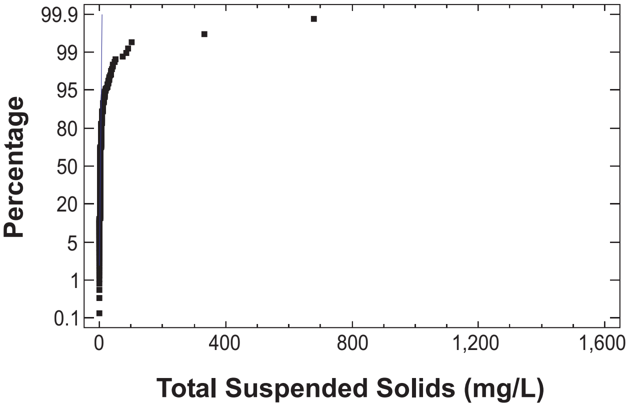

Figure 37. Cumulative plot of total suspended solids values from BMU 2.

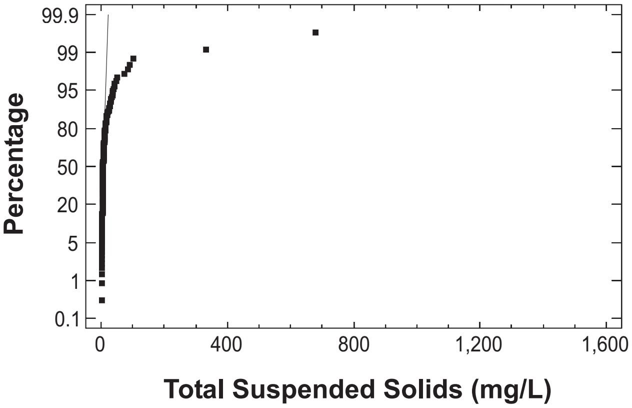

Figure 38. Cumulative plot of total suspended solids values from BMU 5.

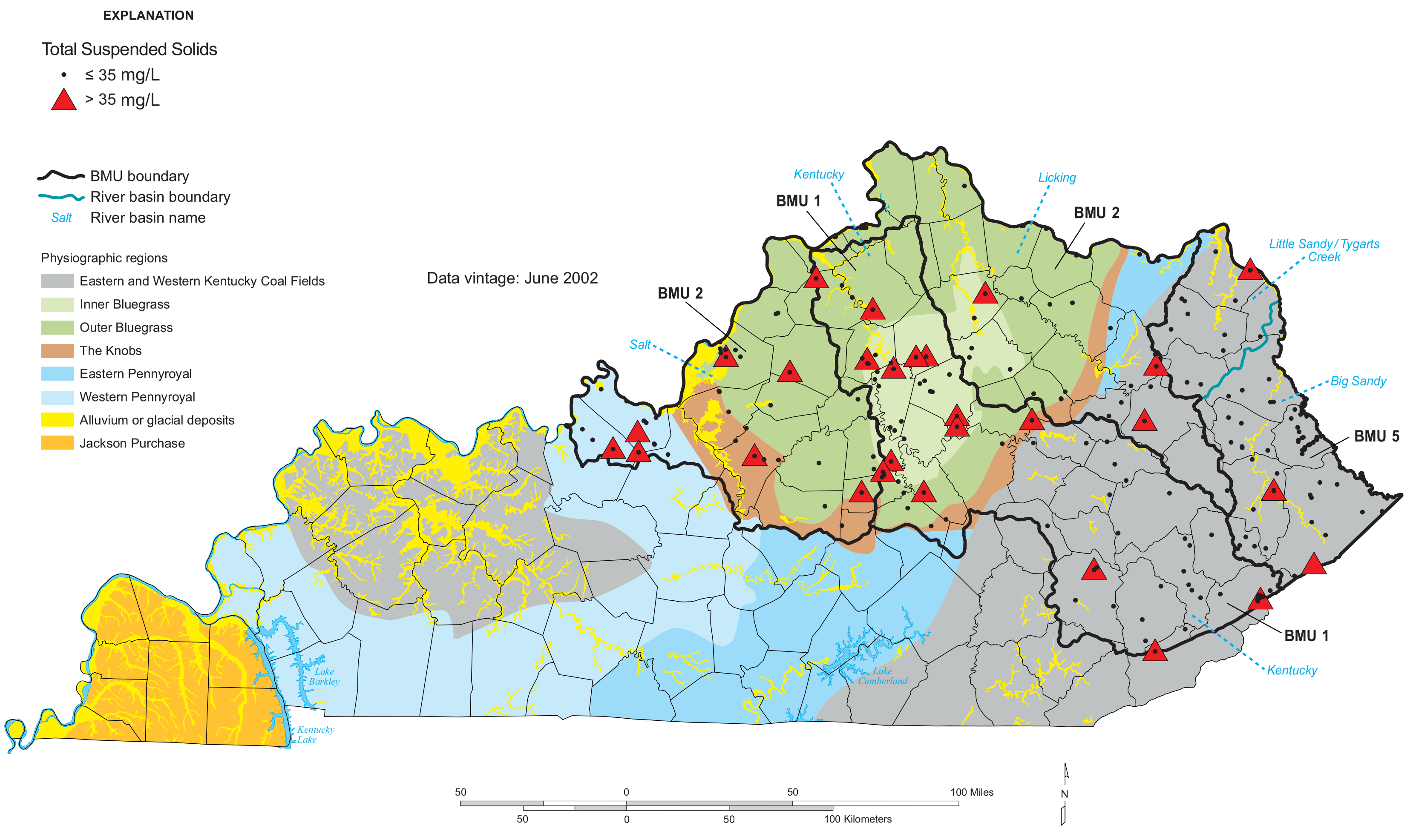

Figure 39. Locations of sampled sites and ranges of total suspended solids values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

having more than 35 mg/L total suspended solids, 24 are springs and only four are wells. Shallow wells are more likely to produce turbid water than deeper wells (Fig. 43).

In summary, total suspended solids values generally do not present problems for groundwater use in the project area. Only 40 of 1,223 measurements from 28 of 245 sites exceed the DOW-recommended value of 35 mg/L. Twenty-four of the 28 sites at which this value is exceeded are springs, where turbulent flow and transport of suspended solids is expected. There is no evidence of a nonpoint-source contribution to groundwater at the sampled sites.

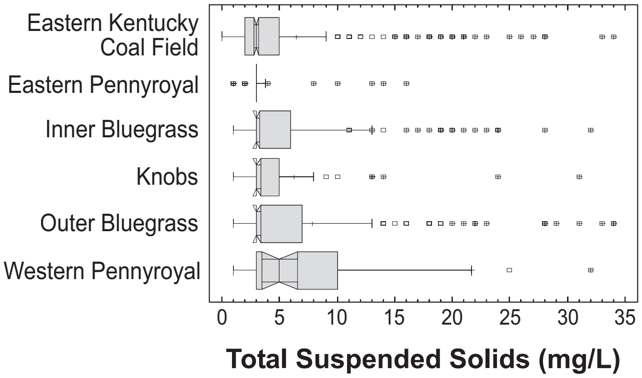

Figure 40. Summary of total suspended solids values grouped by physiographic region. Higher values have been omitted to better show the majority of the data.

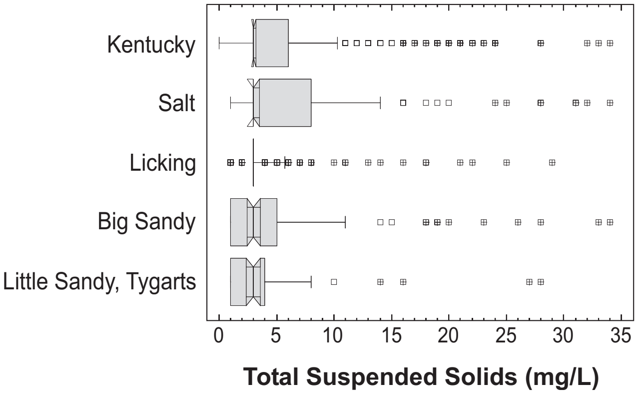

Figure 41. Summary of total suspended solids values grouped by major watershed. Higher values have been omitted to better show the majority of the data.

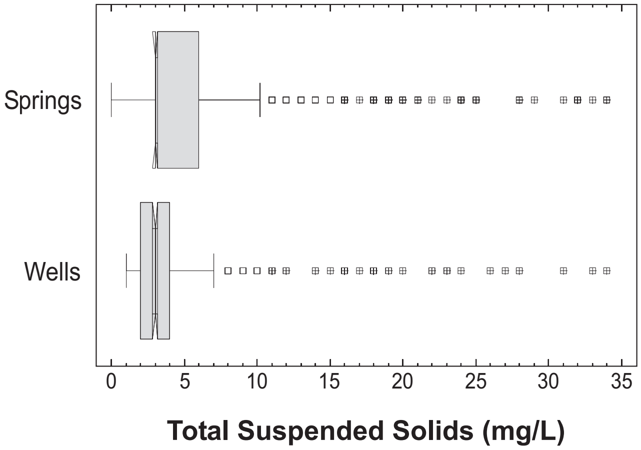

Figure 42. Comparison of total suspended solids values from wells and springs.

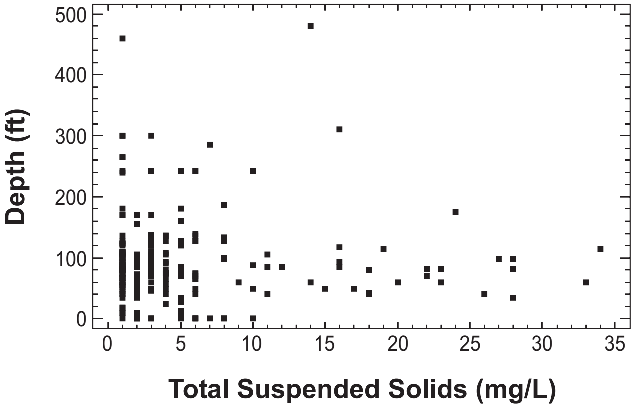

Figure 43. Plot of total suspended solids values versus well depth.