Results

Water Properties

pH. The parameter 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 many dissolved constituents, and provides a good indication of the types of minerals groundwater has reacted with as it flows from recharge to 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 value 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 (Hem, 1985).

There are no health-based drinking-water standards for pH. High or 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 U.S. Environmental Protection Agency has established a secondary maximum contaminant level for pH of 6.5 to 8.5.

The data repository contained 1,605 measurements from 262 sites (Table 5). Values from 89 sites did not meet SMCL criteria.

The cumulative data plot (Fig. 5) shows that more than 20 percent of the values were less than 6.5, but only two values were greater than 8.5.

Sampled sites were distributed fairly evenly through the project area (Fig. 6). Sites where pH values were less than 6.5 or greater than 8.5 were distributed throughout the area.

There was little difference in median values or interquartile ranges between the Big Sandy watershed and the Little Sandy River–Tygarts Creek watershed (Fig. 7). The highest pH values occurred in the Big Sandy watershed, whereas values less than 6.5 occurred in both watersheds.

Table 5. Summary of pH values (standard units). SMCL=6.5 to 8.5.

Number of values	1,605
Maximum	10.4
75th percentile	7.4
Median	6.9
25th percentile	6.4
Minimum	2.6
Interquartile range	1.0
Number of sites	262
Number of sites < 6.5	87
Number of sites > 8.5	2

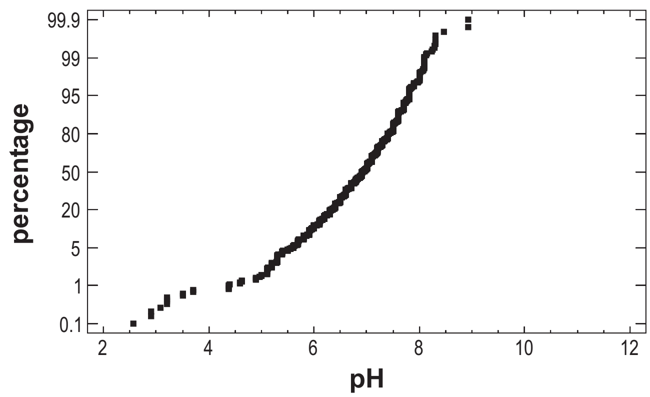

Figure 5. Cumulative plot of pH values. SMCL=6.5 to 8.5.

There was little difference in median value or interquartile range of values between water from wells and springs; however, water from wells had a larger total range of values and more low pH values than water from springs (Fig. 8).

Shallow wells showed a greater range of pH values than deeper wells (Fig. 9). This is expected if the deeper groundwaters have equilibrated with bedrock, therefore restricting the range of pH values, whereas shallower groundwater systems have not.

In summary, within the project area, pH values ranged from 2.6 to 10.4. More than 75 percent of the values fell within the recommended range of 6.5 to 8.5. Sites that did not meet this criterion were distributed throughout the region and not concentrated in either watershed. Well water had a greater range of pH values than water from springs; water from shallow wells showed a greater range of pH values than water from deeper wells. Some pH values less than 5.0 were very likely the result of acid mine drainage. There was no strong evidence that nonpoint-source chemicals have significantly affected pH in groundwater. A statewide

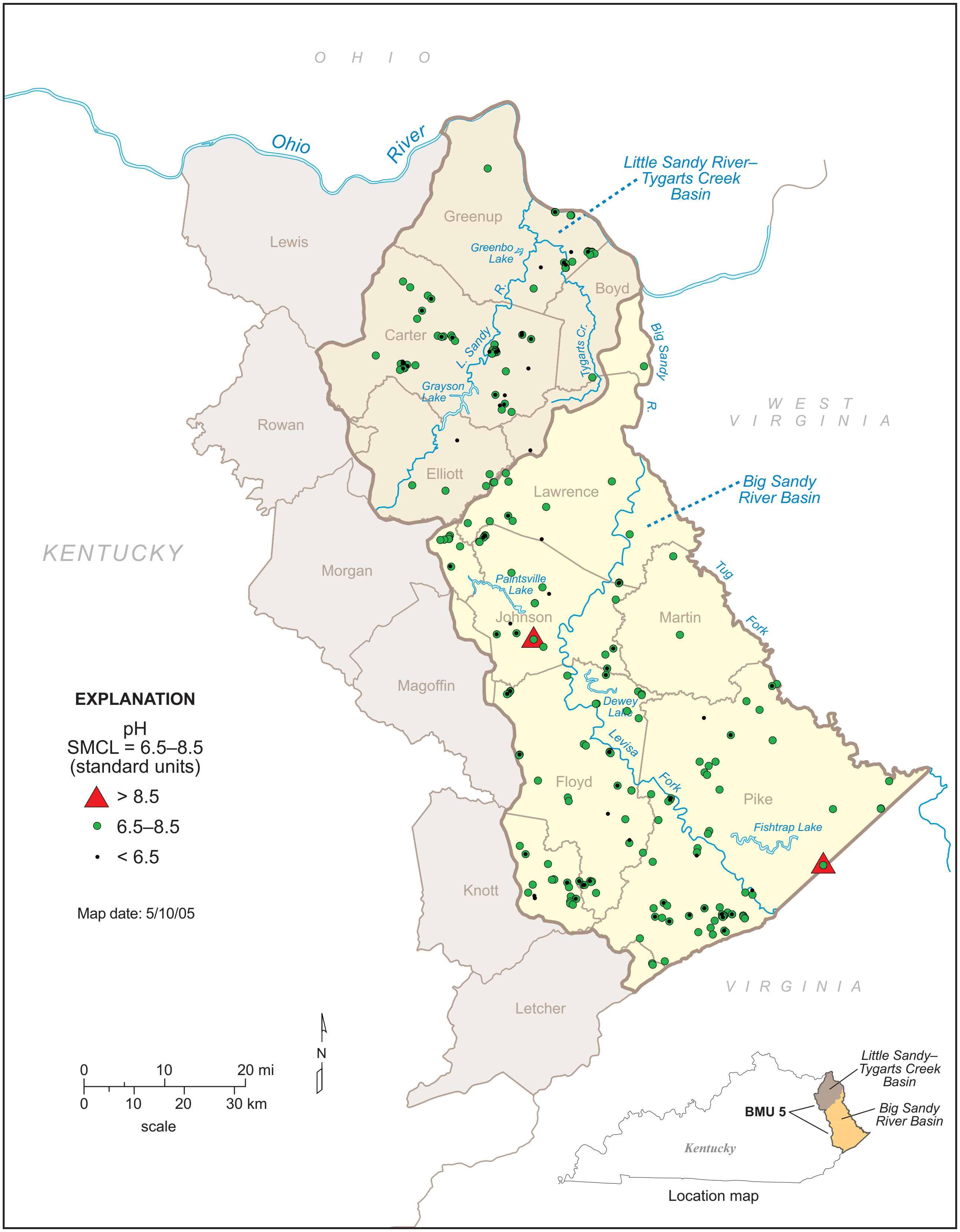

Figure 6. Locations of sampled sites and ranges of pH values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

summary of pH data is available (Fisher, 2002b) and can be viewed on the KGS Web site (kgsweb.uky.edu/olops/pub/kgs/ic06_12.pdf).

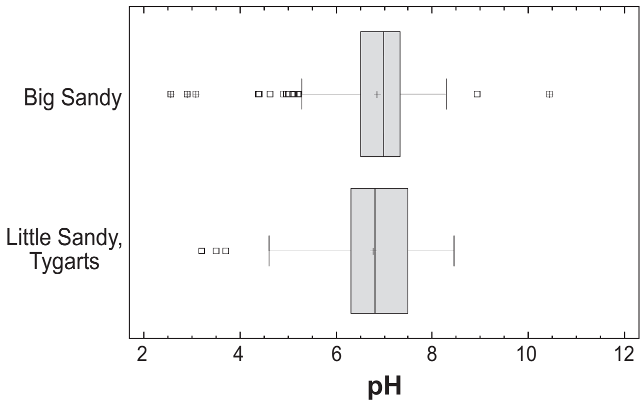

Figure 7. Summary of pH values grouped by watershed. SMCL=6.5 to 8.5.

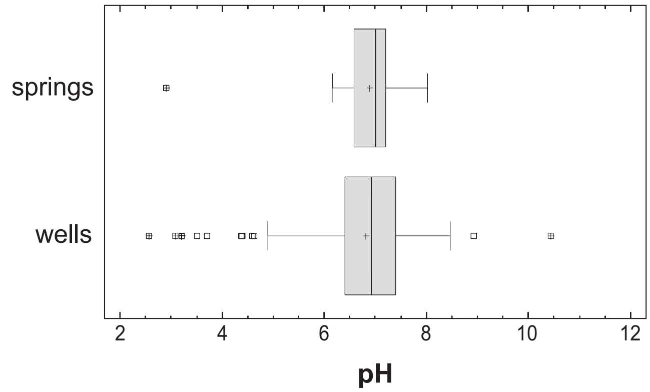

Figure 8. Comparison of pH values from wells and springs. SMCL = 6.5 to 8.5.

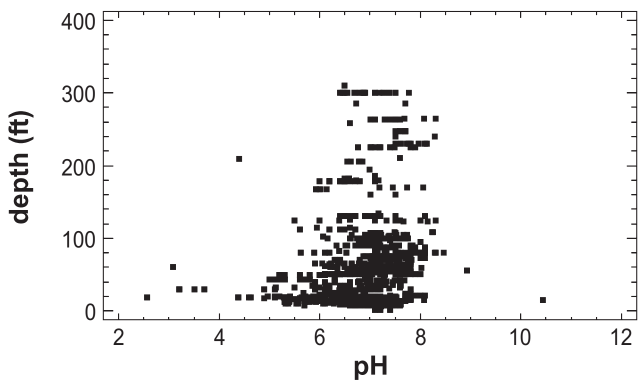

Figure 9. Well depth versus pH values. SMCL=6.5 to 8.5.

Total Dissolved Solids. Total dissolved solids is the sum of all dissolved chemicals in water, expressed as milligrams per liter. TDS can be measured as the weight of the residue remaining after a volume of water has been evaporated to dryness or calculated by adding all the solute concentrations from a full chemical analysis.

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

Potable water: up to 500 mg/L

Slightly saline water: adequate for drinking and irrigation: 500–1,000 mg/L

Moderately saline water: potable only in cases of need; may be used for some crops and aquiculture: 1,000–2,500 mg/L

Saline water: adequate for aquiculture and industrial use: 2,500–5,000 mg/L

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

Brine: greater than 35,000 mg/L.

The EPA has set a secondary drinking-water standard of 500 mg/L for total dissolved solids. Water having TDS values greater than 500 mg/L typically has an unpleasant taste and may stain objects or precipitate scale.

The data repository contained 145 reports of total dissolved solids from 62 sites in the project area (Table 6). The 75th percentile value was less than 500 mg/L. Only 19 of 62 sites yielded groundwater with more than 500 mg/L total dissolved solids.

More than 80 percent of all reported values were potable water (total dissolved solids less than 500 mg/L; Fig. 10).

Sites from which total dissolved solids values were reported were distributed throughout the project area, as were sites where water contained more than 500 mg/L of dissolved solids (Fig. 11).

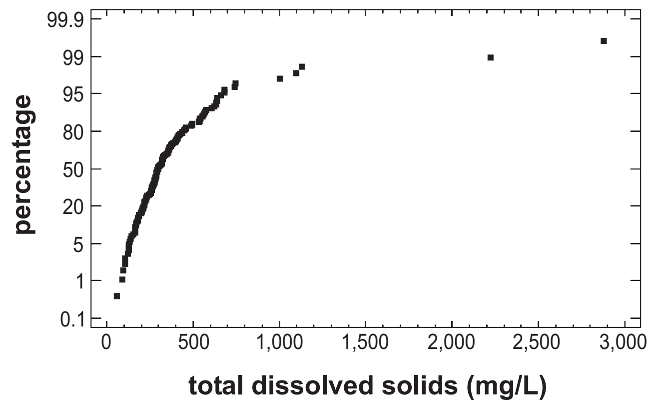

Figure 10. Cumulative plot of total dissolved solids values. SMCL=500 mg/L.

There was little difference in median value or interquartile range of total suspended solids values between the Big Sandy and Little Sandy–Tygarts Creek watersheds (Fig. 12).

Groundwater from wells had a slightly higher median value of total dissolved solids than groundwater from springs (Fig. 13), and a slightly larger interquartile range of values.

With the exception of a few high TDS reports from wells less than 75 ft deep, there was no systematic trend of total dissolved solids with well depth (Fig. 14).

In summary, approximately 70 percent of the sites in the project area yielded potable groundwater (total dissolved solids less than 500 mg/L). Sites where total dissolved solids values exceeded 500 mg/L were scattered throughout the area and not concentrated in either watershed. There was no evidence that nonpoint-source chemicals were strongly influencing regional trends in total dissolved solids values.

Table 6. Summary of total dissolved solids values (mg/L). SMCL=500 mg/L.

Number of values	145
Maximum	2,880
75th percentile	414
Median	298
25th percentile	222
Minimum	60
Interquartile range	192
Number of sites	62
Number of sites > 500 mg/L	19

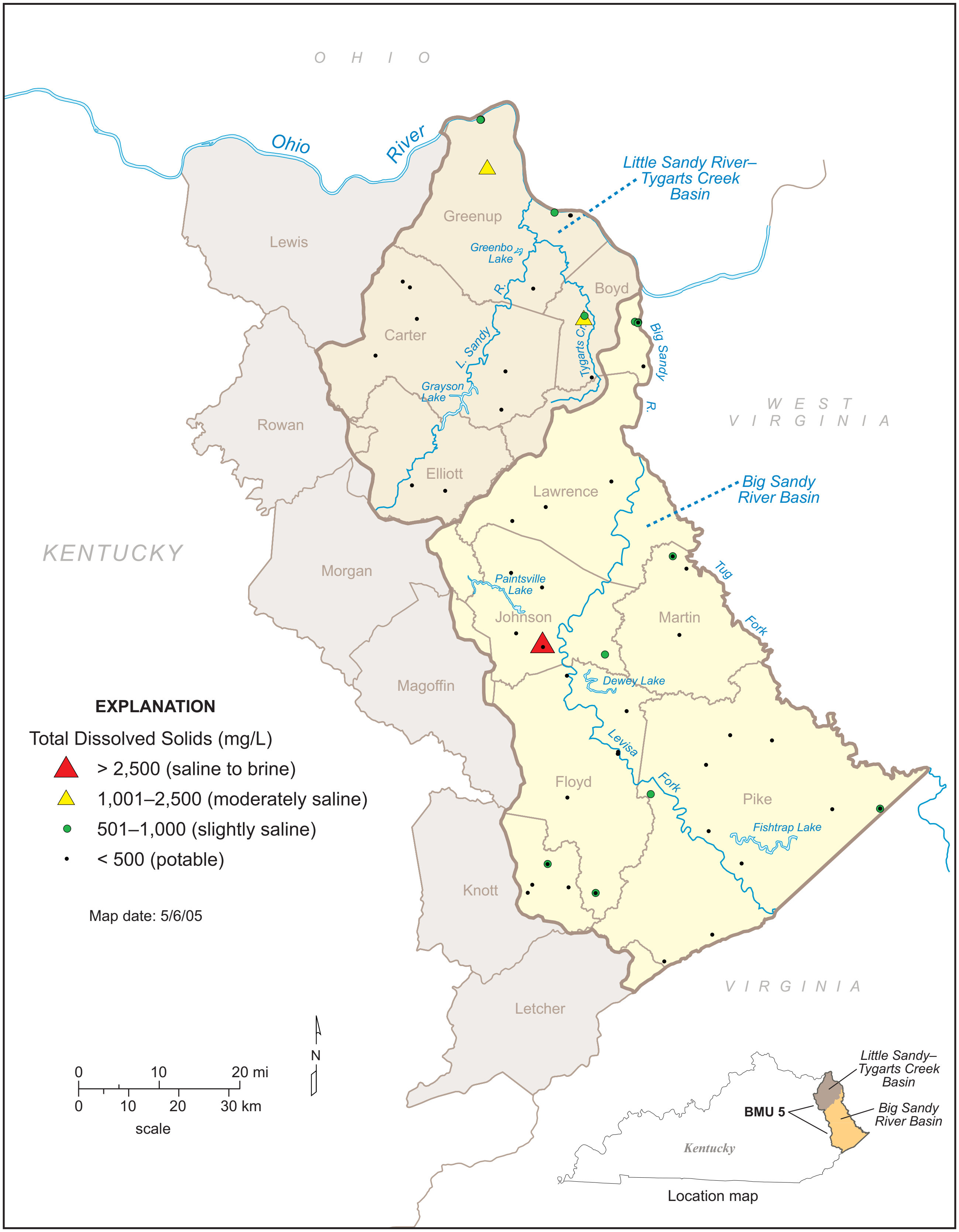

Figure 11. Locations of sampled sites and ranges of total dissolved solids values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

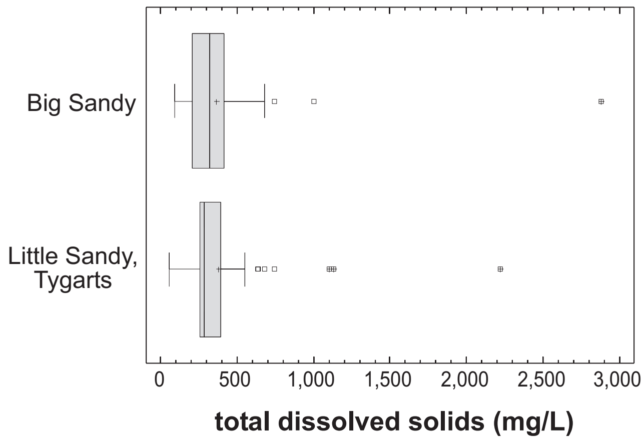

Figure 12. Summary of total dissolved solids values grouped by watershed. SMCL=500 mg/L. Higher values were excluded to better show the majority of the values.

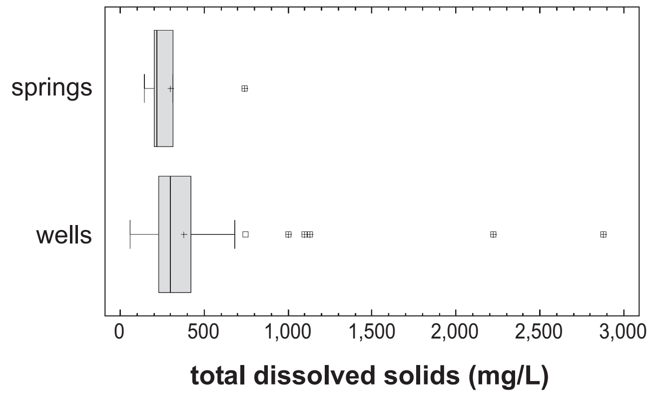

Figure 13. Comparison of total dissolved solids values from wells and springs. SMCL=500 mg/L.

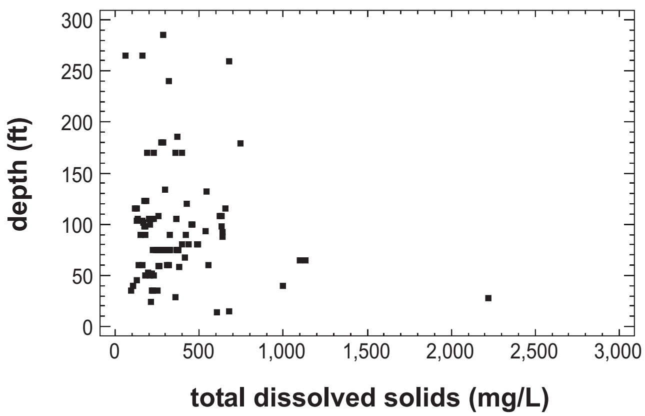

Figure 14. Total dissolved solids values versus well depth. SMCL=500 mg/L.

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). There are no health or water-use standards based on conductance because it does not directly indicate water quality.

The data repository contained 2,154 conductance measurements from 1,048 sites in the project area (Table 7). This large number of measurements was the result of the extensive field sampling program associated with the National Uranium Resource Evaluation project (Smith, 2001). Values ranged from 0 to 205,000 µS/cm.

Table 7. Summary of conductance values (µS/cm).

Number of values	2,154
Maximum	205,000
75th percentile	580
Median	325
25th percentile	195
Minimum	0
Interquartile range	385
Number of sites	1,048

The data distribution showed a sharp break in slope at a value of about 500 µS/cm (Fig. 15), which suggests that two different populations were included in the data set. More than 95 percent of the reported values were less than 500 µS/cm.

Sample-site density is less in the northern part of the project area (Fig. 16) because sampling for the National Uranium Resource Evaluation program did not extend there. Conductance values greater than 10,000 µS/cm occurred predominantly in the central part of the Big Sandy watershed.

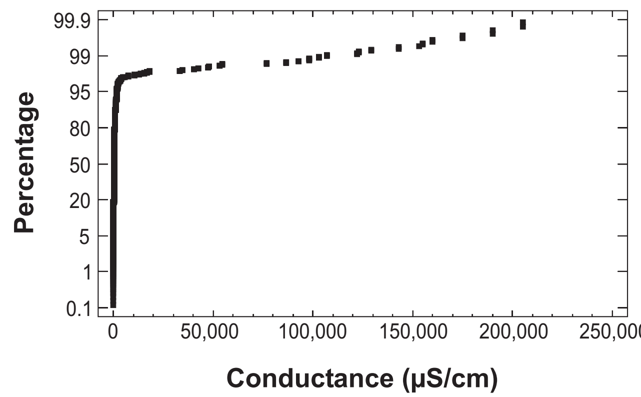

Figure 15. Cumulative plot of conductance values.

The Big Sandy River and Little Sandy River–Tygarts Creek watersheds produced groundwater with similar median values and interquartile ranges (Fig. 17). The total range of conductance values was also similar between the two watersheds.

The median conductance value, as well as the interquartile range of values, was similar for water from wells and from springs (Fig. 18). Water from wells showed the highest conductance values as well as the largest total range of values, however.

Most conductance values from wells were less than 5,000 µS/cm (Fig. 19). There was a sharp increase in conductance values in water deeper than 600 ft, however. This depth closely matches the depth of the freshwater–saline water interface mapped by Hopkins (1966) in the same area.

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 directly associated with high conductance values. Conductance values were as high as 205,000 µS/cm in the project area. There is no systematic regional variation, however. More than 95 percent of the reported values were less than 5,000 µS/cm, and more than 98 percent of the reported values were less than 10,000 µS/cm. The highest conductance values reported in the project area were from wells deeper than 600 ft, where wells probably produce sodium chloride water. There was no strong indication of nonpoint-source effects on conductance values in the project area.

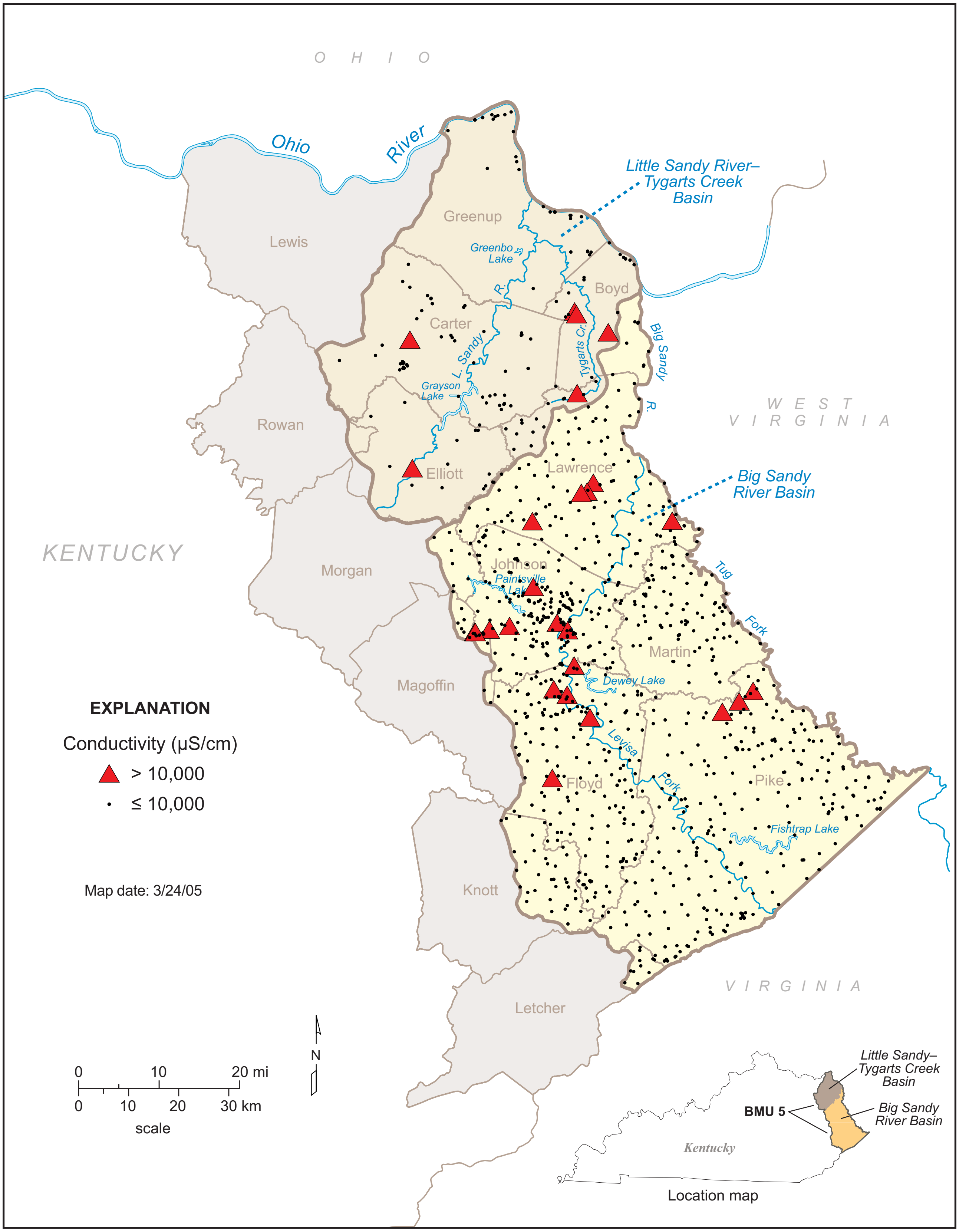

Figure 16. Locations of sampled sites and ranges of conductance values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

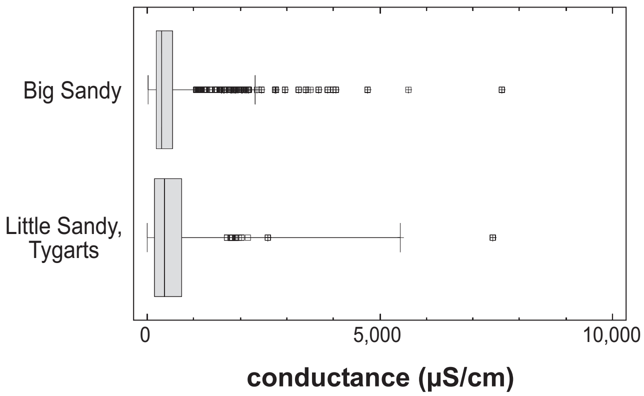

Figure 17. Summary of conductance values grouped by watershed. Higher values were excluded to better show the majority of the values.

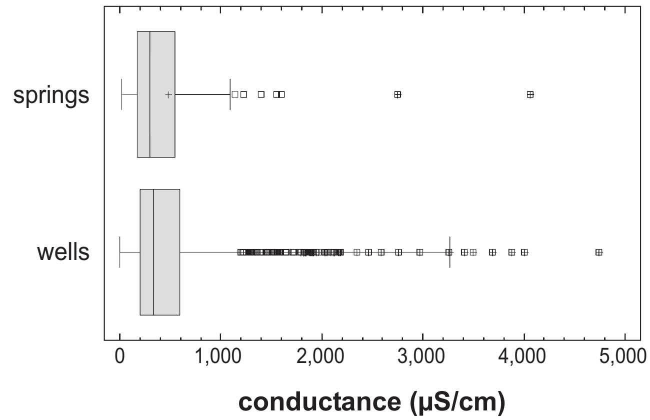

Figure 18. Comparison of conductance values from wells and springs. Higher values were excluded to better show the majority of the values.

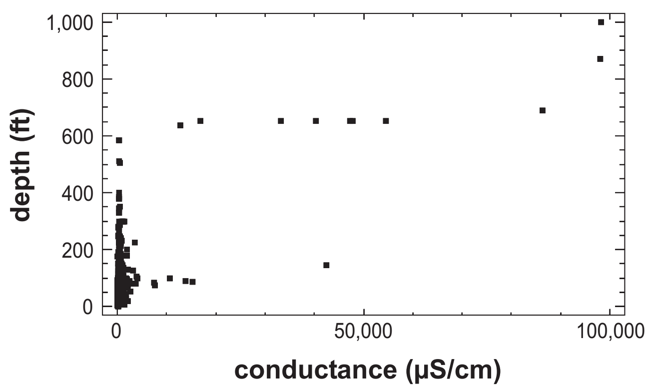

Figure 19. Conductance values versus well depth.

Hardness. Hardness describes 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:

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

Table 8 is a frequently used classification of hardness in water supplies (U.S. Geological Survey, 2006).

Table 8. 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 for individual samples were combined according to the above equation to produce a total of 274 groundwater hardness values at 137 sites in the project area (Table 9). Soft to moderately hard water was found at 69 of 137 sites.

Table 9. Summary of hardness values.

Number of values	274
Number of sites	137
Sites with soft water (0–17 mg/L)	3
Sites with slightly hard water (18–60 mg/L)	23
Sites with moderately hard water (61–120 mg/L)	43
Sites with hard water (121–180 mg/L)	25
Sites with very hard water (> 180 mg/L)	43

Approximately 50 percent of the reported values represent soft to moderately hard water (hardness less than 120 mg/L; Fig. 20).

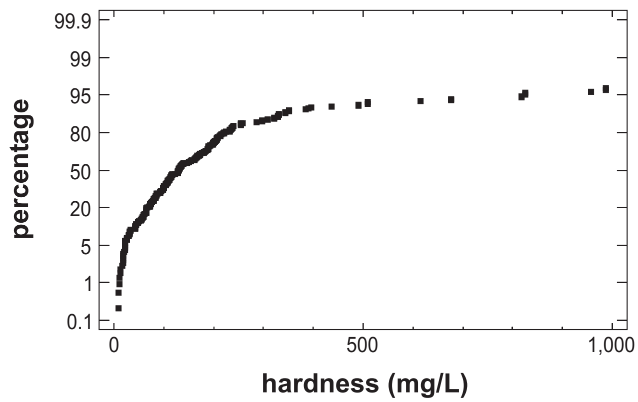

Figure 20. Cumulative plot of hardness values. Six values greater than 1,000 mg/L were excluded to better show the majority of the values.

The distribution of sampled sites was extremely uneven, most sites being in the southern part of BMU 5 (Fig. 21). Sites producing hard to very hard water were distributed throughout the Big Sandy watershed, and concentrated along the northeastern border in the Little Sandy–Tygarts Creek watershed.

Hardness values in the Big Sandy watershed had a lower median value and smaller interquartile range than values in the Little Sandy River and Tygarts Creek watersheds (Fig. 22).

All sampled sites were wells, so no comparison with groundwater from springs was possible. The hardest water was reported from wells deeper than 600 ft; three values from wells deeper than 600 ft exceeded 15,000 mg/L. Water ranging from soft (less than 17 mg/L) to very hard (greater than 180 mg/L) was found in wells between 0 and 200 ft deep (Fig. 23).

In summary, approximately half the sampled sites produced soft to moderately hard water. A concentration of sites produced hard to very hard water along the northeastern border of the project area along the Ohio River, which resulted in the Little Sandy–Tygarts Creek watershed having a higher median hardness value than the Big Sandy watershed. Soft to very hard water was found in wells from a few tens of feet deep to 200 ft deep. Because hardness results from a combination of calcium and magnesium concentrations, no nonpoint-source impact was evident from the available data.

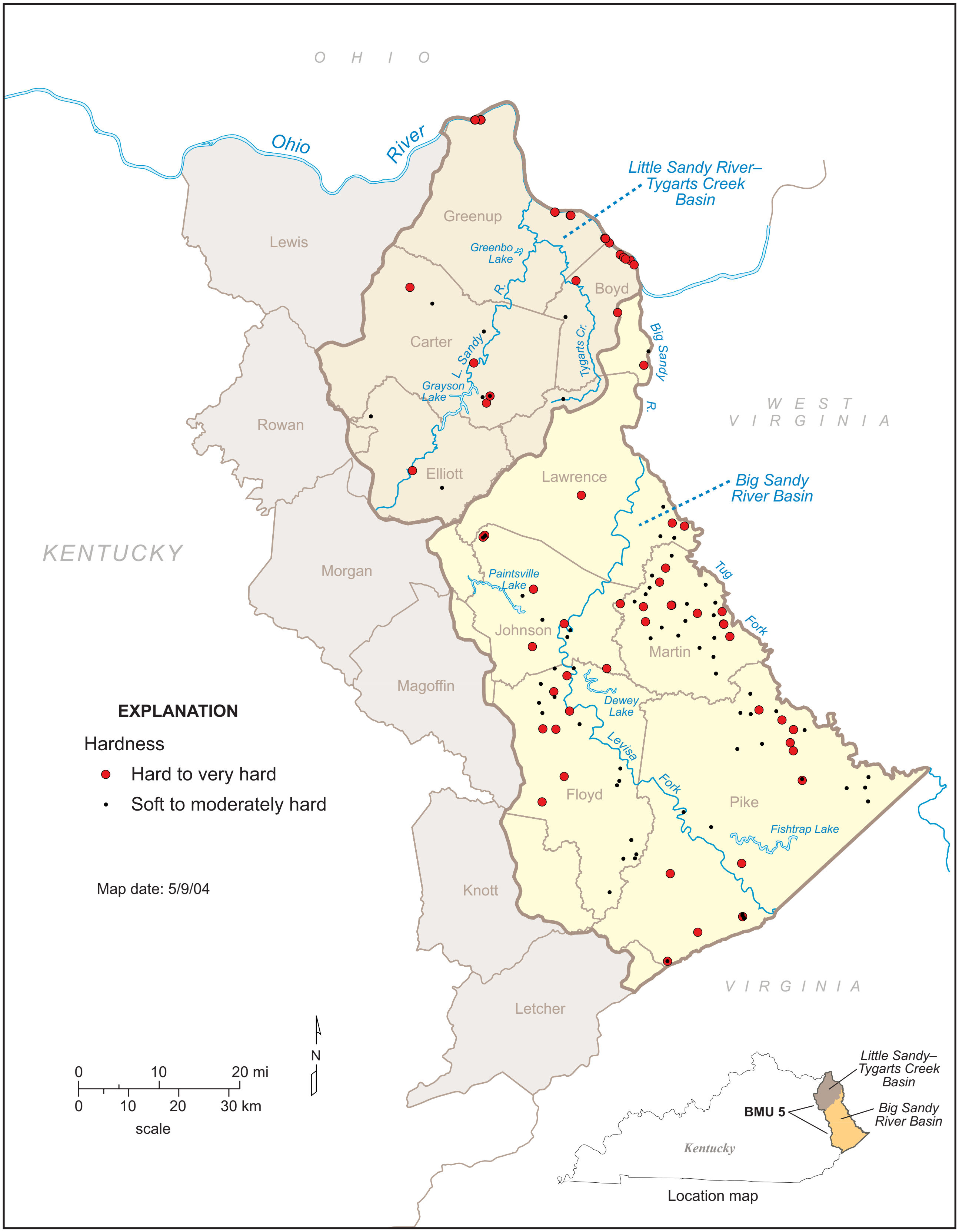

Figure 21. Locations of sampled sites and ranges of hardness values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

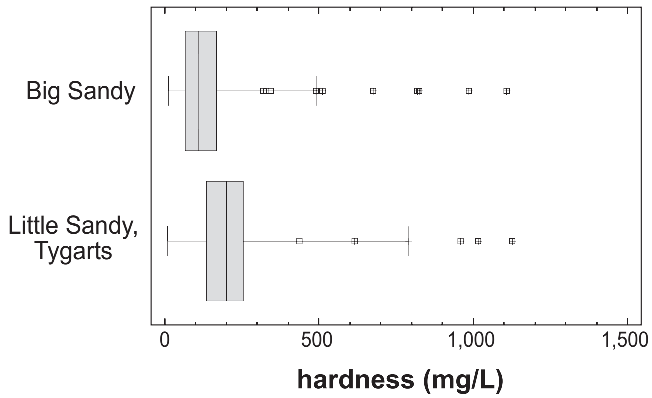

Figure 22. Summary of hardness values grouped by watershed. Higher values were excluded to better show the majority of the values.

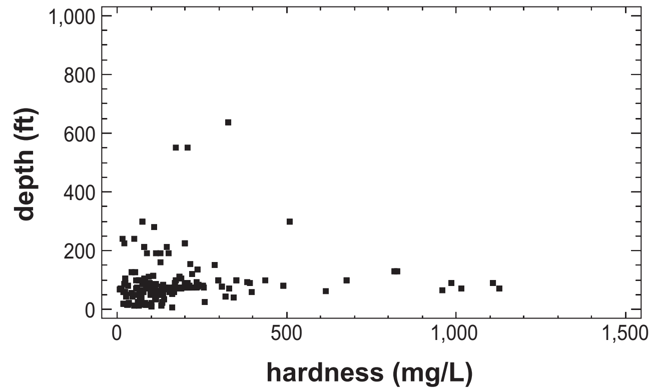

Figure 23. Hardness values versus well depth. Three values greater than 1,500 mg/L were excluded to better show the majority of the values.

Total Suspended Solids. Particulate material is reported as total suspended solids. Total suspended solids 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 where the water has been vigorously stirred during purging prior to sample collection, or from wells that intercept a fracture or karst conduit with turbulent flow. 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 suspended material, however, so water high in suspended solids may also contain significant 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 data repository contained 185 reports of total suspended solids from 82 sites (Table 10). Only three sites produced water that had more than 35 mg/L of suspended solids (Table 10, Fig. 24).

Total suspended solids values were reported from relatively few sites in BMU 5 (Fig. 25). Only three sites produced water with more than 35 mg/L of total suspended solids.

The median value and range of values for total suspended solids was about the same in the two watersheds (Fig. 26).

Only four of the 82 sites were springs, so no valid comparison could be made between springs and wells.

Table 10. Summary of total suspended solids values (mg/L). KPDES recommendation=< 35 mg/L.

Number of values	185
Maximum	125
75th percentile	5
Median	3
25th percentile	1
Minimum	< 1
Interquartile range	4
Number of sites	82
Number of sites > 35 mg/L	3

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

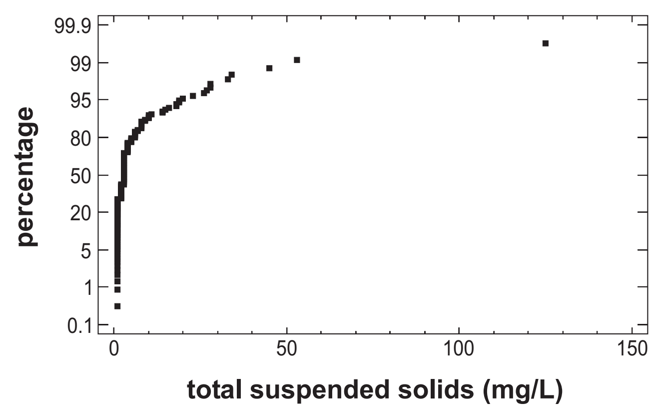

Figure 24. Cumulative plot of total suspended solids values. KPDES recommendation=< 35 mg/L.

The highest total suspended solids values occurred in shallow wells (Fig. 27).

In summary, total suspended solids refers to the amount of particulate material in a water sample. Val-

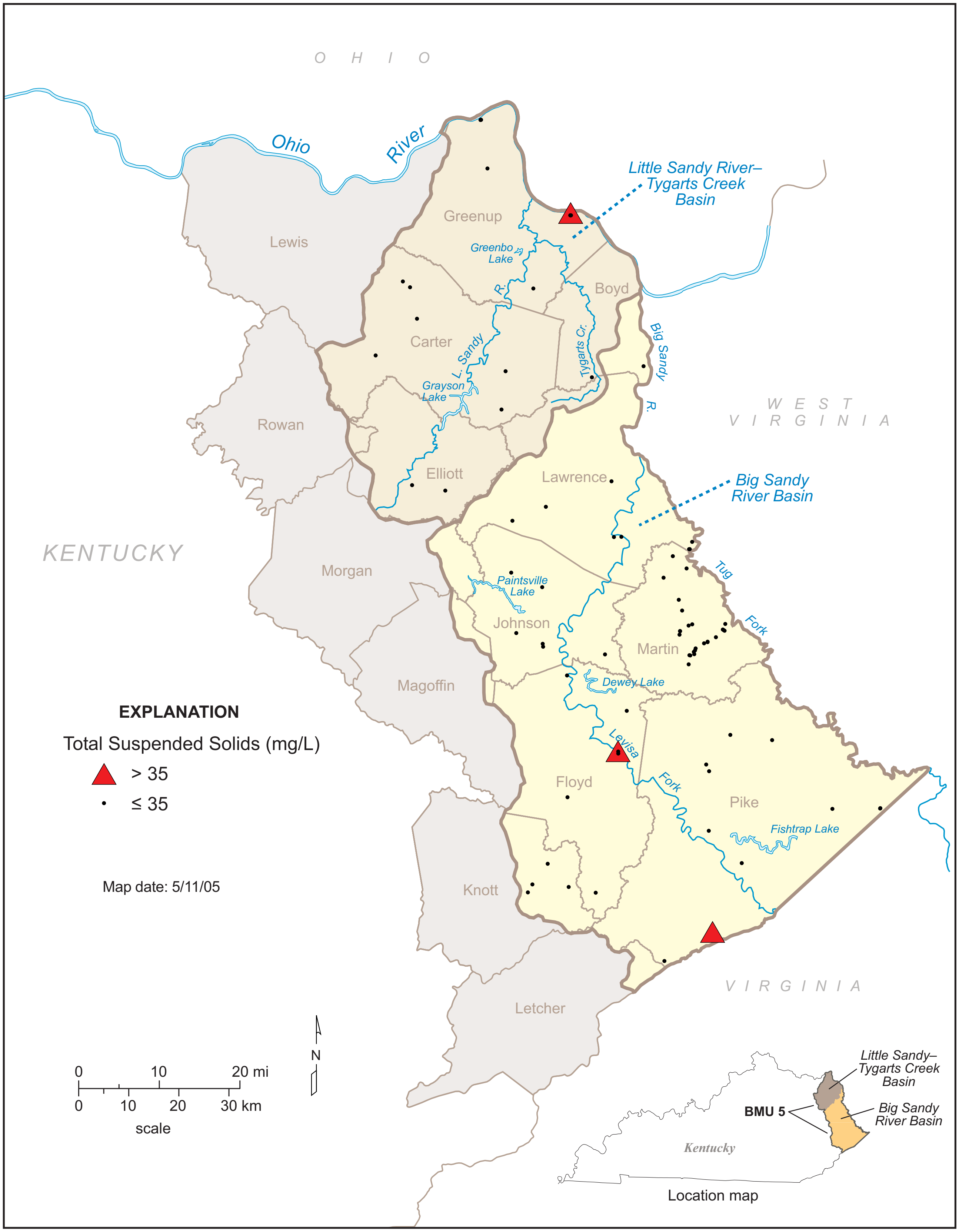

Figure 25. Locations of sampled sites and ranges of total suspended solids values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

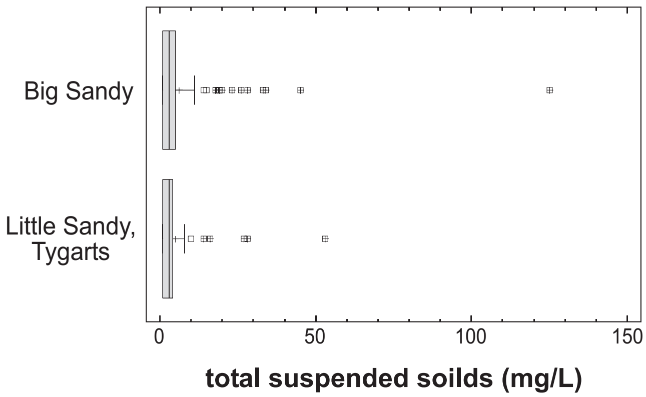

Figure 26. Summary of total suspended solids values grouped by watershed. KPDES recommendation=< 35 mg/L.

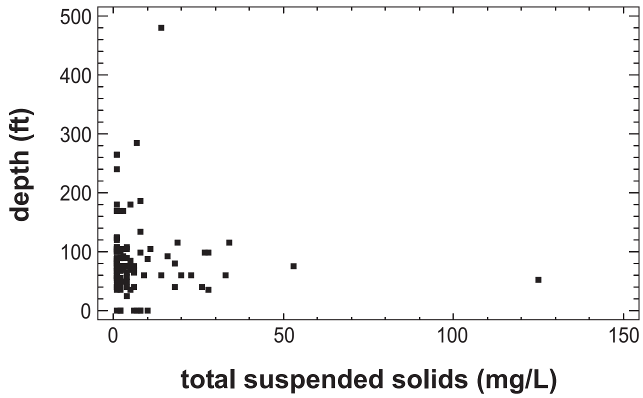

Figure 27. Total suspended solids values versus well depth. KPDES recommendation=< 35 mg/L.

ues will be very low unless there is either turbulent flow to keep particles in suspension or dissolved solutes precipitate in the sample collection bottle. Large amounts of suspended solids can clog filters and stain clothing, but there are no health effects associated with particulate material. Total suspended solids values in BMU 5 groundwater were generally low, and there was no significant difference between the two watersheds. There was no evidence that nonpoint-source contamination has added particulate material to groundwater in the project area.