MONITORING GROUNDWATER QUALITY IN KENTUCKY: FROM NETWORK DESIGN TO PUBLISHED INFORMATION

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Biographical Sketches of Authors

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Peter Goodmann has worked for the Kentucky Department for Environmental Protection for 10 years and has managed the Groundwater Branch, Kentucky Division of Water, for over 8 years. Mr. Goodmann is responsible for overseeing the implementation of Kentucky's wellhead protection program, groundwater protection program, water-well driller certification program, karst research and mapping projects, groundwater data collection and compilation including statewide ambient groundwater monitoring, and developing groundwater quality reports.

James Webb is the Supervisor of the Technical Services Section of the Groundwater Branch. This section administers various groundwater monitoring programs and provides technical assistance to other state, federal, and local agencies, as well as to consultants and the public.

Abstract

The Kentucky Geological Survey and the Kentucky Division of Water are collaborating to characterize groundwater quality statewide, within major physiographic regions, and within major watersheds. Our goals are to determine the amounts and sources of solutes and evaluate whether nonpoint-source (NPS) chemicals have affected this valuable resource. The resulting information is needed to develop groundwater-quality standards, evaluate groundwater protection programs, and make informed decisions to protect groundwater resources.

Major activities include (1) selecting representative sample sites and analytes; (2) collecting and analyzing groundwater; (3) integrating water-quality data from various databases designed by diverse agencies for a variety of purposes; (4) reconciling different analytical methods, analyte names, detection limits, and documentation levels; (5) selecting appropriate statistical methods and graphical displays for data summation; and (6) producing and circulating reports.

Completed reports and ongoing investigations summarize and evaluate concentrations of nutrients, pesticides, and volatile organic compounds as well as naturally occurring solutes such as major and minor inorganic ions and metals. Results show that concentrations of most inorganic solutes, including metals, are primarily controlled by bedrock lithology. Some springs and shallow wells have exceptionally high levels of nutrients and detectable amounts of synthetic organic chemicals, suggesting that NPS chemicals have entered the shallow groundwater system. These findings are being used to evaluate the effects of natural processes, land uses, and NPS chemicals on regional groundwater systems and to improve groundwater protection efforts.

INTRODUCTION

The Kentucky Geological Survey (KGS, a research center at the University of Kentucky) and the Kentucky Division of Water (DOW; a division of the Kentucky Environmental and Public Protection Cabinet) are collaborating to summarize the quality of Kentucky's groundwater, evaluate the impacts of natural processes and nonpoint-source chemicals on groundwater quality, and circulate the findings to state agencies and the general public. In order to accomplish this, KGS and DOW must convert groundwater-quality data that is housed in different databases and repositories into understandable information, and then make that information both accessible and available to organizations, agencies, and the public.

The questions being addressed are:

- What is the ambient (regional, not affected by point-source emissions or discharges) quality of groundwater?
- How does groundwater quality vary across the state?
- What processes control or have impacted groundwater quality?
- How does quality restrict the potential uses of groundwater?
- How can groundwater quality be protected?

Our approach is to (1) gather all available groundwater-quality data for a selected group of analytes, (2) summarize the data, (3) evaluate groundwater quality with respect to selected criteria, (4) evaluate sources of dissolved chemicals, (5) produce summary reports, and (6) circulate and explain the findings.

METHODS

Gather and Standardize Analytical Data

We chose 33 analytes that would indicate both natural and anthropogenic contributions to groundwater chemistry and groundwater quality. These included inorganic properties and solutes, nutrients, pesticides, and volatile organic compounds.

The DOW Groundwater Monitoring Program and the KGS Kentucky Groundwater Data Repository are the main data sources. The Groundwater Monitoring Program has been active since 1995. Under this program approximately 120 wells and springs are sampled quarterly each year, and an additional 30 to 50 sites are sampled quarterly for one year. Groundwater samples are collected and analyzed under rigorous QA/QC protocols for a variety of inorganic and organic chemicals, making this program the most important source of high-quality analytical reports. The Kentucky Groundwater Data Repository was established in 1990 to archive all groundwater data collected throughout Kentucky. The Groundwater Data Repository contains a large number of results of analyses by the U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE), and others, in addition to data transferred from Groundwater Monitoring Program. These data were collected and analyzed under a variety of protocols and conditions. Therefore, it is necessary to examine each record and resolve differences in samples types, analyte names, reporting units, and detection limits to determine whether that analytical report can be used.

Summarize Results

We use a variety of methods to summarize and illustrate groundwater quality data to inform a diverse audience. In this paper we describe our methods and show examples of each.

Map of sample sites and ranges of values: A map of sample sites, bedrock geology and topography as described by Kentucky's physiographic regions, and ranges of reported values shows site distribution, sample density, and relations between values and bedrock type. Values of properties and solutes for which EPA has established maximum contaminant levels (MCLs) or secondary maximum contaminant levels (SMCLs) are grouped to show where MCLs and SMCLs are met or exceeded (Figure 1).

Tabular summary: A summary table shows quartile values (minimum, 25th percentile, median, 75th percentile, and maximum) for each analyte, number of samples analyzed, and number of sites sampled (Table 1). We use nonparametric measures because the distributions of water-quality data rarely follow a normal distribution. We also summarize the percent of sites where groundwater quality does not meet MCL or SMCL values (Table 2).

Physiographic Region	Nr. of values	Nr. of Sites	Minimum	25th percentile	Median	25th percentile	Maximum
Eastern Kentucky Coal Field	5087	797	1.70	6.30	6.84	7.30	11.60
Eastern Pennyroyal	88	44	3.90	7.10	7.51	7.74	8.21
Inner Bluegrass	171	42	6.19	7.38	7.60	7.78	8.65
Knobs	76	37	2.80	7.10	7.40	7.78	8.40
Outer Bluegrass	228	79	6.12	7.20	7.40	7.59	8.41
Jackson Purchase	201	91	4.10	6.10	6.41	6.76	8.20
Western Kentucky Coal Field	348	57	4.20	6.71	7.20	7.76	12.35
Western Pennyroyal	948	317	5.80	7.30	7.55	7.74	8.90

Table 1. Summary of pH values for the major physiographic regions of Kentucky.

Region	%Sites < 6.5	% Sites > 8.5
Eastern Kentucky Coal Field	41	2
Eastern Pennyroyal	22	0
Inner Bluegrass	2	0
Knobs	16	0
Outer Bluegrass	2	0
Jackson Purchase	56	0
Western Kentucky Coal Field	35	26
Western Pennyroyal	3	0

Table 2. Percent of sites where pH was observed to be above or below the EPA SMCL of 6.5 to 8.5.

Graphs of data distributions: Normal probability plots (Figure 2) show the data distribution and allow users to determine what percentage of reported values are less than or greater than a value of interest (MCL, SMCL, etc.). Box-and-whisker diagrams (Figure 3) show the median value, the range of the central 50 % of the measurements (interquartile range, or IQR), and outliers. These graphs are also used to compare values between various physiographic regions (Figure 4-7).

Physiographic Region	Number of Values	Number of Sites	Minimum Value	25th Percentile	Median Value	75th Percentile	Maximum Value
Eastern Kentucky Coal Field	5,087	797	1.70	6.30	6.84	7.30	11.60
Eastern Pennyroyal	88	44	3.90	7.10	7.51	7.74	8.21
Inner Bluegrass	171	42	6.19	7.38	7.60	7.78	8.65
Knobs	76	37	2.80	7.10	7.40	7.78	8.40
Outer Bluegrass	228	79	6.12	7.20	7.40	7.59	8.41
Jackson Purchase	201	91	410	6.10	6.41	6.76	8.20
Western Kentucky Coal Field	348	57	4.20	6.71	7.20	7.76	12.35
Western Pennyroyal	948	317	5.80	7.30	7.55	7.74	8.90

Table 1. Summary of pH values for each of the major physiographic regions of Kentucky.

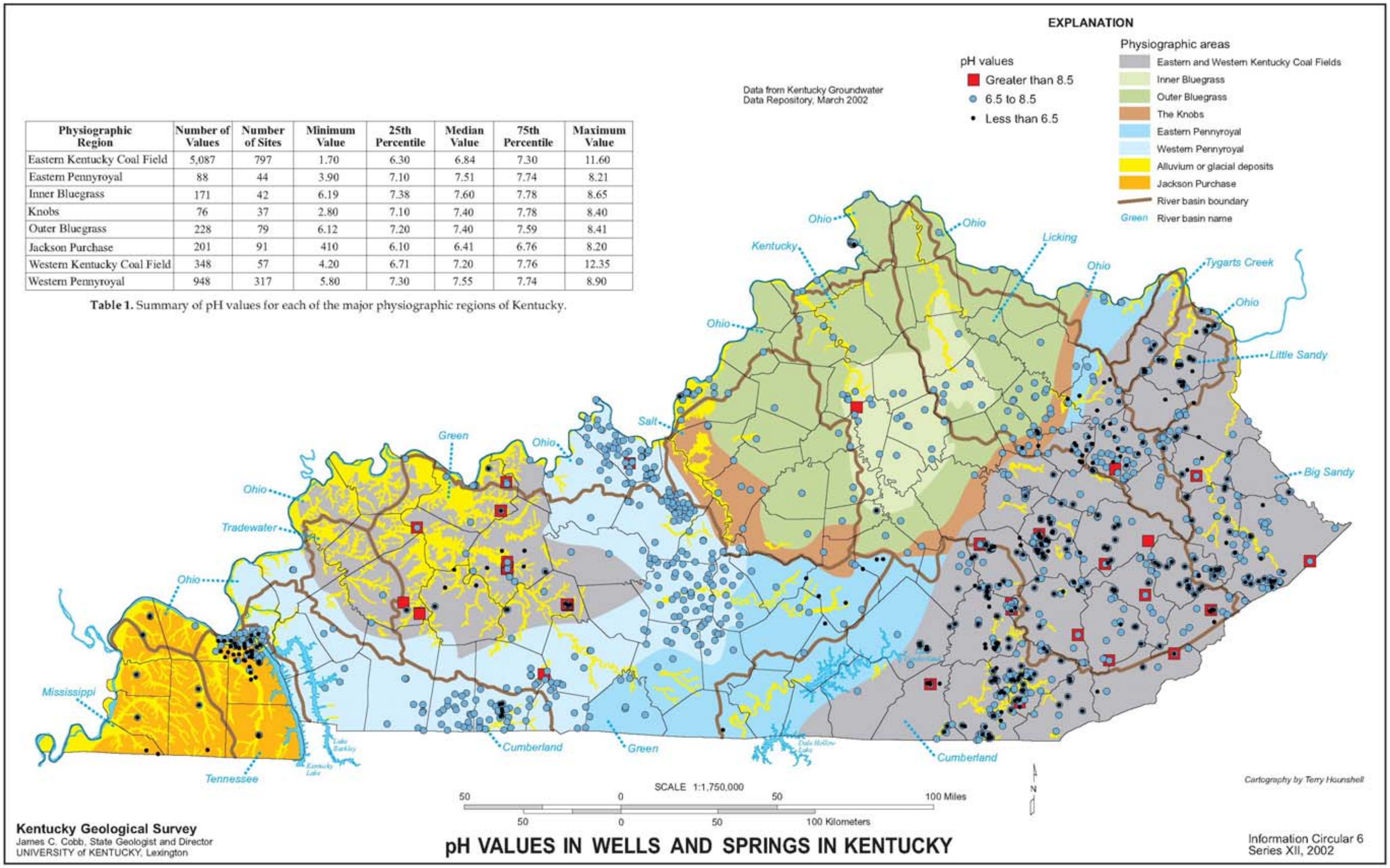

Figure 1. Map showing sampled wells and springs, ranges of pH values, physiographic regions, and major river watersheds. SMCL = 6.5 to 8.5

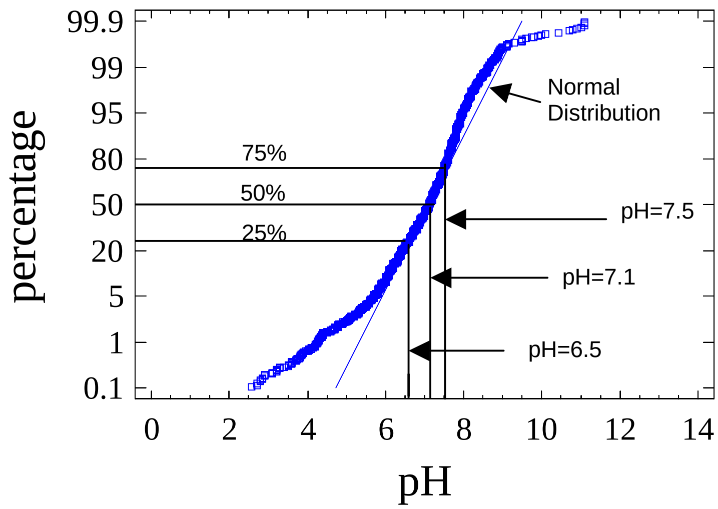

Figure 2. Probability plot for all pH values in Kentucky groundwater showing the data distribution, how it differs from a normal data distribution (shown by the straight line), maximum and minimum values, and the 25th, 50th, and 75th percentile values.

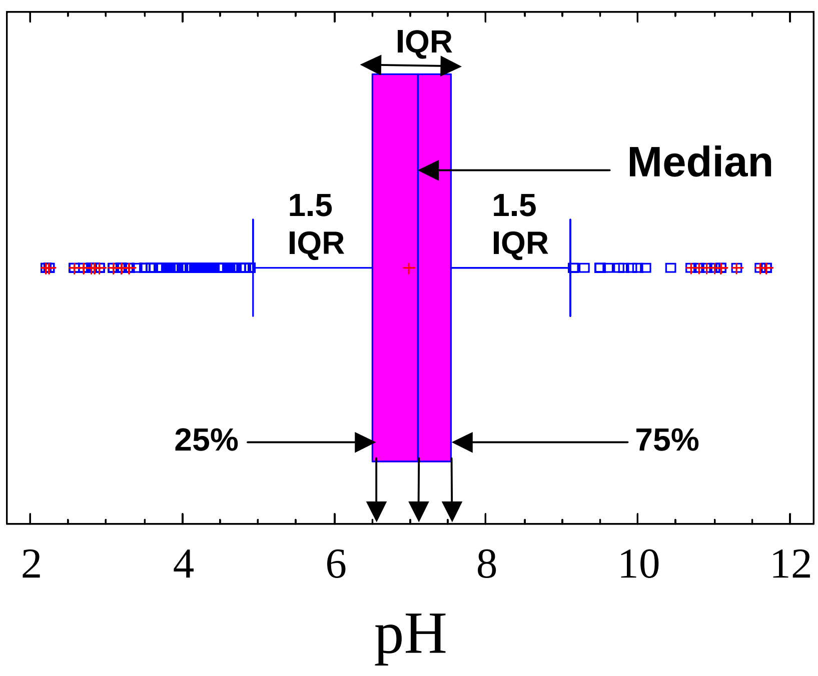

Figure 3. Box-and-whisker plot for all pH data. Box encloses the central 50% of all values, from the 25th percentile to the 75th percentile (the interquartile range, or IQR). Vertical line through box marks the median value. Whiskers extend 1.5 times the IQR above the 75th percentile value and below the 25th percentile value. Outlier values higher or lower than the extent of the whiskers are shown as individual squares

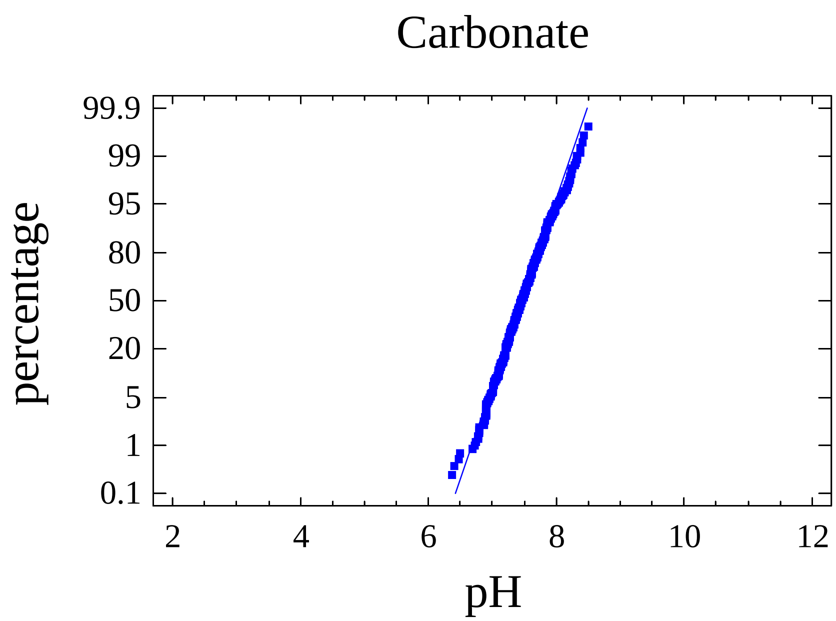

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Figure 4. Probability plot of pH data from wells and springs in carbonate terrain. Note the small range compared to Figure 2 and that the data follow a normal distribution.

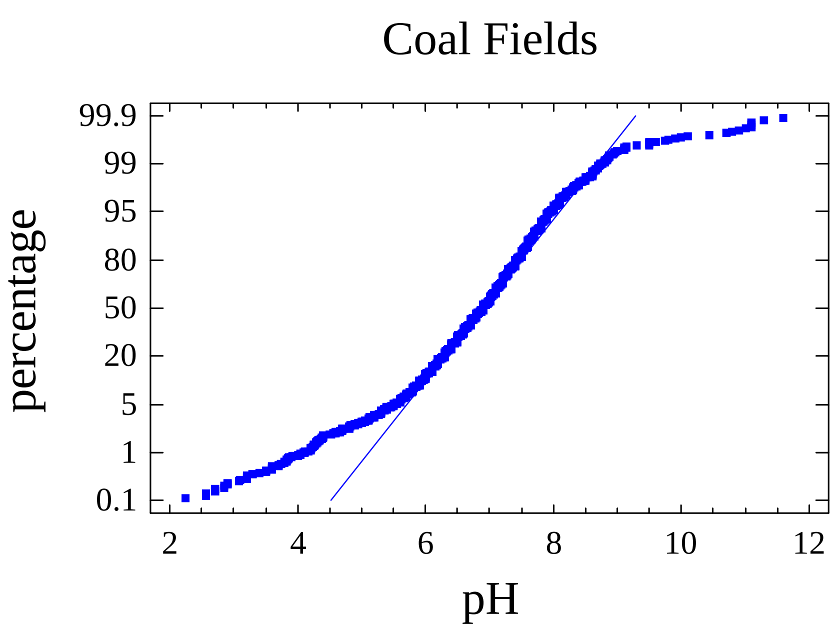

Figure 5. Probability plot of pH data from wells and springs in the Eastern and Western Coal Fields. Note that the highest and lowest pH values are found at sites in the coal fields (compare to Figure 2). Note also that the data follow a normal distribution between pH values of about 5.5 and 9.0, with both high and low outlier values.

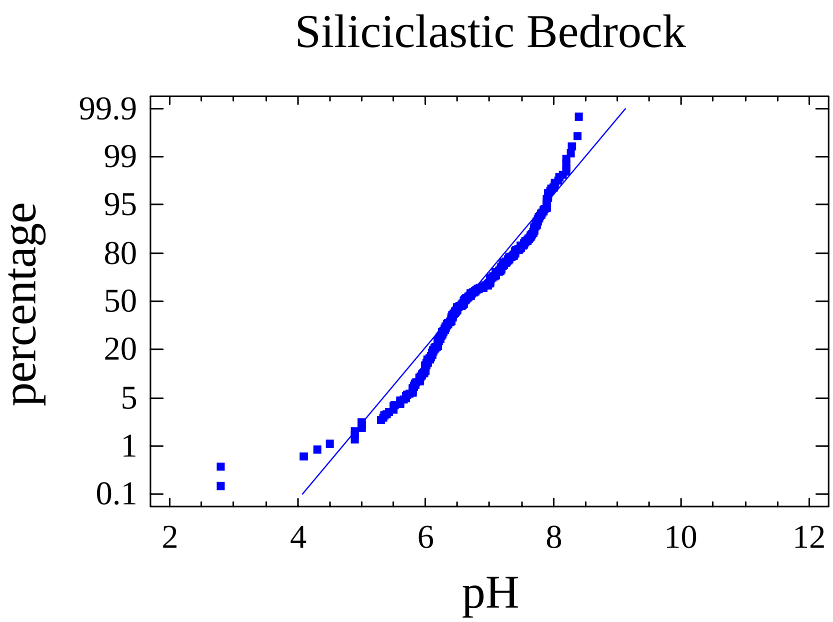

Figure 6. Probability plot of pH data from wells and springs in mixed sandstone, siltstone, and poorly lithified sandy aquifers. Note that the data do not follow a normal distribution; rather the data distribution suggests that several distinct populations of data are included.

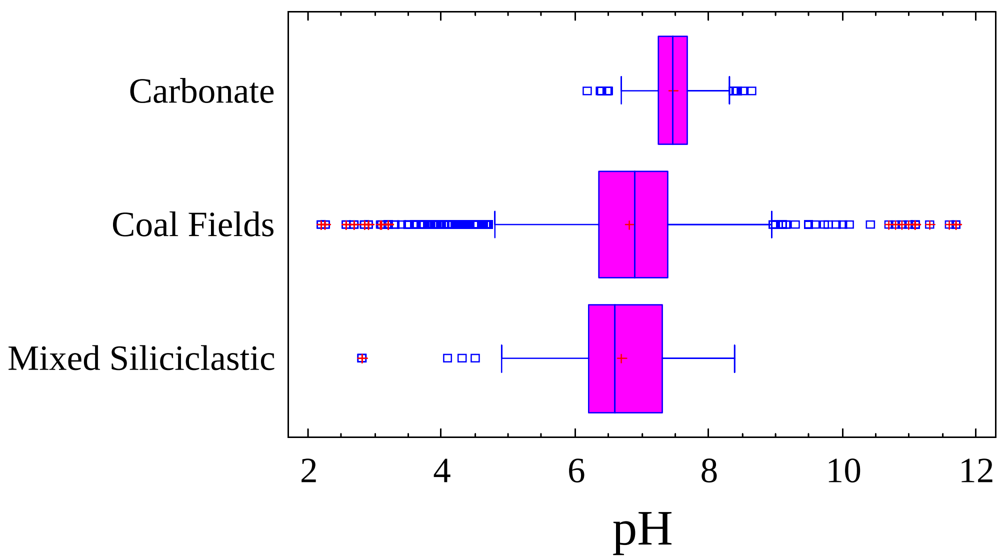

Figure 7. Box-and-whisker diagram comparing pH values from wells and springs in three different terrain types. Note the higher median value and small interquartile range of values from carbonate terrain, the larger interquartile ranges for groundwater from the coal fields and mixed siliciclastic terrain, and the extreme range of pH values from sites in the coal fields.

We also use box-and-whisker diagrams to compare values from different subgroups, for example, springs versus wells (Figure 8), and total (unfiltered sample) versus dissolved (filtered sample) concentrations (Figure 9).

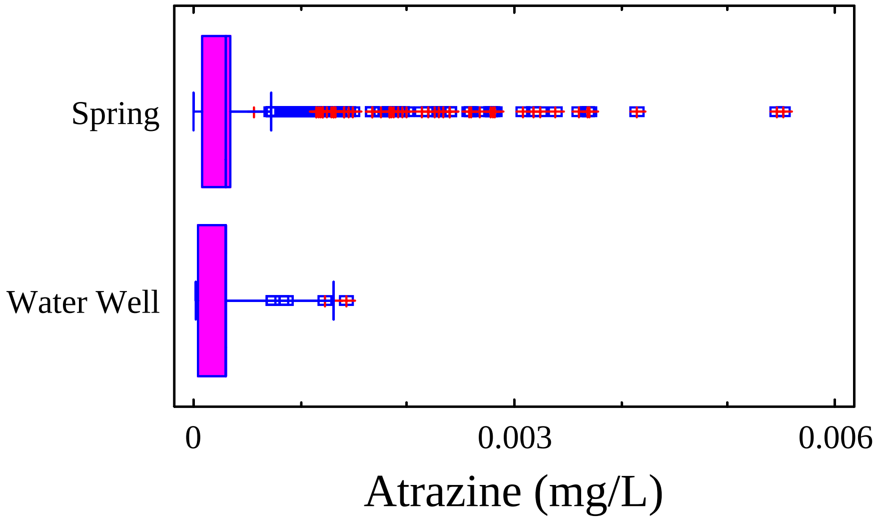

Figure 8. Comparison of atrazine values measured in springs versus wells. The interquartile ranges are similar, but springs yield many more values greater than about 0.001 mg/L than wells. The data show that relatively high atrazine concentrations are more likely in springs than in wells.

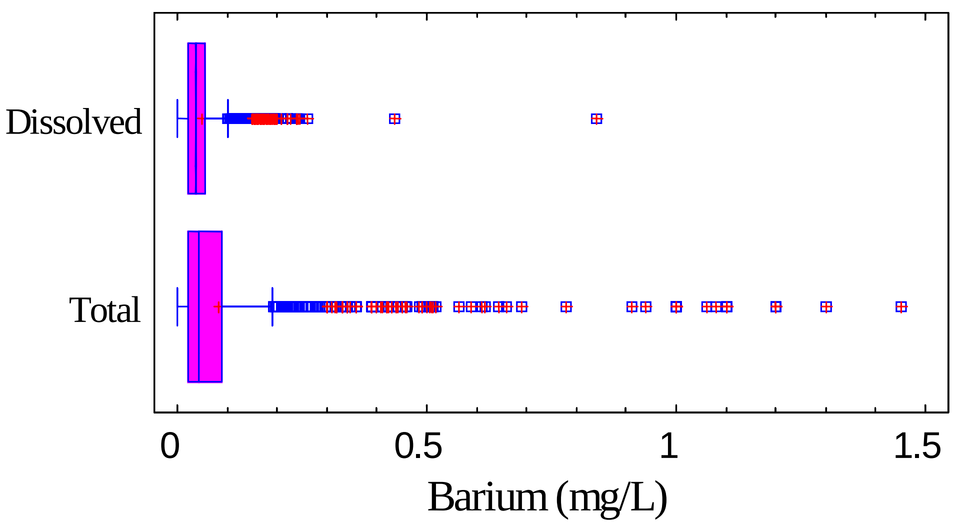

Figure 9. Comparison of dissolved versus total barium concentrations. Concentrations greater than about 0.2 mg/L are much more common in total (unfiltered water) samples than in dissolved (filtered water) samples, suggesting that significant amounts of barium are associated with suspended solid material.

Plotting analyte concentrations versus well depth (Figure 10) shows how groundwater quality differs in shallow, intermediate, and deep groundwater systems.

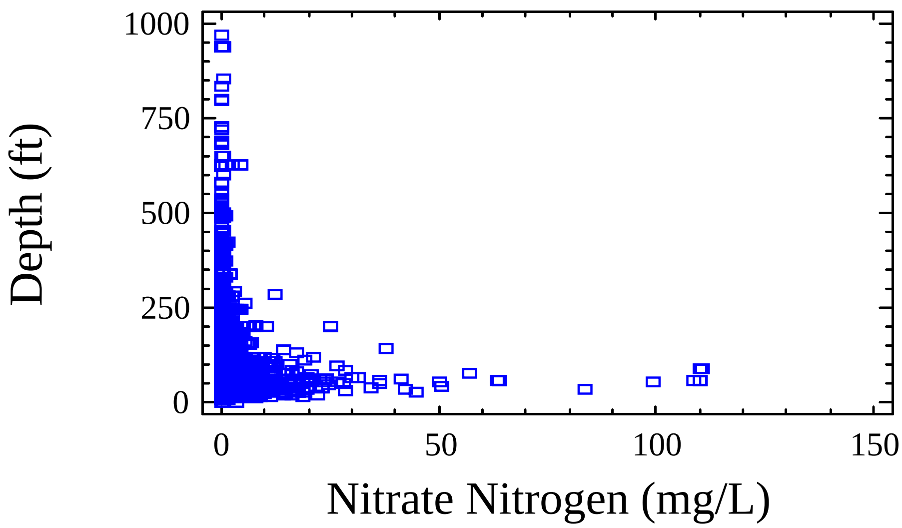

Figure 10. Plot of nitrate nitrogen concentrations versus well depth. Nitrate nitrogen concentrations greater than 10 mg/L (the MCL) are generally found only in wells that are less than about 150 feet deep.

Evaluate Sources of Chemicals

Our main goal is to determine whether the observed concentrations and patterns of values result from natural processes or from the contribution of nonpoint-source chemicals. Some constituents such as fluoride, metals, and nutrients can have anthropogenic as well as natural sources. In these cases we examine whether concentrations exceed the limits of what can be explained by natural processes and whether the concentration trends differ with differing bedrock geology or other natural changes in landscape and land use. Synthetic organic chemicals such as pesticides and volatile organic compounds have few or no natural sources. The presence of these chemicals in wells or springs at levels above analytical detection usually suggests a nonpoint source. Unequivocal determination of nonpoint-source impacts cannot be made on the basis of these data summaries but must be field-checked for verification.

Produce Summary Reports

Both DOW and KGS have published summary reports on groundwater quality and both groups have additional reports in preparation. DOW completed the first such report (Webb and others, 2002) and will produce a second report later this year. KGS has completed a data summary of groundwater quality that covers approximately half of the state (Fisher and others, 2003), and has three additional reports in preparation. We have also published four maps of groundwater quality (Fisher and others 2002a, b, Conrad and others, 1999a, b) and summaries of groundwater resources for each county in Kentucky. Within the next 4 years we intend to make the groundwater-quality data available from our Web sites along with the appropriate mapping and graphing software, so that users can interactively investigate groundwater quality from any internet-connected site.

Circulate and Explain the Findings

Our ultimate goal is an informed public that understands and appreciates the value of groundwater in Kentucky, the current quality of that resource, and the threats to it. To this end we produce reports and send copies to the Division of Water and its regional offices, other Departments and Divisions of the Kentucky Environmental and Public Protection Cabinet, the Governor's Office and the Kentucky Environmental Quality Commission, River Basin Teams, Natural Resources Conservation Service offices, Agricultural Extension offices, and the Kentucky Water Resources Research Institute. Copies are also placed on both the KGS and DOW Web sites. Both DOW and KGS frequently receive public inquiries regarding groundwater quality, and these reports are sent to anyone who requests them.

DOW and KGS are collaborating to develop interactive, Web-based access to groundwater quality data and the tools for mapping and summarizing analyte concentrations. We expect this will be accomplished within four to five years. Groundwater quality data will then be available to any person who has access to the internet. Both DOW and KGS will continue to respond to inquiries regarding groundwater resources and groundwater quality, and to give educational presentations about our work.

SUMMARY

The Kentucky Division of Water and the Kentucky Geological Survey have been collaborating for nearly 10 years to convert groundwater quality data into useful public information. This effort involves all aspects of water-quality monitoring networks, from the selection of sample sites and analytes to be measured to communicating the results to citizens, agencies, and organizations. We expect the need for this type activity to significantly increase in the future, as the demand for groundwater supplies increases and the public becomes more informed about how groundwater quality can restrict potential uses of this natural resource.

For additional information on these programs please visit our Web sites:
Kentucky Division of Water: http://www.water.ky.gov/
Kentucky Geological Survey: http://www.uky.edu/KGS/water/watertop.htm

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