Report on the Condition of Ambient Groundwater in Kentucky

Analysis of the Ambient Groundwater Quality Monitoring Network Data

Kentucky Division of Water: Watershed Management Branch

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Executive Summary

The Kentucky Division of Water (DOW) has systematically sampled ambient groundwater for more than 20 years. For the first time, these data have been analyzed in order to characterize groundwater trends in Kentucky. The Kentucky Interagency Groundwater Monitoring Network (or "Network") was established to characterize groundwater that has not been contaminated. Monitoring stations for the network are not chosen to be pristine, rather, they are chosen to reflect general groundwater conditions in the state. Stations come from a range of surface land use types: agriculture, urban/suburban, and forested.

The data were examined statewide, and also categorized by physiographic region and by groundwater source (well or spring). We examined trends over time and detections of 43 parameters at 49 monitoring stations throughout the state. The Mississippian Plateau had the most monitoring stations (24 of the 49 stations). The larger sample size gave more power to detect trends, which is reflected in the results.

General trends across the state include increases in the concentrations of several metals, decreases for some nutrients, increases in conductivity and pH, and decreases in sulfates. The report delineates more specifically where these statewide trends originate and characterizes differences by physiographic region and source. Continued monitoring over time will ensure early detection of problems, and the ability to address these problems before they become entrenched.

Introduction

Before 1995, ambient groundwater quality data throughout the state were inadequate to assess groundwater quality on a regional, basin-wide or statewide scale. In order to address this situation, the Kentucky Division of Water (DOW) initiated statewide ambient groundwater monitoring in 1995 to begin the long-term, systematic evaluation of groundwater quality throughout the state. In 1998, legislation established the Kentucky Interagency Groundwater Monitoring Network (or "Network"), which formalized groundwater assessment efforts (KRS 151.625 and 151.629). Oversight for this network is through the Interagency Technical Advisory Committee on Groundwater (ITAC), which includes the DOW and other state and federal agencies. Further information about ITAC and its member agencies can be found at the Network webpage: http://www.uky.edu/KGS/water/gnet/.

The Network is a collaborative effort amongst several state and federal government agencies. DOW has taken the lead on the groundwater quality portion of the Network. The Network is designed to assess and document ambient groundwater quality throughout the Commonwealth of Kentucky. Herein, *ambient groundwater quality* refers to the existing condition of groundwater in Kentucky at a given time that is free from anthropogenic contamination. The Network goals are part of DOW's larger mission "*To manage, protect and enhance the quality and quantity of the Commonwealth's water resources for present and future generations…*" The three major goals for the Network (Sendlein and others, 1996) are:

1) **Provide baseline data on groundwater resources**. The determination of current ambient groundwater conditions in each major area of Kentucky, and documentation of trends in groundwater quality are paramount to this program. The emphasis is on representing ambient groundwater conditions where there is current use, potential for future development or a direct influence on surface water.

2) **Characterize groundwater resources**. Evaluation of the quality and quantity of the resource with regards to spatial and temporal variability. The various aquifer types and individual aquifers of Kentucky have unique properties for groundwater quality and occurrence. Any adequate strategy for resource protection must be based on an understanding of natural availability and chemical characteristics, and the variability of each.

3) **Disseminate information collected and created by the Network**. Sharing of information with other agencies and the general public increases the utility of Network data. Data may be shared through various reports or presentations prepared for specific topics or regions of Kentucky. Data are also

shared through The Kentucky Groundwater Data Repository at the Kentucky Geological Survey (KGS) as tabular datasets that can be obtained by anyone with an interest.

Network Objectives

The Network objectives were developed to meet three main goals. These objectives are achieved through planning, program design, utilizing information from previous investigations, field reconnaissance, collaboration with ITAC partners and coordination with other DOW programs. Although the goals of the Network are relatively static, the objectives and strategies used to meet them may change over time.

1) Ensure that all monitoring sites represent ambient groundwater conditions. This objective is relatively easy to achieve through careful field reconnaissance and literature/database review. The purpose is to make sure that the monitored groundwater source is not impacted by a current point source or previous contamination.

2) Locate monitoring sites within each of the major physiographic regions of Kentucky. This is accomplished by utilizing GIS created from The Kentucky Groundwater Data Repository database when initializing the site selection process. This is followed by verification of site locations during field reconnaissance.

3) Represent each of the various aquifer types (granular, fracture flow and karst) present in Kentucky. This objective is partly accomplished through locating monitoring sites in each physiographic region. However, each physiographic region can have more than one aquifer type present. Use of geological maps, field observations, driller's logs and previous investigations ensure that each aquifer type is represented adequately.

4) Set sampling frequencies that allow for adequate groundwater characterization with optimum spatial distribution. This is achieved by collecting more frequent samples at new sites, with a schedule that rotates quarterly through each month of the year. This allows for samples to be collected in each season and each month of the year within a three year period. Following the initial three year period, site data are assessed for significant changes to determine the efficacy of decreasing sampling frequency in order to release monitoring resources for additional sites.

5) Support other division and department programs. To that end, public water suppliers (PWS) utilizing groundwater are given priority during site selection. Currently there are 23 PWS monitoring sites in the Network – 18 water wells and 5 springs. These data can be used to inform stakeholders of source water quality and protection efforts. In addition, several large springs that are part of the Network

provide significant base flow to surface streams. Those data can be used in support of the TMDL program, Surface Water Monitoring Programs, Watershed Plan development and Best Management Practice success monitoring, where applicable.

6) Collect and manage all of the data in a user-friendly format. This is achieved with the DOW Groundwater Database, which is regularly uploaded to The Kentucky Groundwater Data Repository at KGS. Those wishing to obtain groundwater data can make an information request through DOW or search for data online in The Kentucky Groundwater Data Repository at the KGS website.

7) Facilitate collaboration among the various local, state and federal agencies with an interest in groundwater resources. This is accomplished through regular meetings with ITAC and its member agencies. This collaboration allows limited monitoring resources to be allocated where they are needed most, and ensures that overlapping efforts are minimized.

Purpose and Scope

The DOW has collected more than 20 years of ambient groundwater samples, partially fulfilling the first major goal of the Network. These data have been utilized in numerous evaluations and assessments of groundwater quality. However, these previous assessments had a more limited scope, focusing on characterizing the current condition of groundwater in specific river basins or regions of Kentucky, or evaluating a single parameter statewide. Webb and others (2002 and 2004) summarized and reported on groundwater quality in the Salt, Licking, and Kentucky River basins. Fisher and others (2004, 2007 and 2008) completed similar reports for the Big Sandy, Cumberland, Green, and Tradewater River basins. Each of these reports also provide in-depth descriptions of the analytes and analyte groups examined in this study. KGS has compiled and analyzed statewide groundwater data for ten individual parameters: nitrate-nitrogen, fluoride, arsenic, pH, selenium, mercury, cadmium, barium, iron, manganese, atrazine and 2,4-Dichlorophenoxyacetic acid (Conrad and others, 1999a-b; Fisher, 2002a-b; Davidson and Fisher, 2005a-c; Davidson and Fisher, 2006; Fisher and Davidson, 2007a-b; and Davidson and Fisher, 2007a-b). KGS has also produced a series of range of value maps for individual analytes on a statewide basis that can be obtained through their groundwater quality search engine online (http://kgs.uky.edu/kgsweb/DataSearching/Water/WaterQualSearch.asp). Further descriptions of analytes and their occurrence in natural waters was written by Hem (2013), which is a useful source of information for understanding ambient groundwater quality.

This study represents the first attempt to evaluate groundwater conditions statewide and to analyze the data for trends. This report addresses the remaining two goals by examining these data, resulting in a characterization of groundwater resources in Kentucky, as well as disseminating this information. This report explores ambient groundwater, looking at descriptive statistics as well as trends over the sampling period. Data are analyzed both statewide and by physiographic region, and look at wells and springs together and separately.

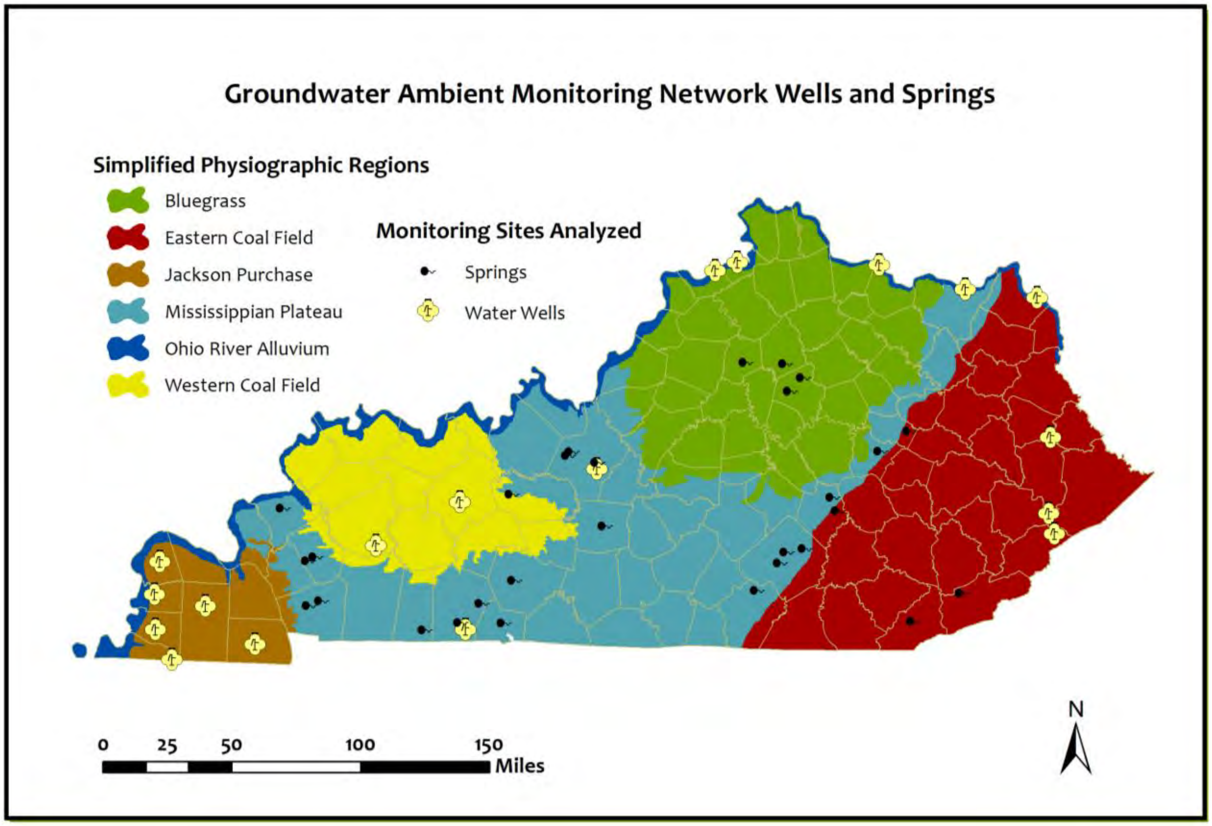
The purpose of this report is to analyze for, and summarize, recognized trends in groundwater quality across Kentucky over the last 20 years. Conclusions regarding causality are outside the scope of these analyses. Determination of the cause(s) of observed trends will require further in-depth and focused groundwater monitoring and assessment.

Background

Physiographic and Geologic Setting

Groundwater occurrence is determined by the rock units, or geologic setting, of a given region. The geologic setting and geologic history give rise to landforms, or physiographic character, of an area, which also plays a role in groundwater distribution. Kentucky is divided into six major Physiographic Regions: Bluegrass, Knobs, Eastern Coal Field, Western Coal Field, Mississippian Plateau and Jackson Purchase (Lobeck, 1930). For the purposes of the Network, alluvial deposits in the Ohio River Valley are considered as a seventh physiographic region. This is due to its depositional history, high groundwater production, and the wide and varied usage of the aquifer. Each of these regions has unique rock units and landforms that drive groundwater occurrence and yield. For a full discussion of Kentucky's Physiographic Regions please refer to McDowell (2001), from which the following descriptions were drawn. Figure 1 is a map showing these physiographic regions along with the Network monitoring sites used in this study.

Figure 1. Physiographic regions of Kentucky and ambient groundwater monitoring sites used in this study.



Bluegrass. The Bluegrass Region is typically divided into the Inner and Outer Bluegrass sub-regions. The Inner Bluegrass Region is underlain primarily by limestone and shale. The area is characterized by gently rolling hills with generally low relief, and is moderately dissected by surface streams. The soluble limestone in this region is prone to karst development and groundwater primarily flows through fractures and conduits associated with spring and cave systems. The Outer Bluegrass Region is underlain by generally thin-bedded limestone, dolostone and shale. Because the limestone is thin and interbedded with insoluble shale, karst development is minor and local groundwater resources are limited. Groundwater flow is through poorly developed karst conduits and stress relief fractures.

Knobs. The Knobs Region consists of conical hills that form a 10 to 15 mile wide belt around the east, south and west of the Bluegrass. The area is composed of limestone, dolostone, shale and sandstone. Groundwater typically occurs in stress relief fractures and poorly integrated secondary porosity created through dissolution of dolostone. Because lithologic characteristics and groundwater occurrence are so similar, the Knobs Region is included as part of the Bluegrass in analyses for this study.

Eastern Coal Field. The Eastern Coal Field, or Cumberland Plateau, is composed of sandstone, siltstone, clay, shale and coal beds. Uplift and subsequent erosion of this plateau has produced deeply incised, steep-sided valleys that are divided by narrow ridges. Groundwater flow is predominantly through shallow stress relief fractures. However, moderate yet very limited karst development has occurred in limestone exposed along the Pine Mountain Thrust Fault in extreme southeastern Kentucky.

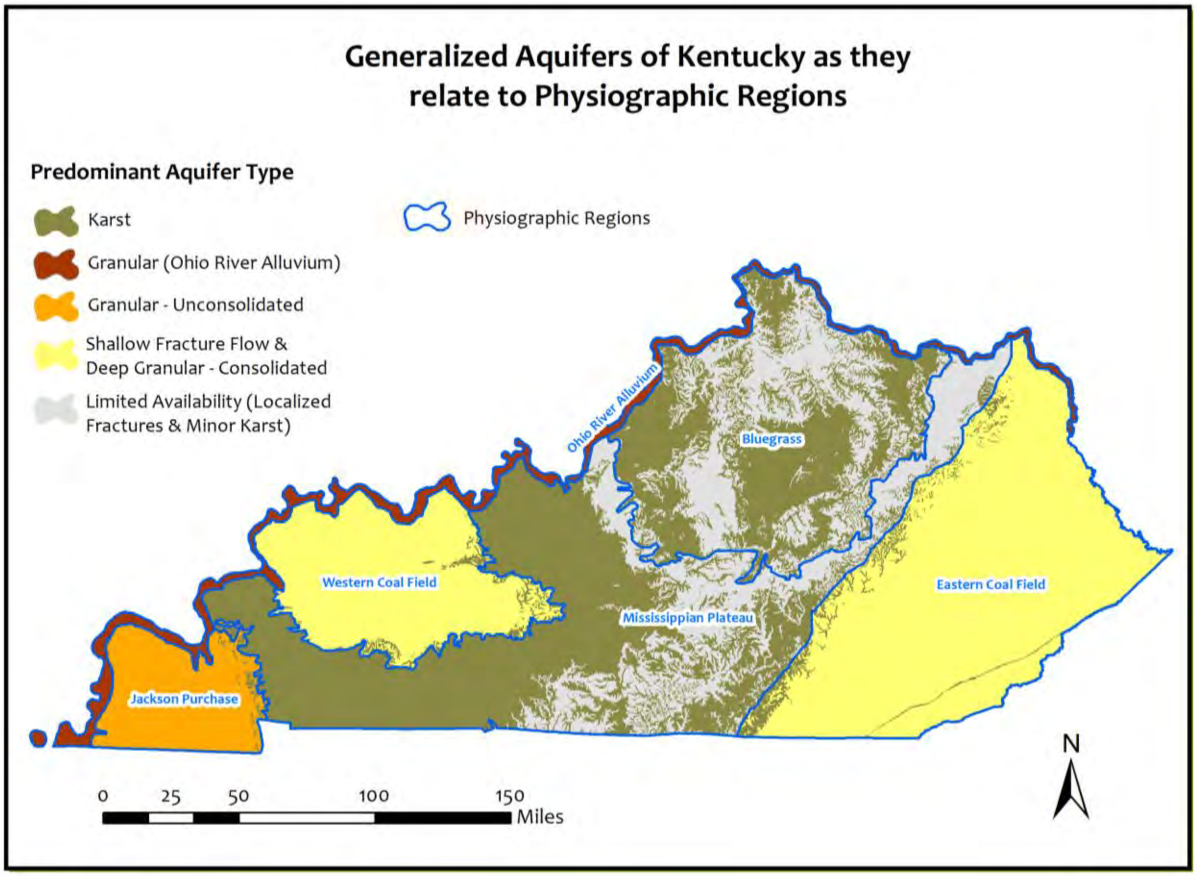
Western Coal Field. The Western Coal Field is characterized by flat-lying sandstone, siltstone, shale, clay and coal beds. Erosion has produced a hilly upland of low to moderate relief that is dissected by streams in wide valleys that tend to be poorly drained and swampy. Groundwater primarily occurs in shallow stress relief fractures. However, several deep consolidated sand deposits and sandstone aquifers are also utilized (Davis and others, 1974).

Mississippian Plateau. The Mississippian Plateau is also known as the Pennyroyal or Pennyrile Plain and is composed of primarily flat-lying limestone. Well-developed karst drainage occurs in this region with an abundance of caves, sinkholes and influent streams. Groundwater flow is predominantly through conduits, but fracture flow and flow along bedding planes also occurs and can be locally important. The western and central portion of this region is known for the sinkhole plain, especially around the Mammoth Cave area. The eastern portion of this region transitions into the uplands of the Eastern Coal Field, and its margins have characteristics of both areas.

Jackson Purchase. The Jackson Purchase Region, or Mississippi Embayment, is the western-most part of Kentucky. It is bounded by the Tennessee River on the east, Ohio River on the north and Mississippi River on the west. The area is underlain by unconsolidated deposits of sand, gravel, silt and clay. These deposits are on top of limestone that dips relatively steeply to the west. Groundwater occurs within the unconsolidated granular aquifers and is generally abundant.

Ohio River Alluvium. The Ohio River Alluvium is comprised of unconsolidated sand, gravel, silt, and clay deposits adjacent to the Ohio River. These deposits consist of glacial outwash and modern alluvial sediments. The sediments form a broad flood plain that is relatively flat and has only minor dissection by tributary streams. Coarse sand and gravel beds in these deposits supply large volumes of groundwater to municipal, agricultural, industrial, and private wells.

Figure 2. Generalized aquifers as they relate to physiographic regions.



As previously mentioned, the rock units and physiographic setting of an area strongly influence groundwater occurrence and yield. Figure 2 shows the generalized aquifer types that are predominant in each physiographic region of Kentucky. Note that this map shows aquifer types, not the extent or distribution of unique, individual aquifers. For example, karst aquifers occur in the Bluegrass and Mississippian Plateau regions. However, the geologic units in which karst has developed in each of these regions differ in depositional history and several key characteristics. Therefore, some natural characteristics of groundwater chemistry will be similar while others may be quite different.

Groundwater Use in Kentucky

Groundwater is a widely used resource in Kentucky. Nearly 1.3 million residents rely on groundwater as a drinking water source, in whole or in part (KDOW internal data). Approximately 100 community water suppliers serving 411,000 Kentuckians rely solely on groundwater as a source. Another 750,000 Kentuckians are served by community water suppliers that rely partially on groundwater sources. Estimates indicate that approximately 130,000 Kentuckians rely on private, domestic groundwater sources for their drinking water supplies. Agricultural use is also very important for crop irrigation and livestock watering. However, agricultural uses are not regulated and only estimated withdrawals are available from the U.S. Department of Agriculture (2012). Groundwater is also used in industrial, commercial and mining-related applications. Regulated groundwater withdrawals are summarized in Table 1, below, in millions of gallons per day (MGD).

Table 1. Daily maximum permitted groundwater withdrawals.

Use Category	No. of Permitted Groundwater Withdrawals	Daily Maximum Permitted Withdrawals (MGD)
Drinking Water Supply	94	185.4
Industrial	66	162.8
Commercial	33	37.3
Mining (Coal)	26	32.8
Mining (Non-coal)	14	25.1
Aquaculture	2	0.9

Monitoring Network Design

The Network is designed to assess ambient groundwater quality. This assessment can be used to evaluate non-point source (NPS) impacts, identify and track trends in groundwater conditions, recognize indications of groundwater quality degradation, evaluate surface water-groundwater interactions, and provide monitoring support for various state and federal regulatory programs. Quality assurance and standardized operations are central to a successful design. The Quality Assurance Project Plan (QAPP) and Standard Operating Procedures (SOP) documents for the Network have been formalized and are available by request.

Analytical Parameters. The parameters chosen for analysis were largely determined through discussions with ITAC during initial development of the Network. A full listing of all analytes currently reported by the laboratory can be found in the QAPP. Table 2 lists the analyte groups and analytes for this study, and a brief summary of what aspect of water quality characterization their inclusion reflects. Parameters were chosen specifically to establish the baseline geochemical characteristics of groundwater and monitor for NPS influence.

Table 2. Analyte groups and specific analytes in this study.

Analyte Group	Summary Comments	Included in Analysis
Bulk Parameters	Basic chemistry and general water quality	pH, Field Conductivity, Temperature, Hardness
Nutrients	Naturally occurring and NPS influence	NO_3, NO_2, PO_4, TKN, Total Nitrogen
Major Inorganic Ions	Water-rock chemistry and NPS influence	Cl^-, F^-, SO_4^-
Metals	Water-rock chemistry	Al, As, Ba, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Ag, Na, Zn
Organics	NPS influence	Pesticides: Alachlor, Atrazine, Cyanazine, Glyphosate, Metalochlor, Simazine
Volatile Organic Compounds	NPS and point source influences	Benzene, Ethylbenzene, Toluene, Xylenes, Methyl-tert-butyl ether (MTBE)

Site Selection. The primary concern for site selection is safe access to groundwater sources for the field samplers. Depending upon the location of the site, this may include landowner permission to access groundwater sources on private land. To adequately characterize spatial variation of groundwater, sites have been selected in each of the physiographic regions and each of the aquifer types of Kentucky (see Figure 1 & 2). Table 3 summarizes the sites used in this study by physiographic region, as well as the sites representing aquifer types within each region. The subset of monitoring sites used in this study were chosen based on the sampling record for each site, as discussed below. A full list of monitoring sites is available in the QAPP.

Following concerns for safe access and representing physiographic regions and aquifer types, selection priority is given to groundwater PWS sites. This is in support of source water protection and drinking water programs. Currently, there are 23 PWS monitoring sites in the Network – 18 water wells and 5 springs.

The next tier site selection requirement is identification of the aquifer being monitored. This requirement is met for water wells with access to driller's logs and construction records in tandem with geologic maps. Preference is given to karst springs with recharge areas that have been delineated through tracer tests and cave mapping.

Most springs that are part of the Network have well-defined catchment areas, while a few still need dye tracing to delineate their recharge area. Other desirable criteria are that the groundwater source is used as a drinking water source (private domestic use or public roadside springs) or for another purpose such as agriculture. However, several of the springs monitored for the Network are unused. These springs provide significant volumes of water to the streams to which they discharge, and therefore have a substantial influence on surface water quality.

Table 3. Summary of monitoring sites by physiographic region and aquifer type.

Region	# Wells	# Springs	Aquifer Type		
			Karst	Fracture Flow	Granular
Bluegrass	-	5	5		
Eastern Coal Field	3	3		6	
Jackson Purchase	6	-			6
Mississippian Plateau	2	22	23	1	
Ohio River Alluvium	6	-			6
Western Coal Field	2	-		1	1
Total	19	30	28	8	13

The Network typically has about 60 active monitoring sites. Occasionally sites are removed due to land ownership changes, other access or safety issues, or wells no longer being used. When sites are removed, priority is given to identifying a replacement that is in the same general vicinity and represents the same aquifer, or aquifer type. Approximately 84 sites have been a part of the Network since its inception in 1995. The 49 sites used in this study were selected based on having adequate datasets as described under general data criteria.

Sampling Frequency. The frequency of sample collection at each site is meant to capture the temporal variation of groundwater resources. All new Network sites are sampled quarterly for three years, with a one-month stagger beginning each calendar year. This allows for samples to be collected from the sites in each season and every month of the calendar year within a three-year period. Following the initial three-year period, data from each site are reviewed for seasonal and annual trends. If the data collected adequately characterize the baseline groundwater conditions with consistent results and no extreme variation, then the sampling frequency is decreased to twice per year. This sampling frequency is maintained for 3-5 years, with the same annual staggering such that sampling events rotate through the seasons. Following this period the sampling frequency is then decreased to once per year, on a schedule that will continue to rotate sampling events through the seasons. This allows continued monitoring of groundwater resources and expansion of Network sites without a major increase in program costs.

Analysis Methods and Results

General Data Criteria and Statistical Methods

For an analyte to be included in the analysis, it must have greater than 1000 sample results. There must be a minimum of 7 years of samples with no gaps greater than a year. The distribution of included analytes over time is shown in Appendix A. The earliest start date for sample periods was January 1, 1995, however start dates varied between analyte groups; the end date for inclusion of samples was December 31, 2015. Two ambient stations (0002-9505 and 0002-9508, Worthington Municipal Water Works) were adjacent to each other. They each met inclusion criteria, but because they were drawing groundwater from the same wellfield and aquifer, we only included the station with the longer record (0002-9508). Table 2 shows the analytes that meet the criteria for inclusion. More details about inclusion and exclusion of analytes are given within each analyte group discussion. Data outliers were investigated and included, corrected, or excluded as warranted. More details about inclusion and exclusion of analytes is given within each analyte group discussion.

Analyses were broken into the following three categories: all sites statewide, by groundwater source (spring or well) statewide, and by physiographic region. Upon a cursory examination of the results of trend tests, significant trends were found more frequently when examining the data statewide, whether for all data, or wells or springs separately. Inherent differences exist between wells and springs that introduce uncertainty into the direct comparability between these two sources of groundwater. In particular, spring recharge is closely tied to surface precipitation and streams, while wells are more insulated from the surface and, depending on depth, may take months to years to recharge. Springs respond to precipitation events similarly to surface streams with rapid peaks in discharge and amplitude changes in concentrations of water quality parameters (Ryan & Meiman, 1996). Flow measures for springs was not consistent and therefore was not incorporated into the study. Any variability in spring measures from flow was considered to be natural.

The ability to detect a trend increases with increasing sample size. Significant trends for physiographic regions are more easily identified in regions with more monitoring stations. Table 3 gives the number of stations for each physiographic region. With the exception of the Mississippian Plateau, which has 24, each physiographic region has 6 or fewer stations. Smaller sample sizes provide less power to determine significance. This idea is borne out when looking at significant trends for metals in physiographic regions (Table 18). For metal analytes, the Mississippian Plateau has 8 significant trends. With the exception of the Bluegrass, the other physiographic regions have 0 - 2 significant trends. Care should be exercised when evaluating each level of analysis for an analyte as physiographic regions are not equally represented.

Basic descriptive statistics were performed on all analyte groups, giving the number of samples, percent of non-detects, the 25th, 50th, and 75th percentiles as well as the maximum value and standard deviation. Trends were determined by calculating the Kendall's tau-b for each station. This trend test does not assume a normal distribution and measures whether the median changes over time. Sample measures were assumed to have a lognormal distribution unless otherwise noted, and data were log-transformed for trend testing. While significance of a trend was not determined for each station, a determination of a monotonic trend for stations within subgroups (physiographic region, wells, springs, or all sites) was determined. The mean tau and 95% confidence interval was calculated. If the confidence interval did not cross zero, then a general statement about a monotonic trend for that subgroup is assumed (Nielsen, 2006). Trends were calculated for all analytes within analyte groups with the exception of pesticides and VOCs. The high proportion of samples below the detection limit for pesticides and VOCs made tests for trends impossible. For more details on Kendall's tau, see Helsel and Hirsch (2002) or Nielsen (2006). SAS 9.4 was used to perform all statistical calculations.

Graphical Methods

Maps created to display trend analyses utilize color coding for each monitoring station and physiographic region. Stations that do not show any trends are illustrated with a blue dash, and regions with no trends are displayed in yellow. Stations with upward trends are marked with red, upward-pointing arrows that are scaled according to the degree of the observed trend. If an upward trend is observed across a region the entire area is coded red. Stations with downward trends are marked with green, downward-pointing arrows that are scaled according to the degree of the observed trend. If a downward trend is observed across a region, the entire area is coded green.

Graphs are also presented displaying the Kendall's tau and 95% confidence interval of the statistic. The length of the confidence interval varies with the number of samples used to compute each Kendall's tau. If the confidence interval does not cross zero, the value depicted by the point is a significant trend. If the confidence interval crosses zero, then no statistically significant trend was detected.

Bulk Parameters

Bulk Parameters analyzed include total hardness and the field measures of conductivity, pH and temperature. These are considered as very general water quality indicators. The data were considered in two sets because of differences in processing the data. The first set included the field parameters and the second set total hardness.

Field Measures

Upon initial examination of data, two large gaps were found in sampling: between December 1996 to January 2001, and June 2003 to January 2005. Consequently, the initial analyses were done on the date range January 2005 through December 2015. Subsequent exploration of records found chains of custody records with data from the gap periods. These data were entered and the analyses run again. Field parameters were assumed to have a normal distribution and not log-transformed for trend analysis. Fit diagnostics supported this assumption (not shown). A seasonal adjustment was examined, but it was determined that season only had an impact on temperature, so the trend was performed on the residuals from the un-adjusted regression for conductivity and pH. Temperature was adjusted for season by using the LOESS procedure in SAS. In this case, the process was to subtract the median for each month from the actual result. A smoothing process was used to create a more continuous fit. The trend test is then performed on the difference between the actual and the expected results. Field measures have no non-detects and the data are normally distributed allowing the use of the more powerful regression to be used to test for trends. A p-value of 0.05 was used to determine significance.

As shown in Table 5, the Kendall's tau test showed a statewide significantly increasing trend in springs for conductivity and pH. Regionally, the Mississippian Plateau and the Bluegrass had significantly increasing Kendall's tau for pH. Both of these regions are characterized by springs as the type of monitoring station that dominates. The more powerful regression analyses (Table 6) showed this same trend for wells and springs together and separately. Time accounted for 6.9% of the variability in conductivity and 3.5% of the variability in pH statewide.

Interestingly, temperature showed no trends over the time period. However, when the trend analyses were run for the date range of 2005-2015 (data not shown), a slight, but significant, increasing trend was found statewide and for springs. When looking at the distribution of data in Figure 28, the first decade of the data were sparser and appear more variable. The increase in temperature for the second decade occurred in springs, but not wells. Springs drain shallow aquifers that are directly connected to the land surface. This increasing trend mirrors the temperature increases that have been noted in increasing air temperatures (Kentucky Department of Fish and Wildlife Resources, 2010). Wells pull from deeper aquifers and consequently are more insulated from atmospheric temperature fluctuations and other surface impacts (Luhmann et al, 2011). Monitoring of temperature should continue to determine if the increasing trend found for the last half of the analysis period persists.

Table 4. Descriptive statistics for field measures.

Field Measures							
Analyte	n	Minimum	25th Pctl	Median	75th Pctl	Maximum	Std Dev
Field Conductivity (uS/cm)	2320	11	287	431	552	2030	235
Field pH	2332	4.20	6.86	7.17	7.50	12.90	0.70
Field Temperature (°C)	2382	4.3	13.3	14.8	16.3	27.1	2.7

Table 5. Trends for field measures for all stations, and wells and springs separately.

Trends for Field Measures for Wells and Springs									
	All			Springs			Wells		
Analyte	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL
Conductivity	-0.235	-0.053	0.130	0.093	0.145	0.196	-0.016	0.086	0.189
pH	-0.128	0.015	0.157	0.079	0.119	0.158	-0.059	0.048	0.155
Temperature*	-0.055	0.081	0.218	-0.040	0.012	0.064	-0.081	-0.023	0.034

*adjusted for season

Significantly increasing trend
Significantly decreasing trend

Table 6. Regression for field measures for all stations.

Regression over time						
	All		Springs		Wells	
Analyte	R^2	p-value	R^2	p-value	R^2	p-value
Conductivity	0.0693	<0.0001	0.0514	<0.0001	0.1046	<0.0001
pH	0.0353	<0.0001	0.0103	<0.0001	0.0943	<0.0001
Temperature*	0	0.947	0.0000	0.8348	0.0002	0.6912

*adjusted for season

Significantly increasing trend
Significantly decreasing trend
*adjusted for season

Figure 3. Mean Kendall's tau for field measures for all stations, and wells and springs, separately.

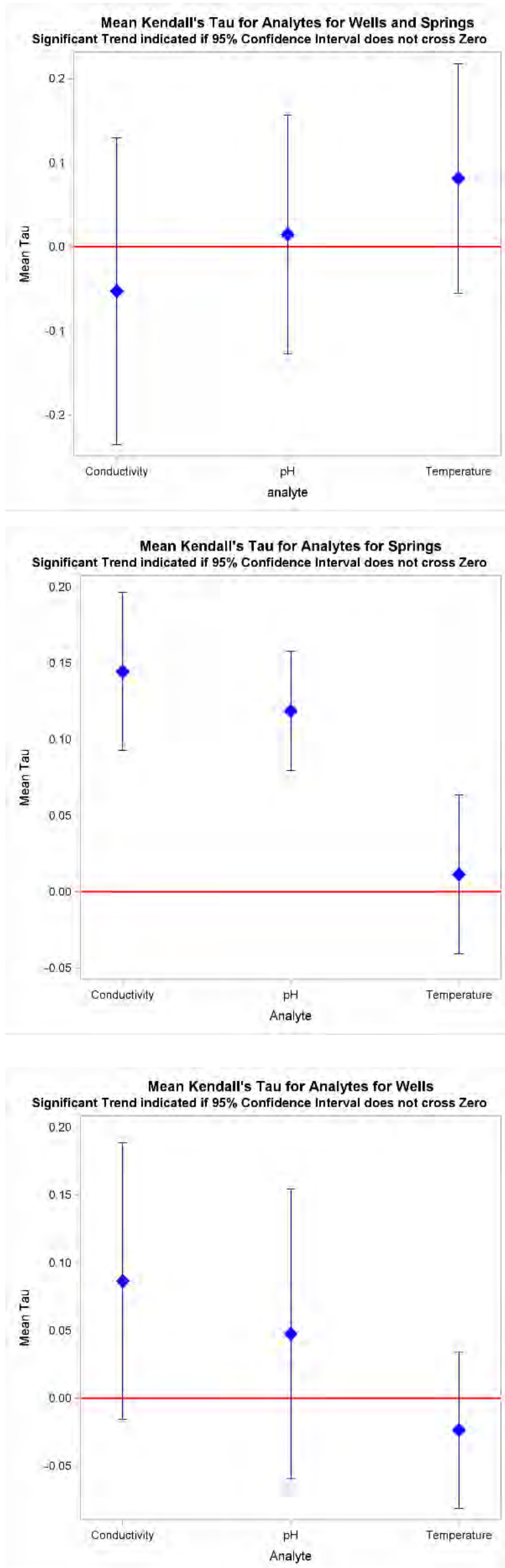


Figure 4. Regression for Conductivity over time.

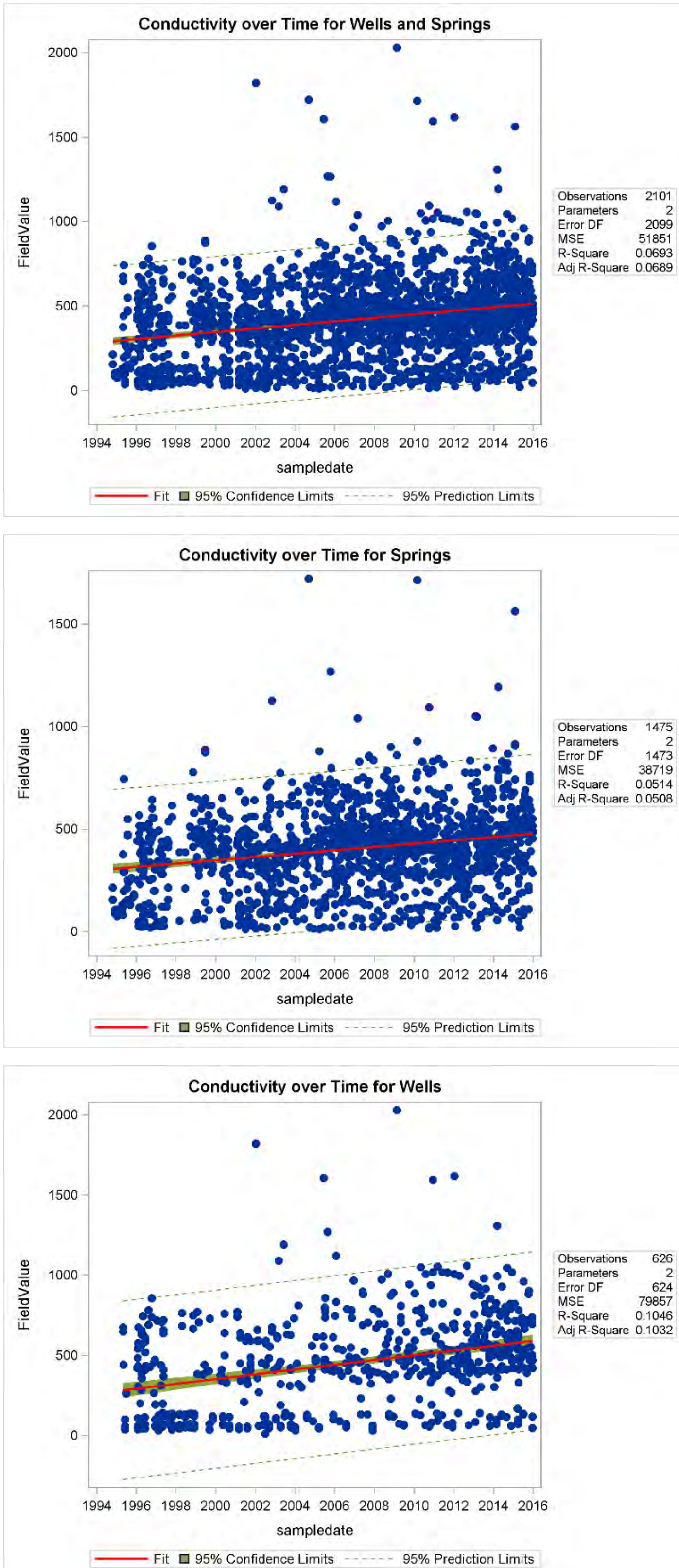


Figure 5. Regression for pH over time.

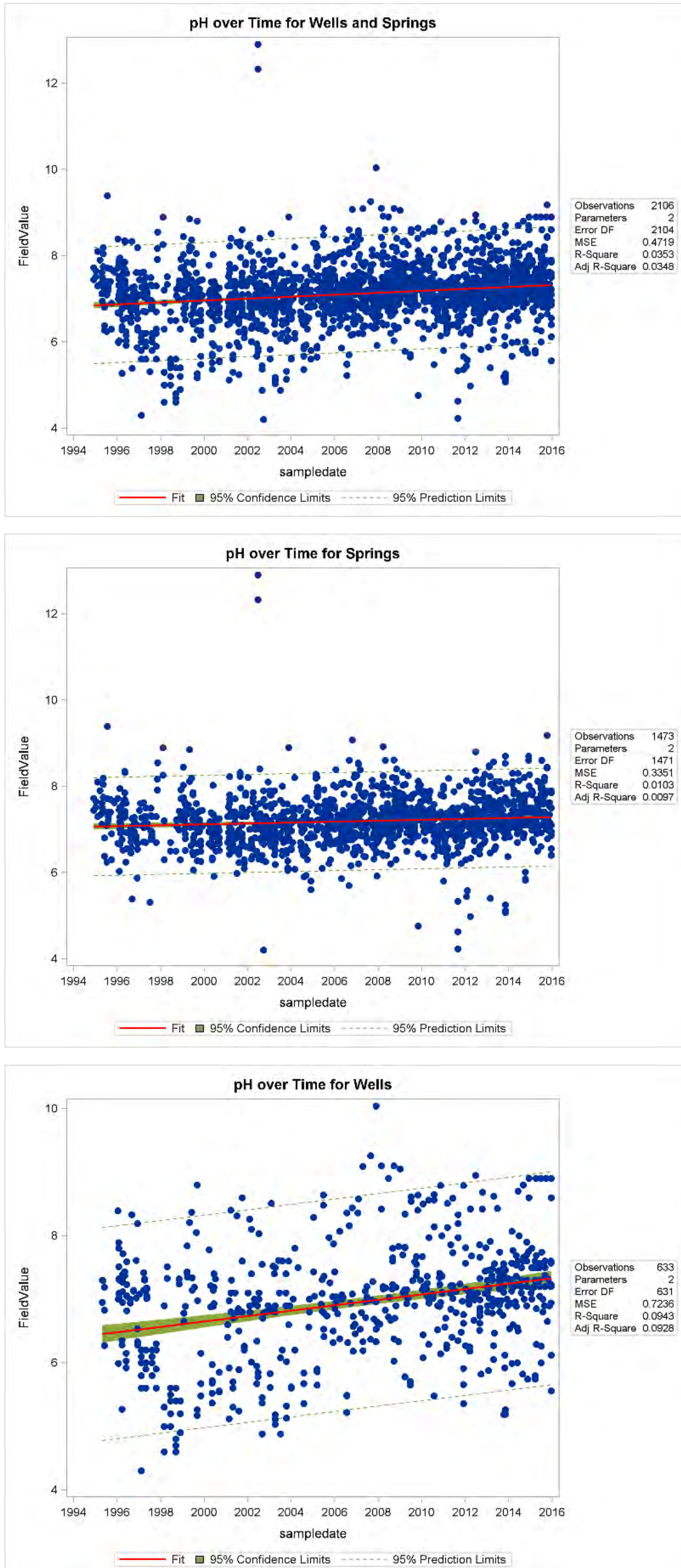
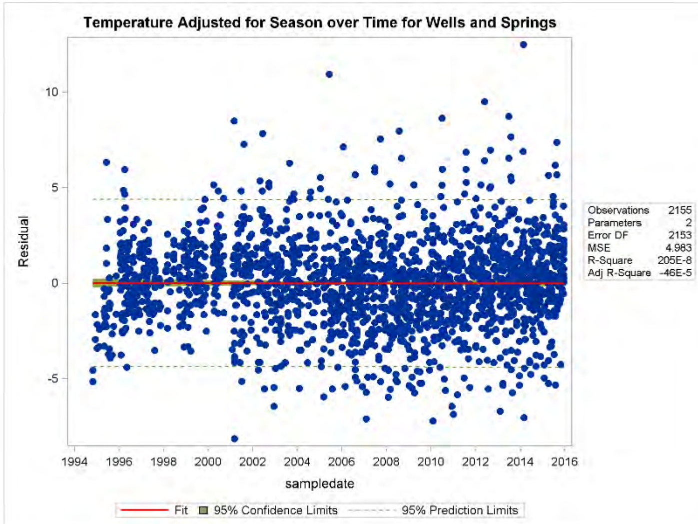
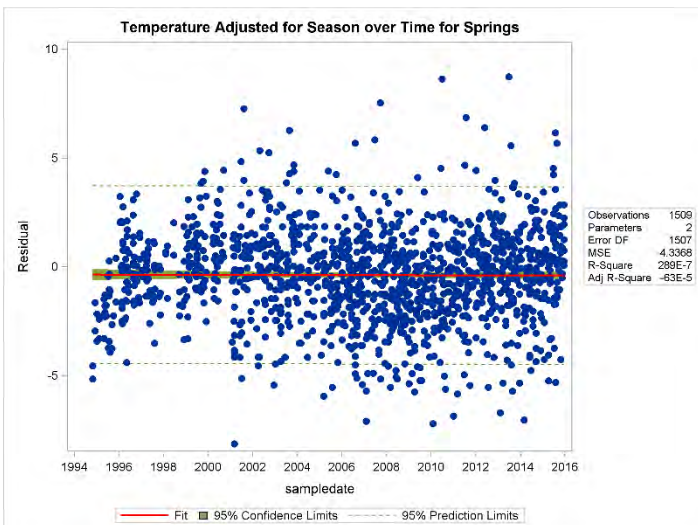


Figure 6. Regressions for temperature, adjusted for season, over time.





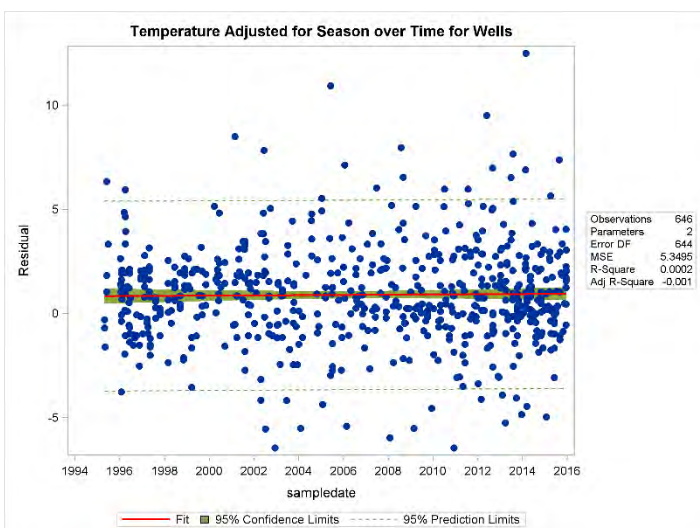


Table 7. Trends for field measures by physiographic region.

Kendall's Tau by Region				
physiographic region	analyte	LCL	Kendall's Tau	UCL
Bluegrass	Conductivity	-0.004	0.191	0.386
	pH	0.055	0.148	0.240
	Temperature	-0.075	-0.007	0.061
E. Coal Field	Conductivity	-0.366	-0.083	0.201
	pH	-0.182	-0.018	0.145
	Temperature	-0.094	0.022	0.138
Jackson Purchase	Conductivity	-0.109	0.117	0.342
	pH	-0.085	0.102	0.290
	Temperature	-0.242	-0.036	0.170
Mississippian Plateau	Conductivity	0.091	0.152	0.213
	pH	0.069	0.115	0.161
	Temperature	-0.052	0.014	0.081
Ohio River Alluvium	Conductivity	0.004	0.151	0.297
	pH	-0.156	0.076	0.308
	Temperature	-0.109	-0.027	0.056
W. Coal Field	Conductivity	-0.482	-0.032	0.418
	pH	-0.511	-0.050	0.411
	Temperature	-0.449	-0.060	0.328

Significantly increasing trend
Significantly decreasing trend

Figure 7. Trends for field measures by physiographic region.

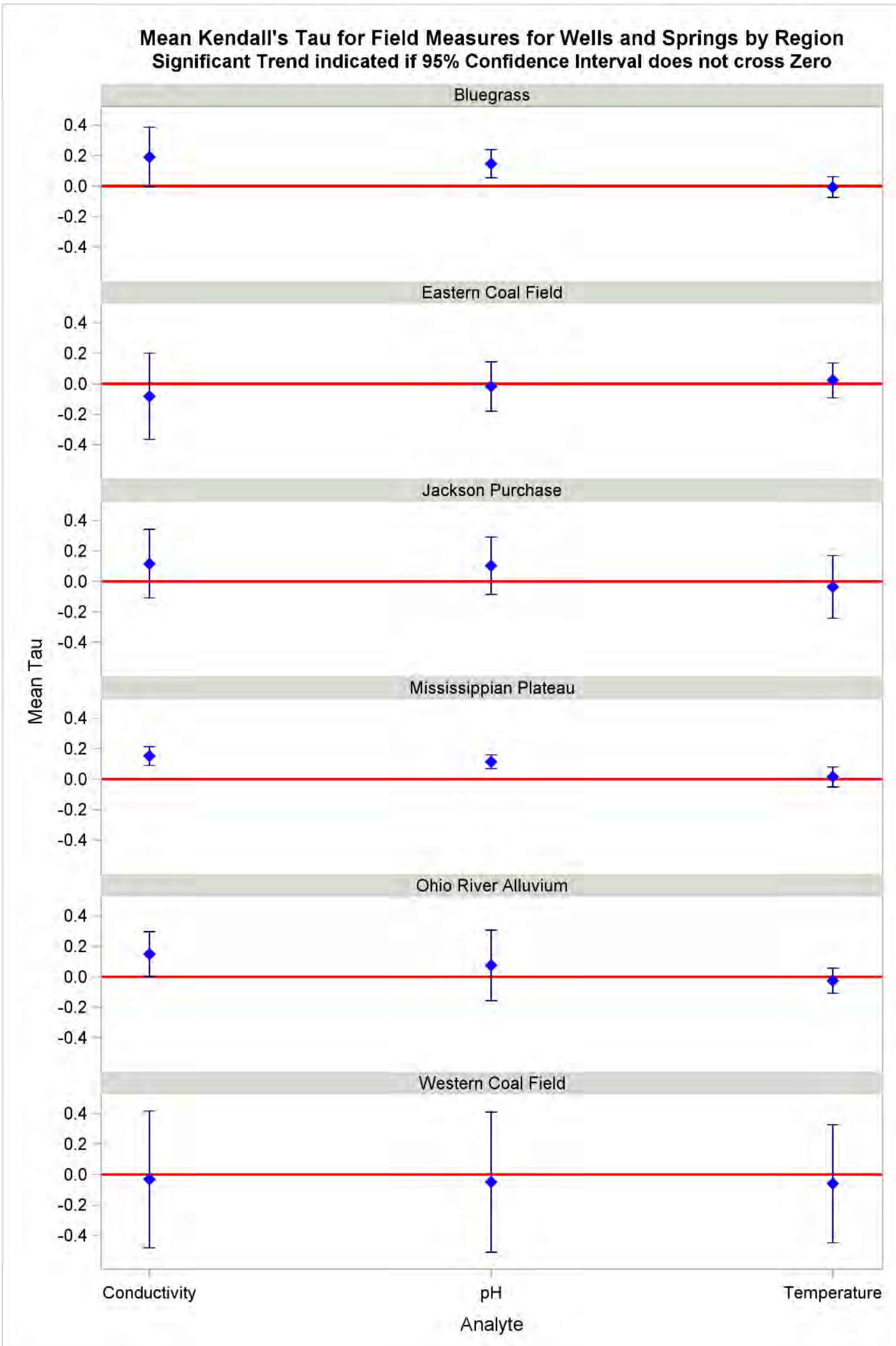
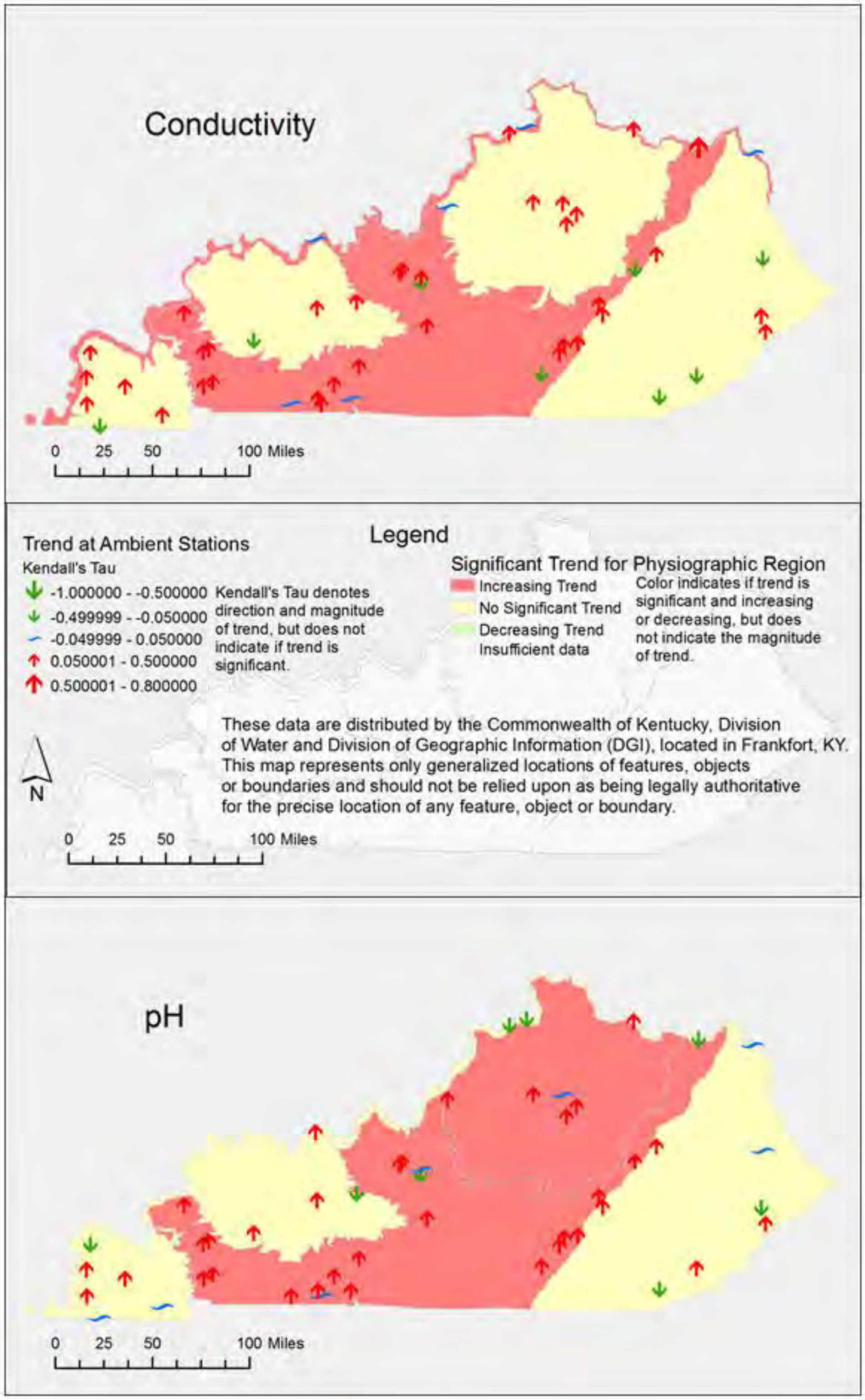
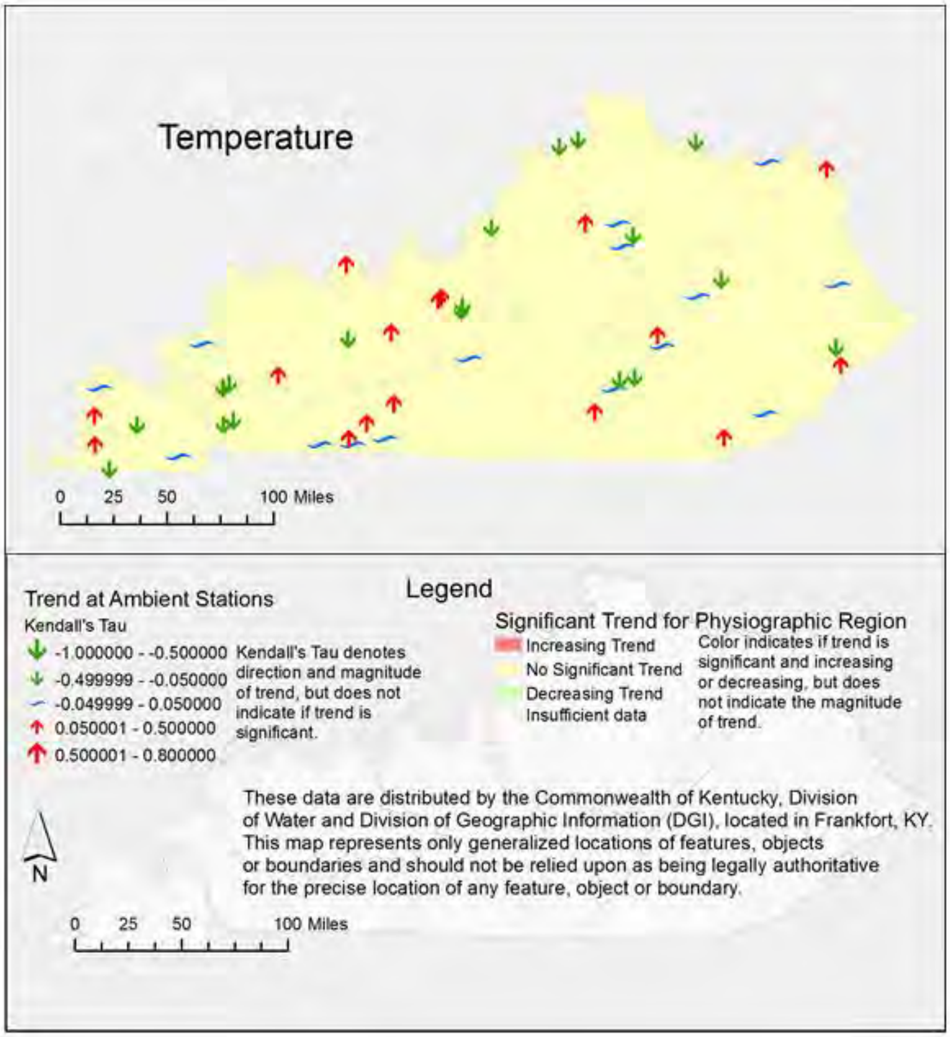


Figure 8. Maps of trends for field measures for monitoring stations and physiographic regions.




Temperature
0 25 50 100 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles

Total Hardness

Total Hardness was calculated from calcium and magnesium using the equation below.

$$Total\ Hardness\ \left({}^{mg}/_{L}\right) = Ca\ \left({}^{mg}/_{L}\right) \times 2.5 + Mg\ \left({}^{mg}/_{L}\right) \times 4.1$$

The distributions of total hardness, calcium, and magnesium were examined to determine which factors drive total hardness. Samples from 1998 through 2015 were included. The trend test was calculated on total hardness only. Total hardness had a bimodal distribution. Depending on region or whether it was a well or spring. Calcium had a normal, lognormal, or bimodal distribution. Magnesium had a lognormal distribution.

Significant increasing trends were found statewide, for wells, and in the Bluegrass. The trend in the Bluegrass seems somewhat contradictory as sample locations are all springs which did not have a trend. One possible explanation is that the individual physiographic regions did not have enough power to detect trends, but did so combined.

Table 8. Descriptive statistics for hardness.

Total Hardness								
PhysiographicRegion	Analyte (mg/L)	% NonDetect	n	25th Pctl	Median	75th Pctl	Max	Std Dev
Statewide	**Ca**	-	2150	37.60	70.35	87.10	166.00	33.22
	Mg	-	2150	4.55	7.15	9.86	102.00	8.53
	Hardness	**0.05**	2150	122.86	208.82	259.82	813.20	106.26
Bluegrass	**Ca**	-	337	81.50	92.90	101.00	146.00	16.27
	Mg	-	337	7.18	8.69	10.60	49.80	5.64
	Hardness	-	337	244.06	272.94	297.80	422.81	47.43
E. Coal Field	**Ca**	**0.46**	216	4.84	29.55	56.25	166.00	34.39
	Mg	-	216	2.15	7.15	18.80	102.00	15.69
	Hardness	-	216	21.05	103.68	220.55	813.20	147.47
Jackson Purchase	**Ca**	-	100	3.08	4.74	8.19	48.30	5.47
	Mg	-	100	1.18	2.15	3.81	6.67	1.43
	Hardness	-	100	12.66	20.69	36.49	136.17	17.73
Mississippian Plateau	**Ca**	-	1086	51.50	70.20	81.90	125.00	22.80
	Mg	-	1086	4.95	6.50	8.00	56.40	3.29
	Hardness	-	1086	151.96	203.12	236.20	457.24	65.25
Ohio River Alluvium	**Ca**	-	180	64.40	98.70	108.00	124.00	33.96
	Mg	-	180	11.30	21.85	32.20	41.30	11.05
	Hardness	-	180	205.34	348.90	396.53	471.83	125.72
W. Coal Field	**Ca**	-	65	3.46	3.77	5.74	7.32	1.27
	Mg	-	65	1.24	1.39	2.04	2.67	0.47
	Hardness	-	65	13.75	14.93	22.88	29.17	5.08

Table 9. Trends for hardness for wells and springs, statewide and by physiographic region.

Trends for Hardness for Springs and Wells				
Groundwater Source	Region	LCL	Kendall's Tau	UCL
All	Statewide	0.0044	0.0633	0.1221
Springs		-0.0301	0.0053	0.0406
Wells		0.0160	0.1548	0.2936
Springs and Wells	Bluegrass	0.0011	0.0422	0.0833
	E. Coal Field	-0.1438	0.0381	0.2201
	Jackson Purchase	-0.5312	-0.0748	0.3816
	Mississippian Plateau	-0.0249	0.0247	0.0742
	Ohio River Alluvium	-0.0132	0.2337	0.4807
	W. Coal Field	-0.0607	0.4023	0.8653

Significantly increasing trend
Significantly decreasing trend

Figure 9. Distribution of hardness parameters statewide.

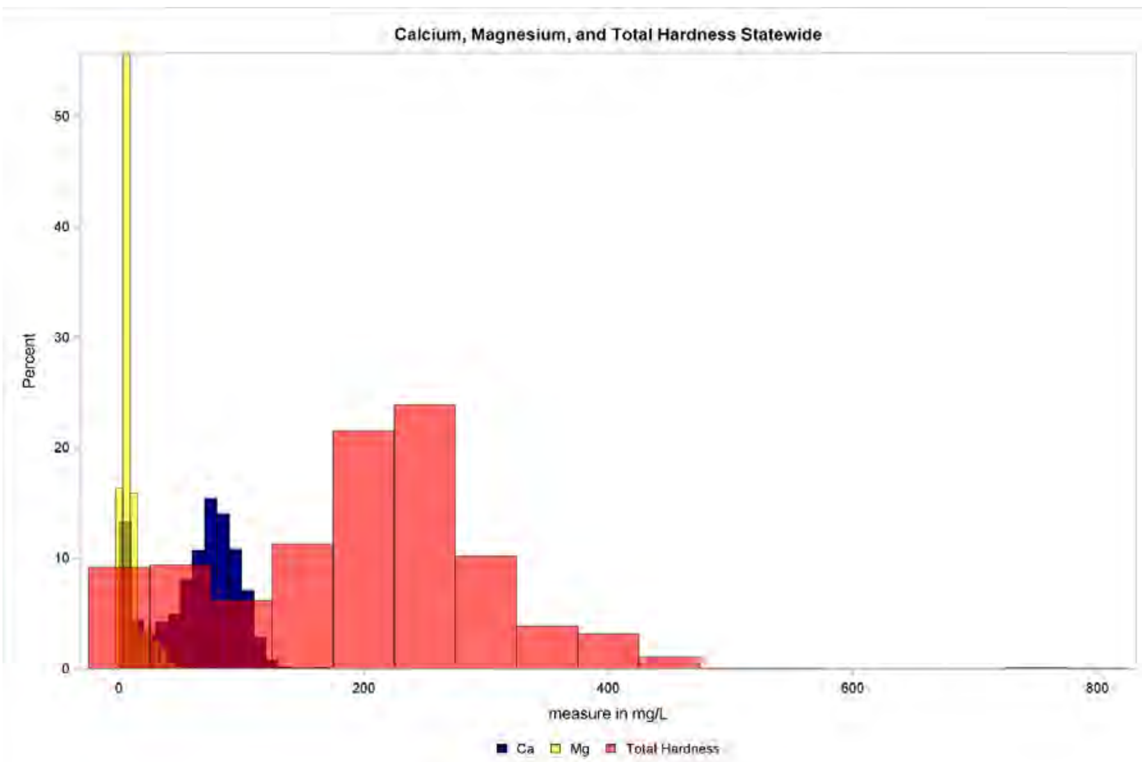


Figure 10. Distribution of hardness parameters for wells and springs.

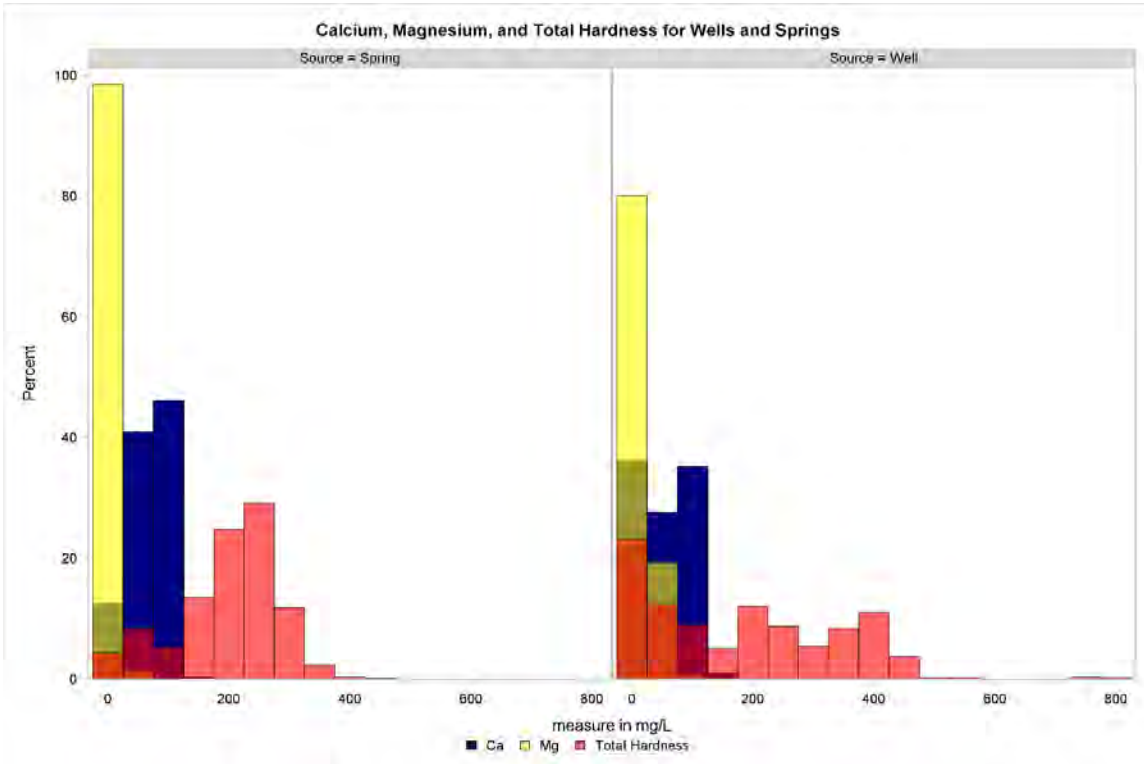


Figure 11. Distribution of hardness parameters by physiographic region.

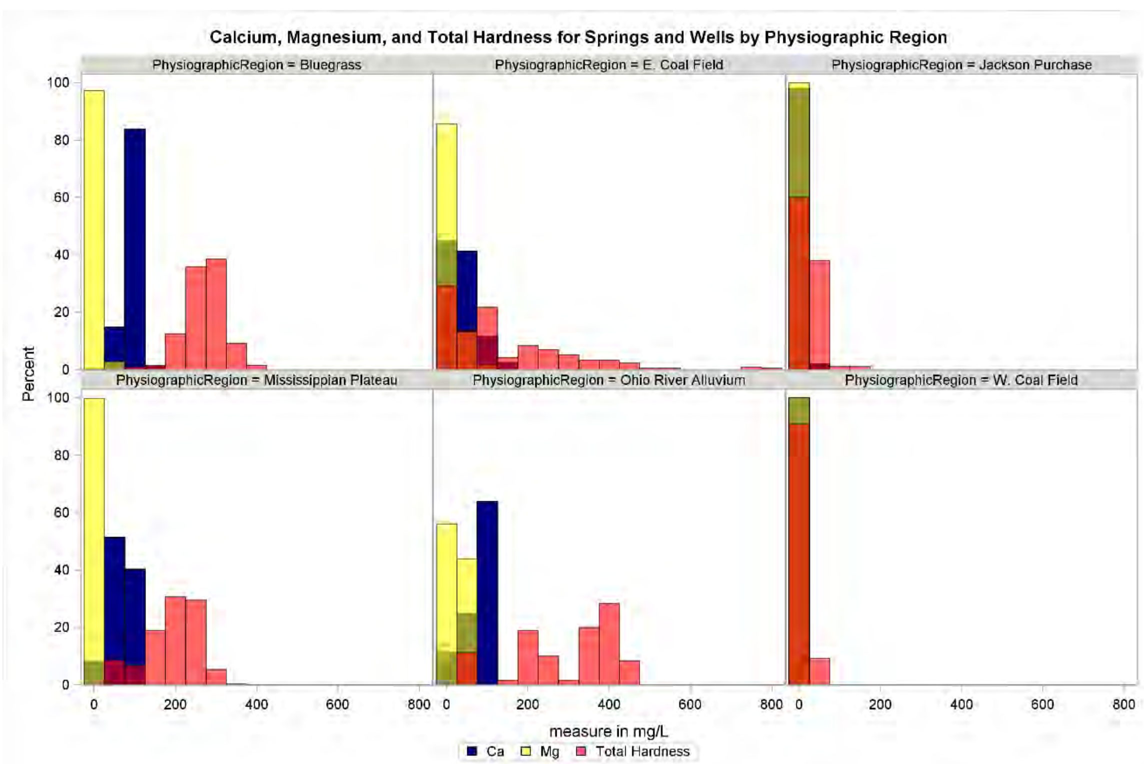


Figure 12. Distribution of hardness parameters for springs by physiographic region.

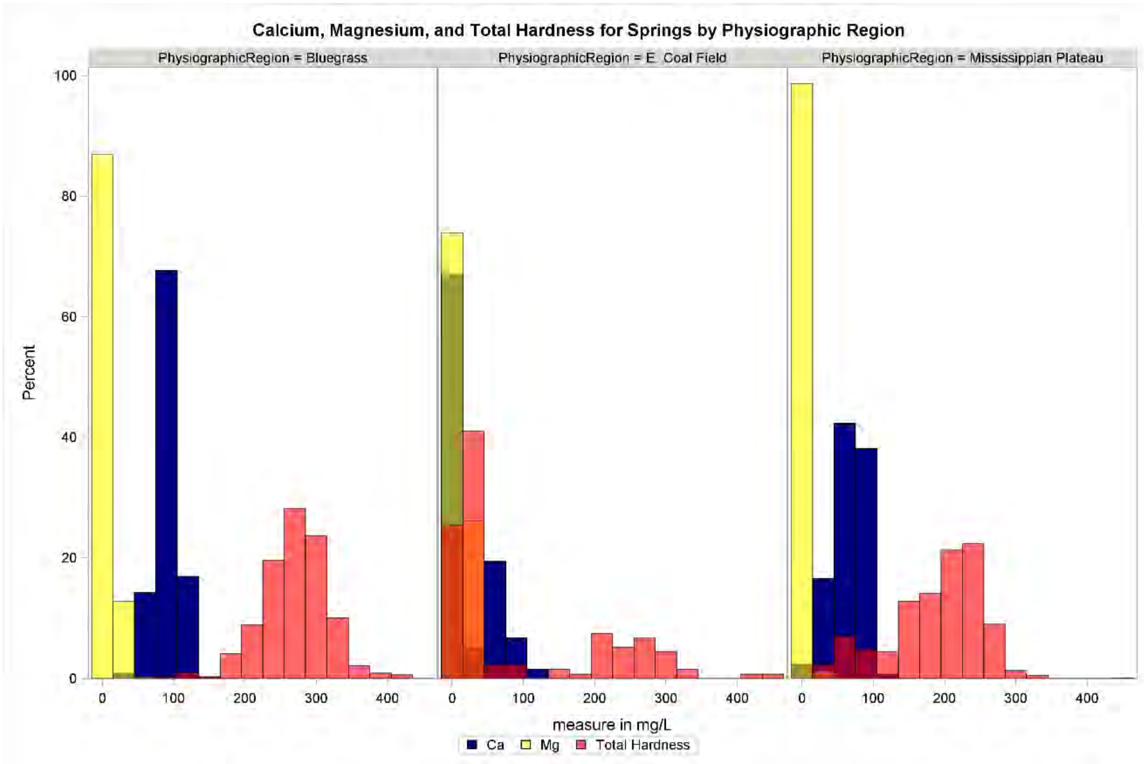


Figure 13. Distribution of hardness parameters for wells by physiographic region.

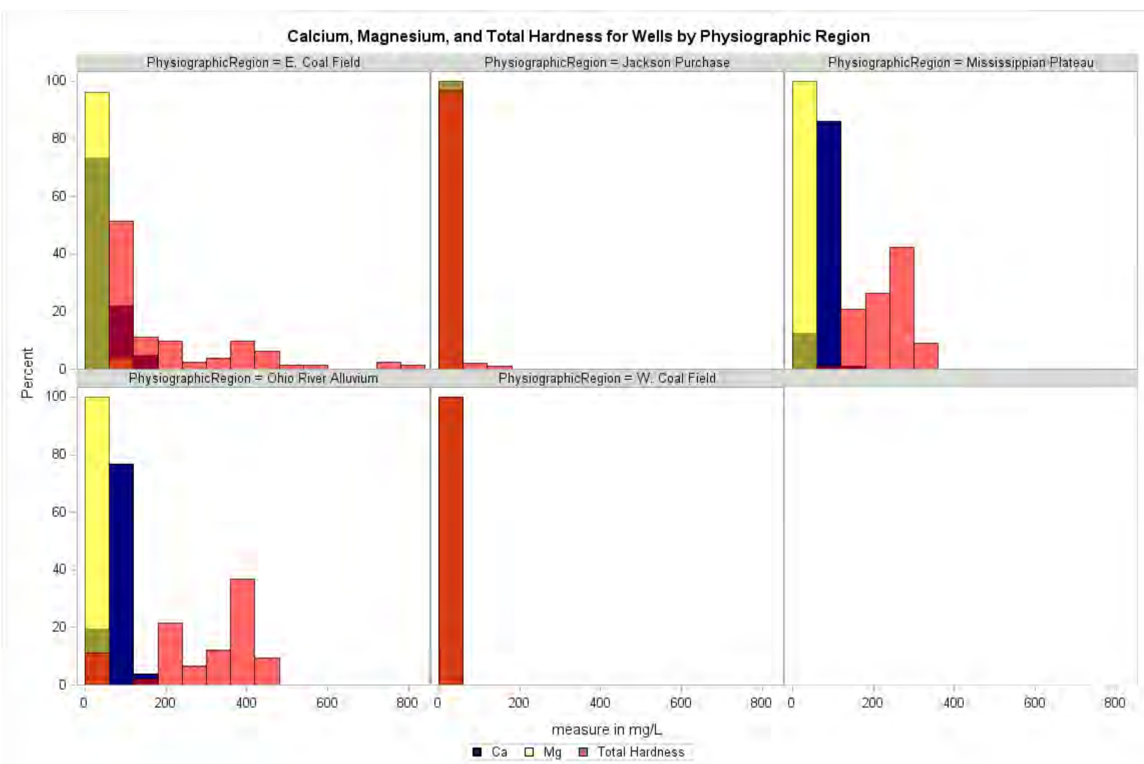


Figure 14. Trend test for total hardness for all stations and by source.

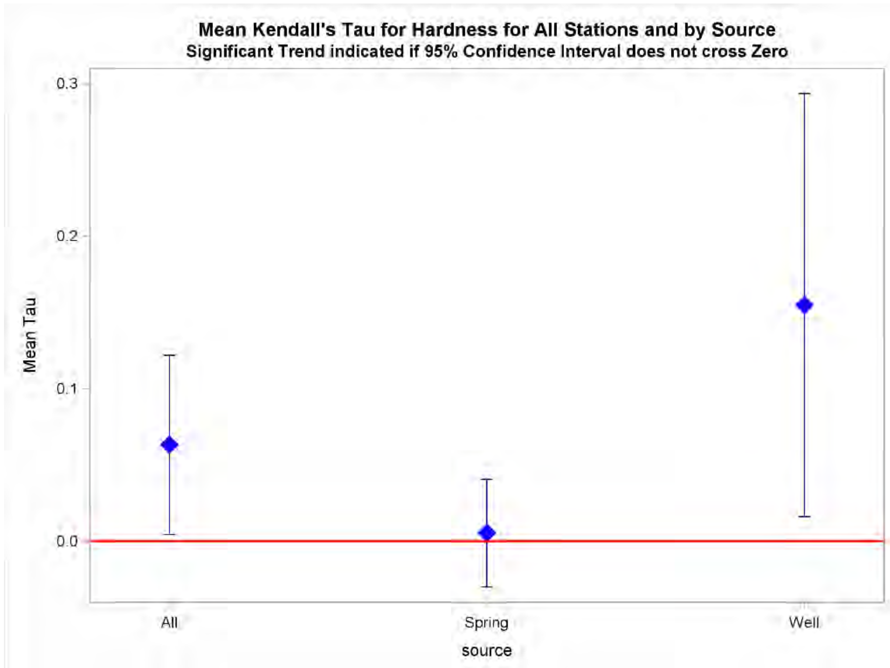


Figure 15. Trend test for total hardness by physiographic region.

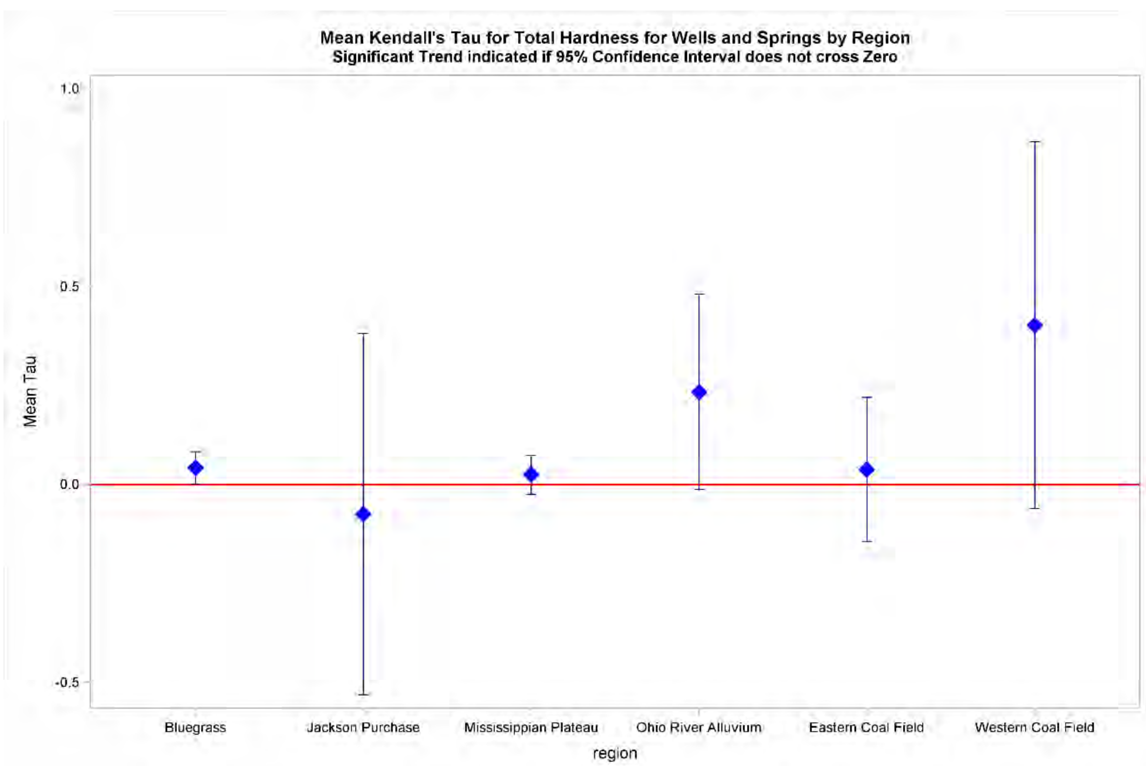
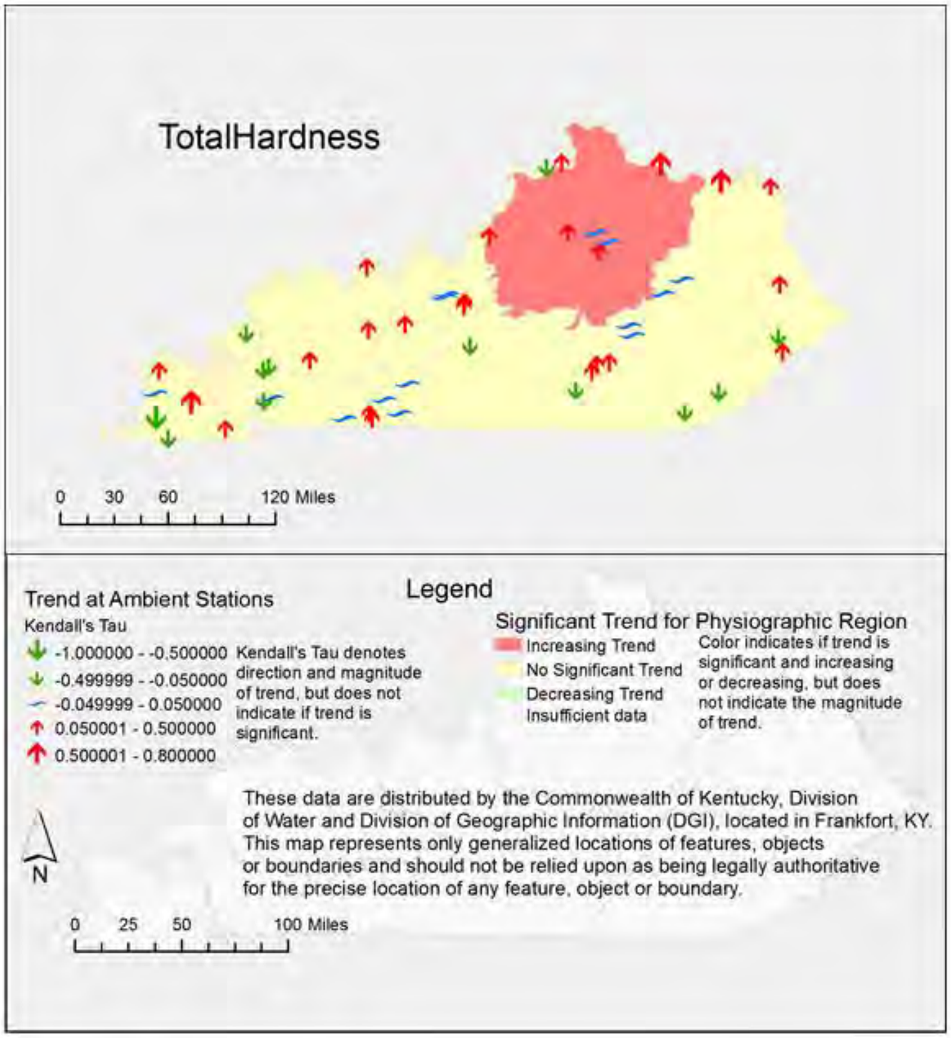


Figure 16**. Map for total hardness for monitoring stations and physiographic regions.**



NUTRIENTS

The sampling time period for most nutrients began in 1995. Total Kjeldahl Nitrogen (TKN) was collected from May of 1995 through October of 2008, and therefore does not represent the entire study period. Total Nitrogen was calculated from TKN, nitrate, and nitrite, and consequently reflects the more limited time span of TKN. Orthophosphate is reported. Sample size for total phosphorus did not meet study criteria.

Orthophosphate had a significant downward trend statewide, for springs, and for wells. When examined by physiographic region, no trend was found for the Bluegrass or Western Coal Field. The Western Coal Field have fewer monitoring stations, and therefore less power to detect trends, as marked by the longer whiskers in Figure 17. The limestone in the Bluegrass is high in phosphorus, having a marked effect on concentrations of orthophosphate in that physiographic region (Cressman, 1973).

Nitrites decreased statewide, with this trend being driven by springs. This is reflected in the spring-dominated Bluegrass and Mississippian Plateau physiographic regions having significant downward trends for nitrite. The Bluegrass also had a significant downward trend for nitrates, but it was not strong enough to reflect a significant trend for springs or statewide.

Table 10. Descriptive statistics for nutrients.

Nutrients - Descriptive Statistics							
Analyte (mg/L)	% NonDetect	n	25th Pctl	Median	75th Pctl	Maximum	Std Dev
Ammonia	76.91	2291	-	-	-	6.25	0.20
Nitrate	5.50	2371	0.60	2.04	3.56	15.50	2.31
Nitrite	66.08	2354	-	-	0.03	0.43	0.02
Orthophosphate	44.27	2356	-	0.04	0.06	5.00	0.13
TKN	79.39	1378	-	-	-	5.31	0.29
Total Nitrogen	1.31	1373	0.62	1.97	3.44	15.50	2.32

Table 11. Trends for nutrients for all stations, and wells and springs separately.

Trends for Nutrients for Wells and Springs									
	All			Springs			Wells		
Analyte	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL
Ammonia	-0.068	-0.027	0.013	-0.061	-0.021	0.019	-0.131	-0.038	0.054
Nitrate	-0.075	-0.012	0.052	-0.034	0.042	0.117	-0.207	-0.096	0.015
Nitrite	-0.273	-0.208	-0.143	-0.350	-0.282	-0.214	-0.211	-0.093	0.025
Orthophosphate	-0.295	-0.239	-0.183	-0.305	-0.232	-0.159	-0.349	-0.253	-0.157
TKN	-0.060	0.000	0.060	-0.061	0.018	0.096	-0.127	-0.027	0.074
Total Nitrogen	-0.020	0.041	0.102	-0.013	0.064	0.142	-0.104	0.001	0.106

Significantly increasing trend

Significantly decreasing trend

Figure 17. Trends for nutrients for all stations, and wells and springs separately.

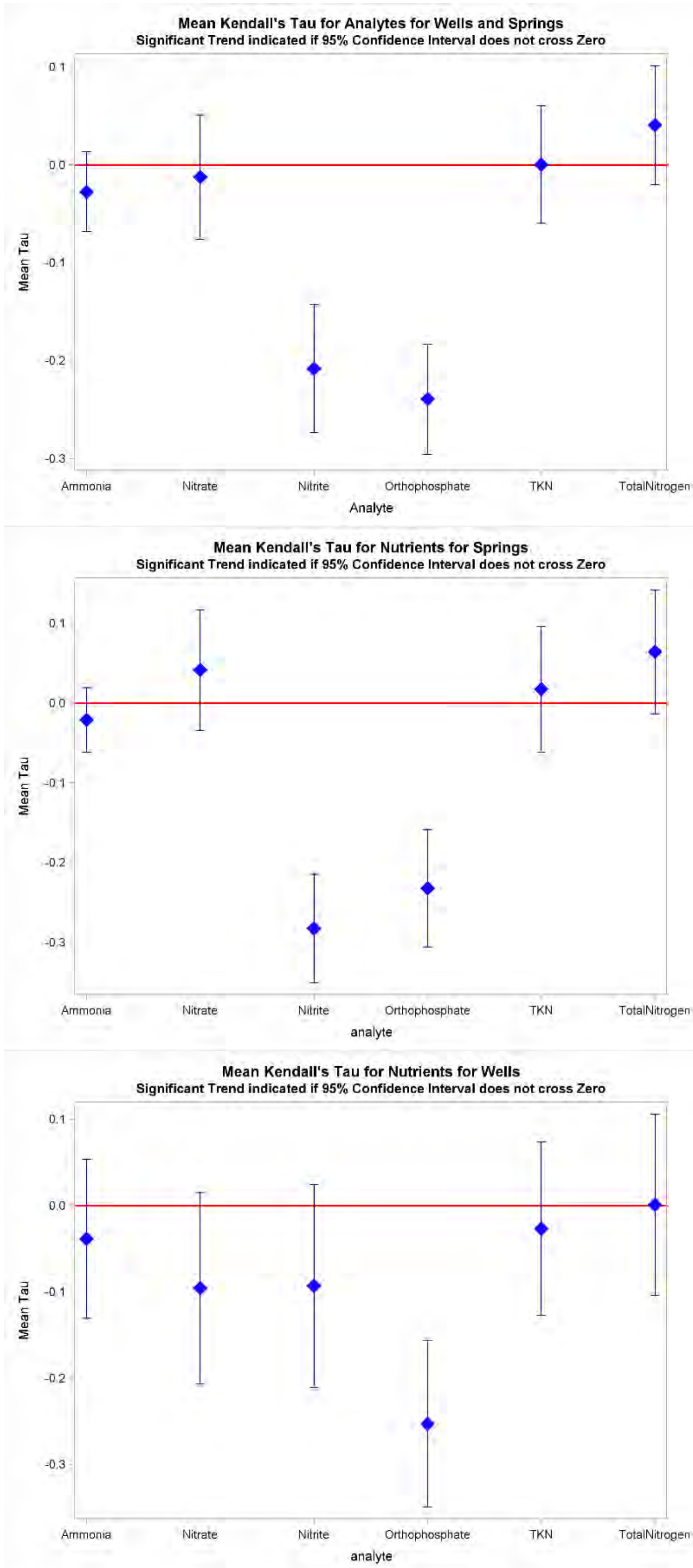


Table 12. Trends for nutrients for all stations by physiographic region.

Trends for Nutrients by Physiographic Region																		
	Bluegrass			E. Coal Field			Jackson Purchase			Mississippian Plateau			Ohio River Alluvium			W. Coal Field		
analyte	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL
Ammonia	-0.073	0.009	0.091	-0.139	0.013	0.165	-0.168	-0.025	0.118	-0.086	-0.034	0.017	-0.223	-0.048	0.127	-4.497	-0.104	4.289
Nitrate	-0.205	-0.144	-0.082	-0.297	-0.093	0.110	-0.343	-0.126	0.092	-0.011	0.076	0.163	-0.264	-0.002	0.260	-3.045	-0.239	2.567
Nitrite	-0.476	-0.256	-0.036	-0.384	-0.132	0.121	-0.439	-0.205	0.028	-0.362	-0.268	-0.174	-0.316	-0.037	0.243	-2.070	-0.115	1.841
Orthophosphate	-0.072	0.035	0.142	-0.432	-0.258	-0.083	-0.489	-0.412	-0.335	-0.342	-0.260	-0.178	-0.406	-0.260	-0.114	-0.236	0.205	0.645
TKN	0.025	0.151	0.277	-0.147	-0.010	0.127	-0.275	0.039	0.354	-0.124	-0.026	0.073	-0.254	-0.093	0.069	-0.111	0.129	0.369
Total Nitrogen	-0.129	-0.005	0.119	-0.231	-0.015	0.202	-0.213	-0.007	0.198	-0.044	0.052	0.149	-0.208	0.094	0.395	-0.350	0.141	0.633

Significantly increasing trend
Significantly decreasing trend

Figure 18. Trends for nutrients for all stations by physiographic region.

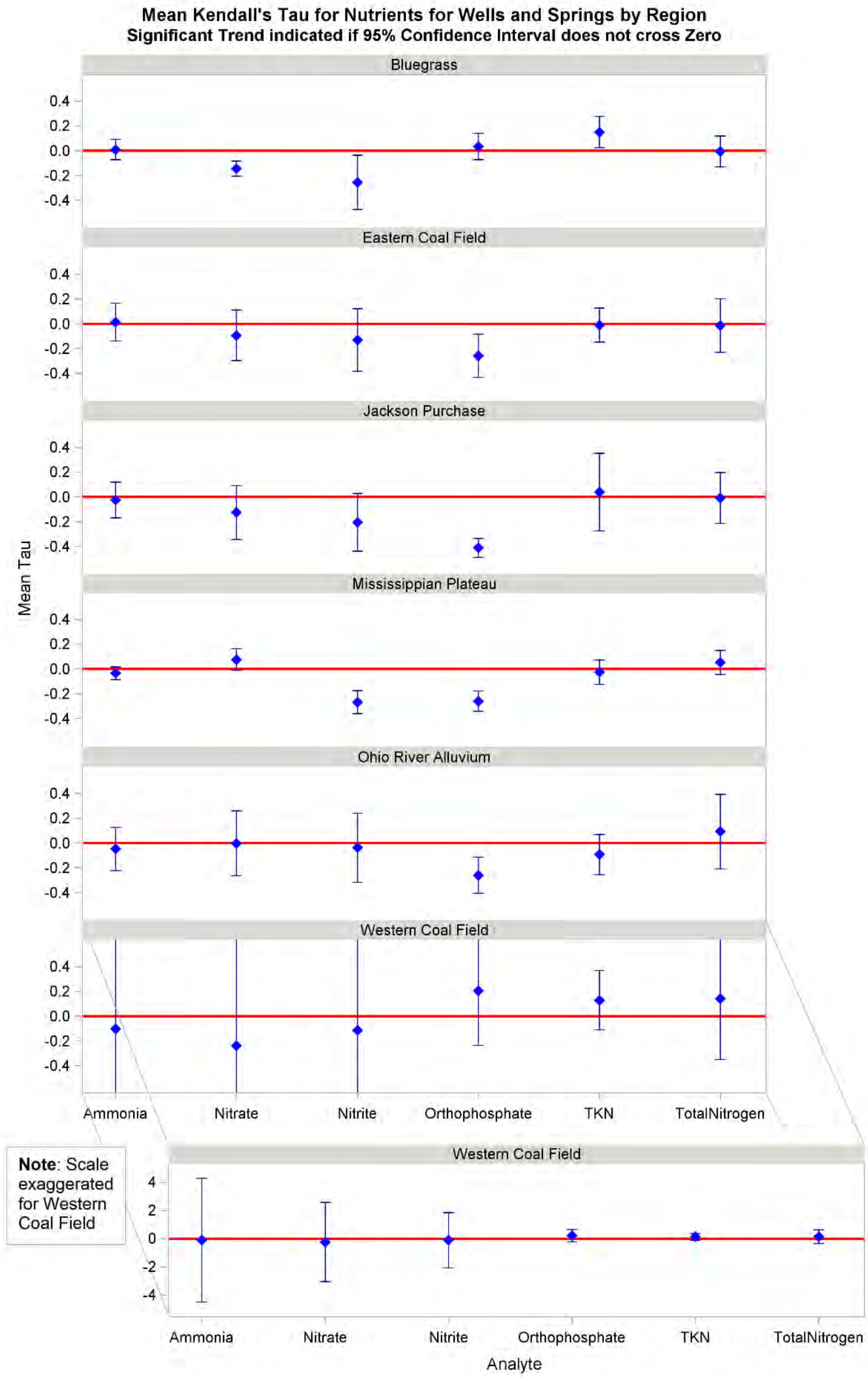
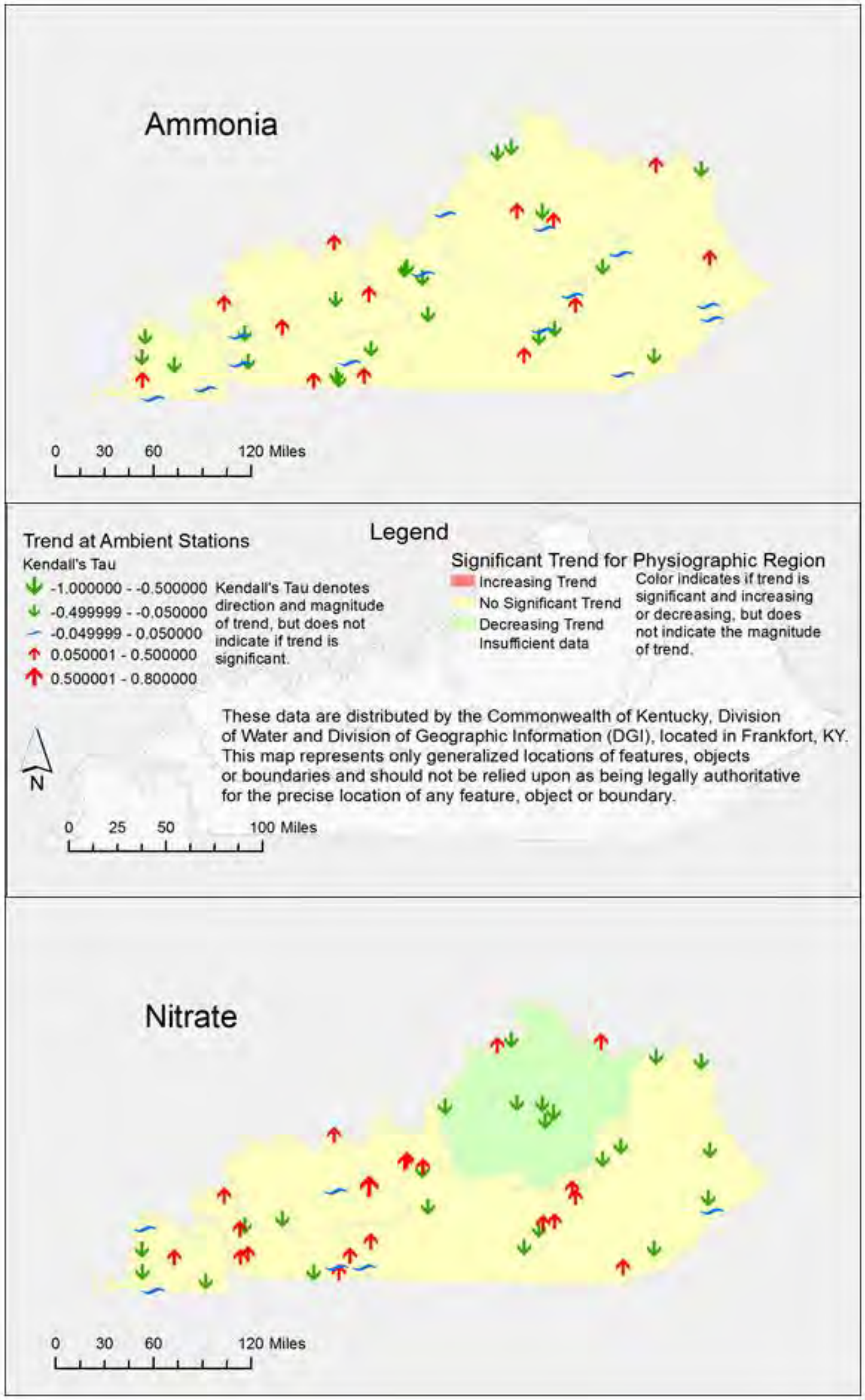
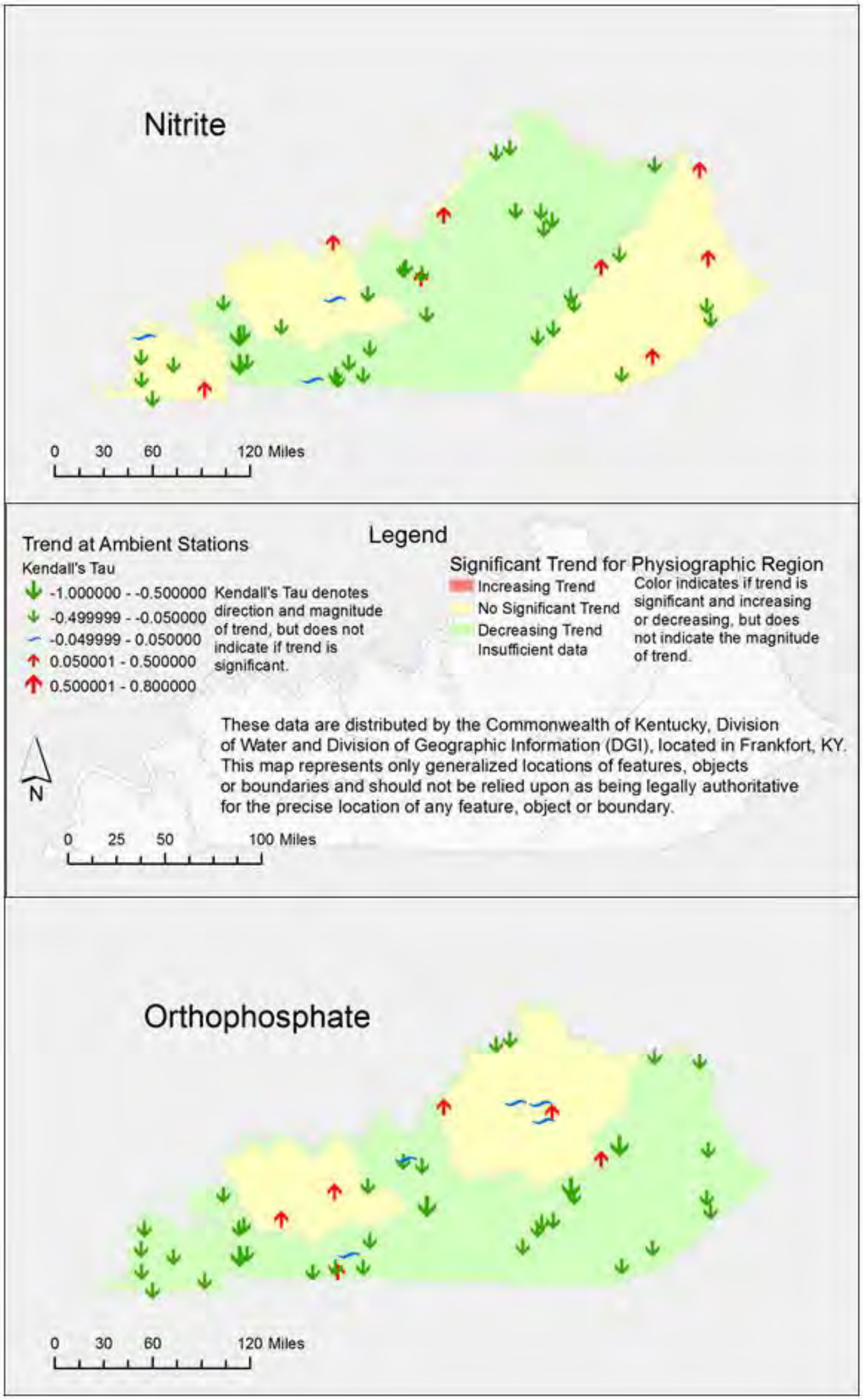
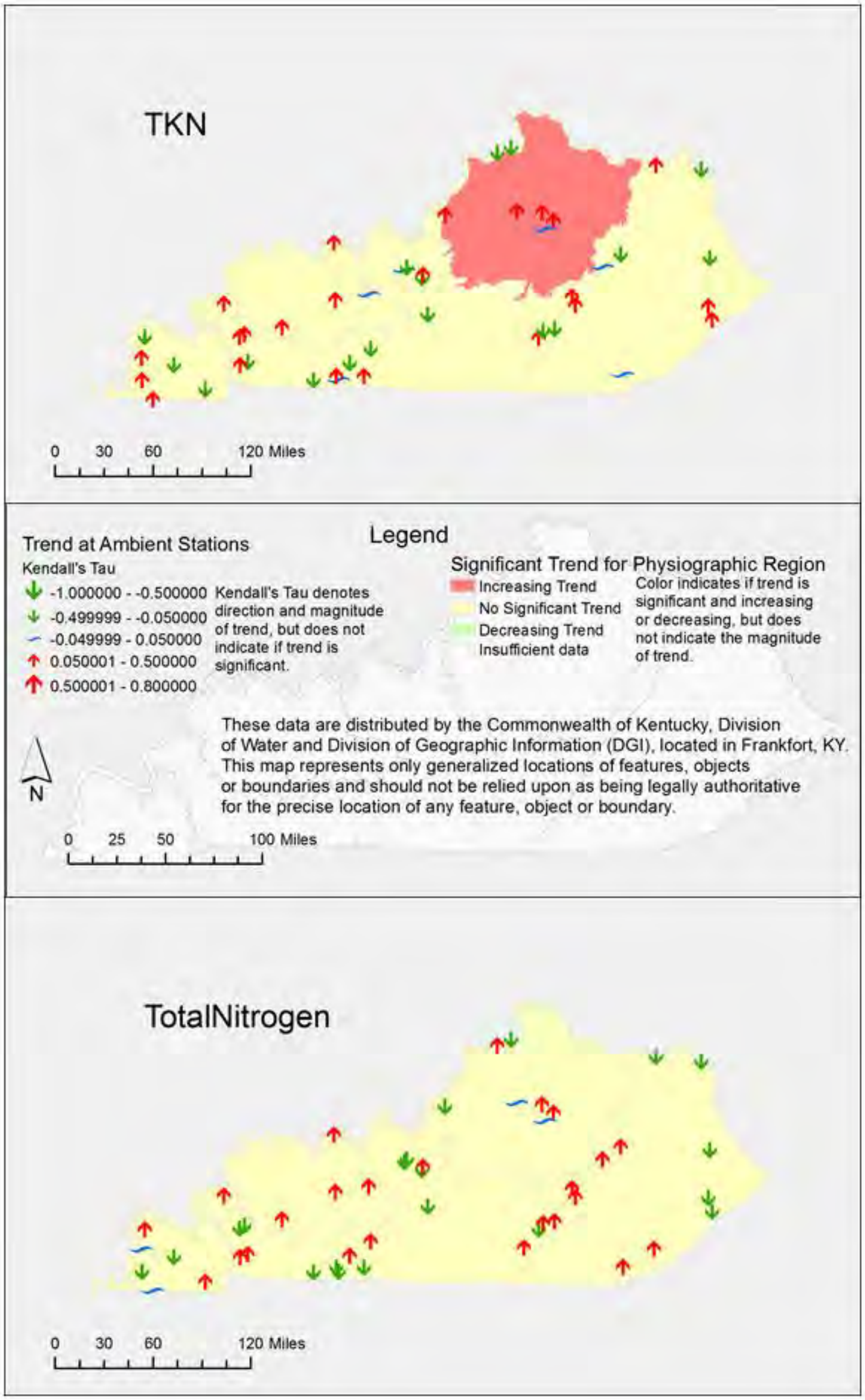


Figure 19. Maps of trends for nutrients for monitoring stations and physiographic regions.




Nitrite
0 30 60 120 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles
Orthophosphate
0 30 60 120 Miles


TKN
0 30 60 120 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles
TotalNitrogen
0 30 60 120 Miles

Major Inorganic Ions

Gaps of greater than one year were present in sampling data prior to 1995; therefore data prior to 1995 were excluded. Chlorides significantly increased for springs and in the Bluegrass. Fluorides showed no trend statewide or by source, but did show a decrease in the Jackson Purchase. While sulfates decreased statewide and for springs. The Mississippian Plateau and Jackson Purchase showed significant decreases in sulfates.

Table 13. Descriptive statistics for major inorganic ions.

Major Inorganic Ions							
Analyte (mg/L)	% NonDetect	n	25th Pctl	Median	75th Pctl	Maximum	Std Dev
Chloride	0.22	1813	4.19	8.04	17.70	1140.00	40.29
Fluoride	4.40	1794	0.08	0.13	0.20	4.19	0.19
Sulfate	44.00	1812	5.60	9.60	33.05	771.00	51.23

Table 14. Trends for major inorganic ions for all stations, and wells and springs separately.

Trends for Inorganic Ions for Wells and Springs									
	All			Springs			Wells		
Analyte (mg/L)	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL
Chloride	-0.051	0.036	0.123	0.033	0.114	0.195	-0.268	-0.086	0.096
Fluoride	-0.125	-0.052	0.021	-0.038	0.013	0.063	-0.325	-0.154	0.016
Sulfate	-0.176	-0.091	-0.006	-0.213	-0.144	-0.075	-0.206	-0.010	0.185

Significantly increasing trend

Significantly decreasing trend

Figure 20. Trends for major inorganic ions for all stations, and wells and springs separately.

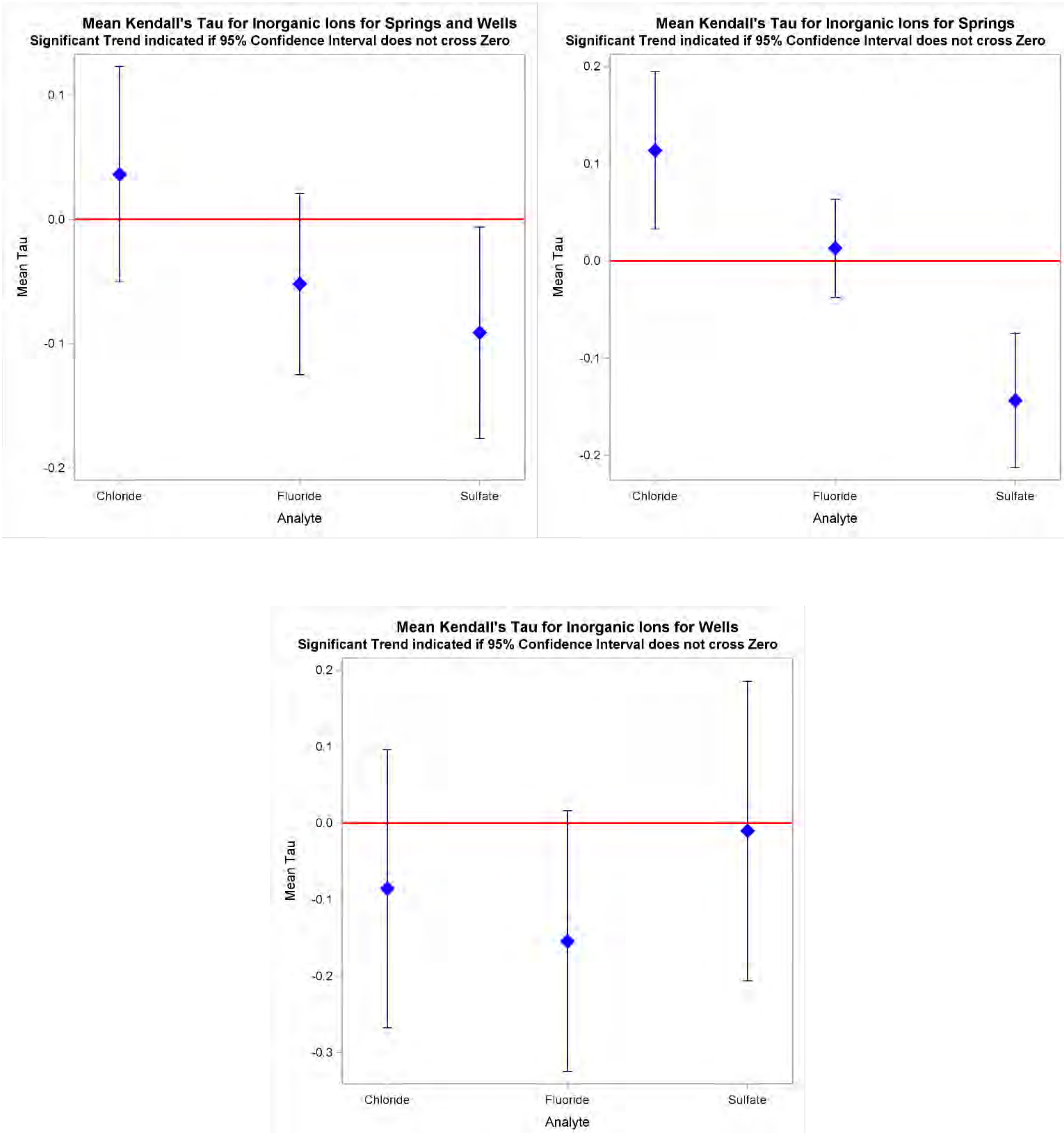


Table 15. Kendall's tau for major inorganic ions by physiographic region.

Trends for Major Inorganic Ions by Physiographic Region																		
	Bluegrass			E. Coal Field			Jackson Purchase			Mississippian Plateau			Ohio River Alluvium			W. Coal Field		
analyte	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL
Chloride	0.179	0.296	0.413	-0.420	-0.089	0.242	-0.750	-0.288	0.174	-0.028	0.070	0.168	-0.212	0.139	0.491	-1.520	-0.209	1.102
Fluoride	-0.045	0.115	0.275	-0.382	-0.065	0.253	-0.920	-0.493	-0.065	-0.040	0.011	0.063	-0.480	-0.122	0.237	-1.824	-0.062	1.701
Sulfate	-0.200	-0.058	0.085	-0.520	-0.158	0.204	-0.596	-0.359	-0.121	-0.234	-0.148	-0.061	-0.529	-0.170	0.189	-7.392	-0.236	6.921

Significantly increasing trend

Significantly decreasing trend

Figure 21. Trends for major inorganic ions by physiographic region.

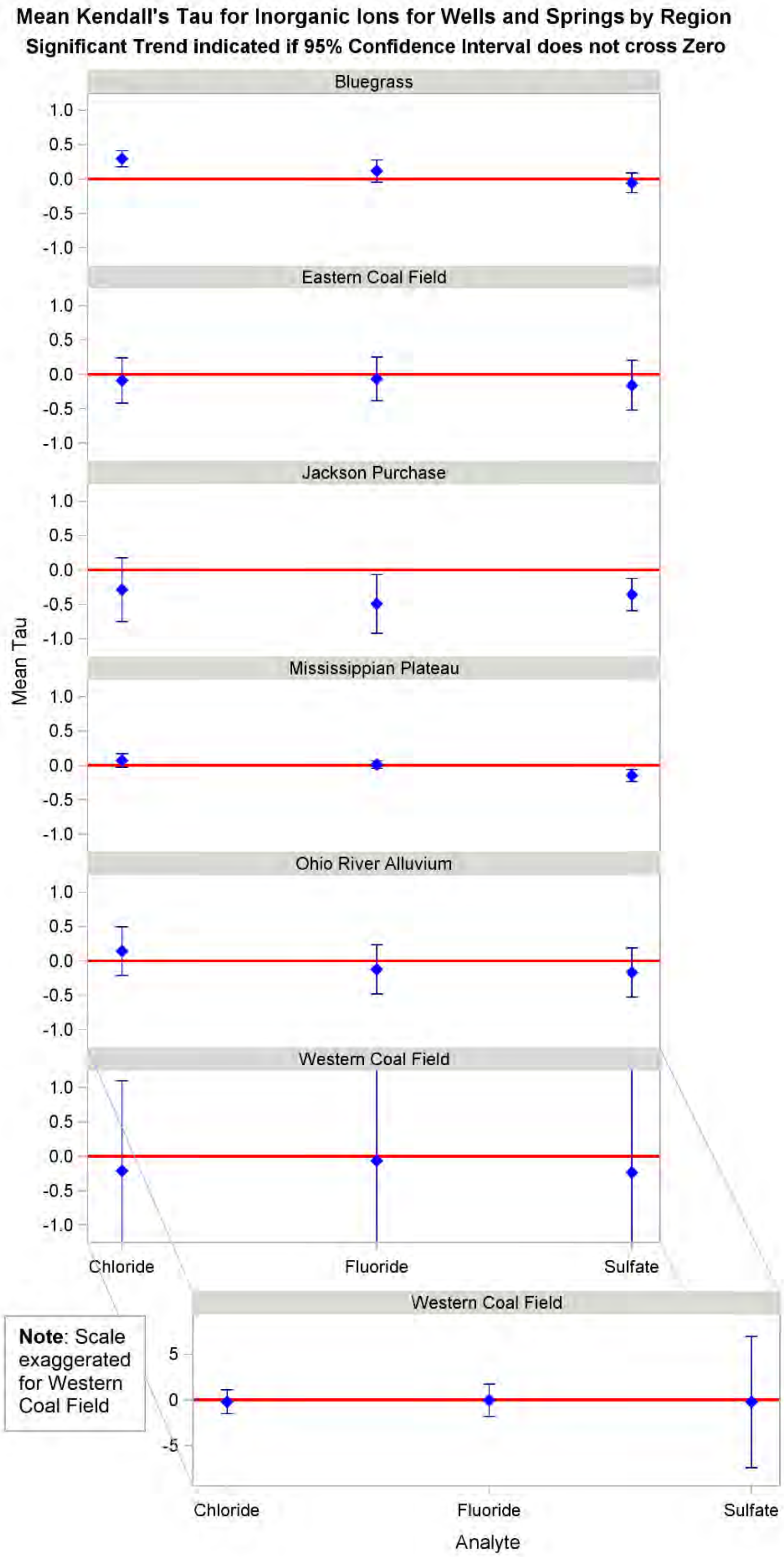
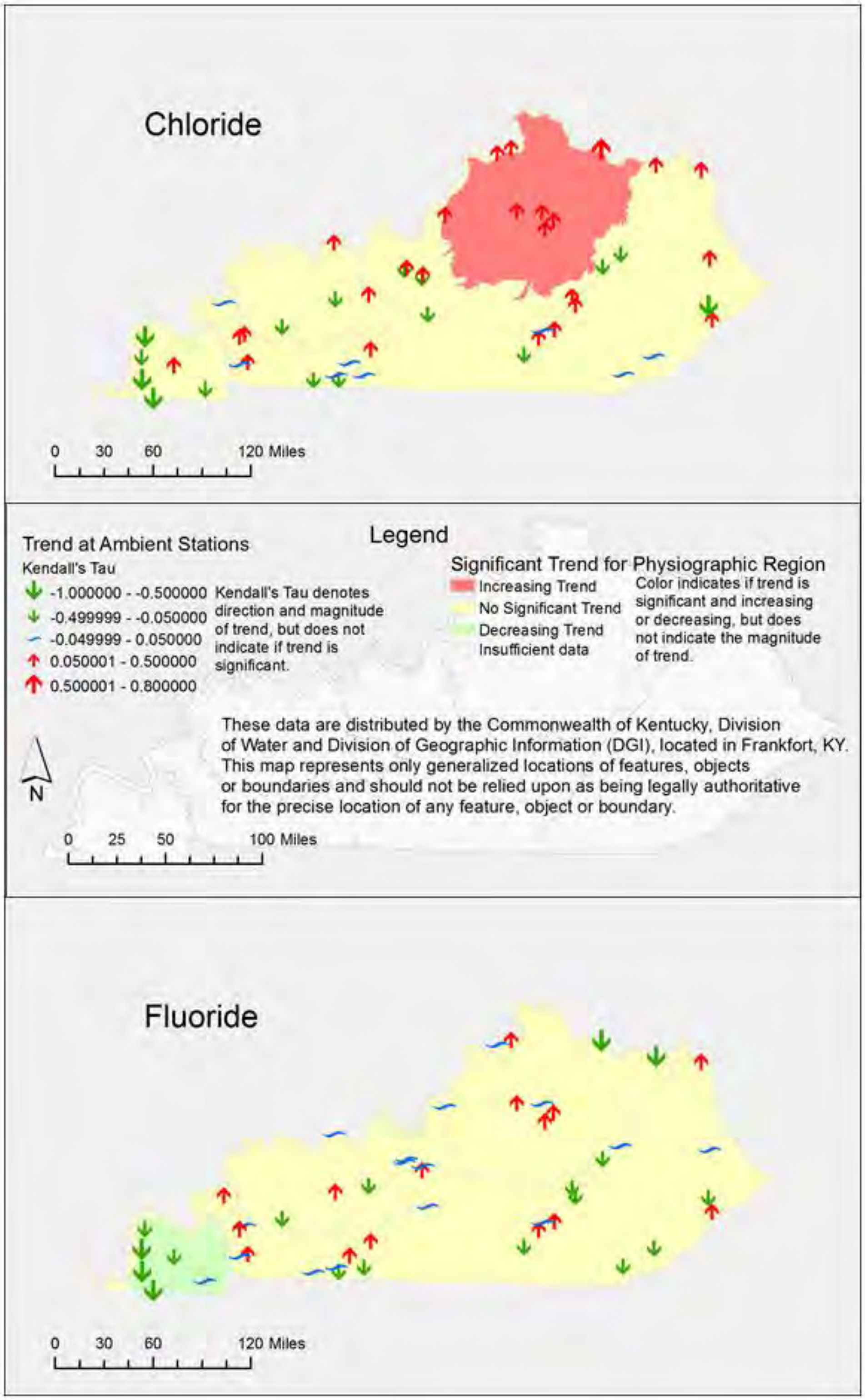
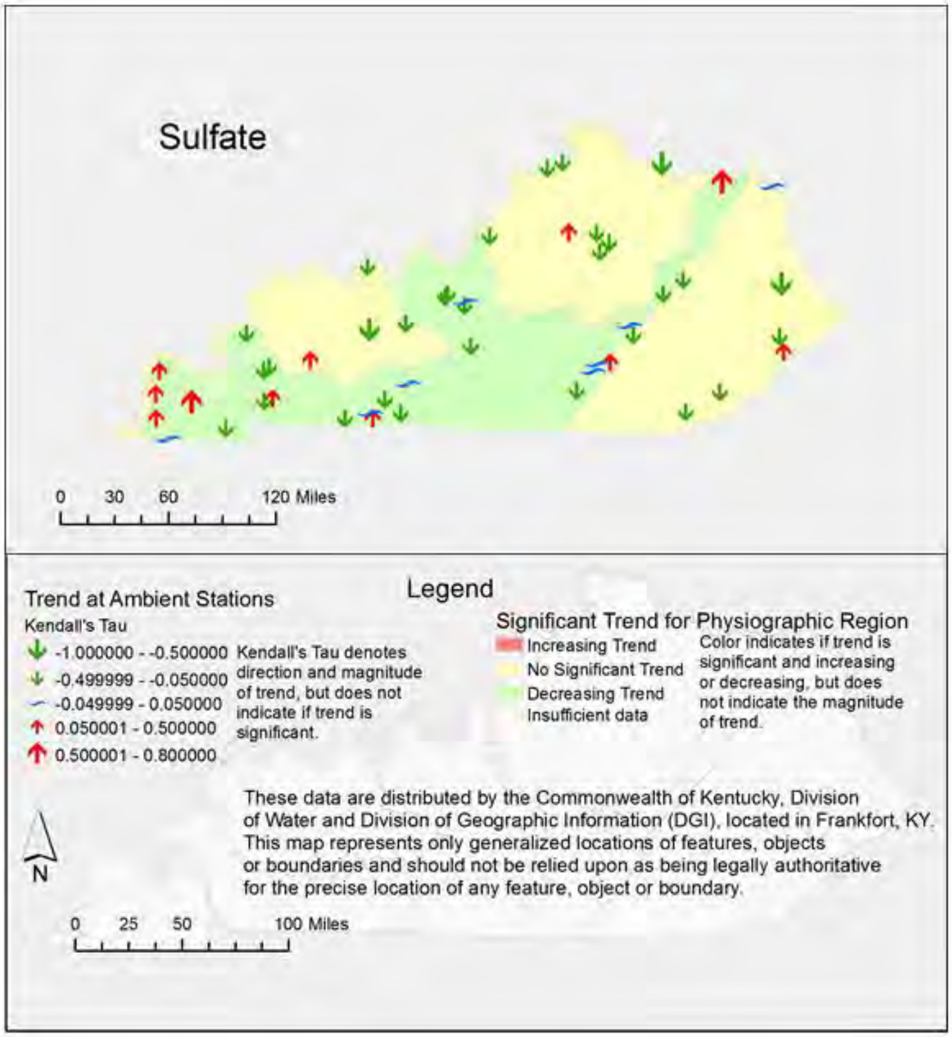


Figure 22. Trends for major inorganic ions for stations and physiographic regions.




Sulfate
0 30 60 120 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles

Metals

Samples prior to 1998 were excluded because of data scarcity (1 or 2 samples a year/analyte). Descriptive statistics are shown in Table 16, and the results of trend tests for individual analytes in Table 17. Figure 23 illustrates the data in Table 17.

Significant increasing trends were found statewide for 7 metal analytes: arsenic, barium, chromium, lead, magnesium, nickel and sodium. Only 2 metals showed decreasing trends statewide: iron and silver. The trends for all springs mirrored the statewide trends, indicating the influence of that dataset. Increasing trends for all wells were observed for 5 metals: arsenic, barium, magnesium, potassium and selenium. The only decreasing trend for all wells was seen for silver.

Regional trends for metals closely resemble those observed in the statewide analyses. The karst-dominated Bluegrass and Mississippian Plateau regions, with closer connections to surface influences, had more significant trends than the other regions. The granular aquifers of the Ohio River Alluvium, Western Coal Field and Jackson Purchase regions displayed limited trends. The Eastern Coal Field showed no trends.

Table 16. Descriptive statistics for metals.

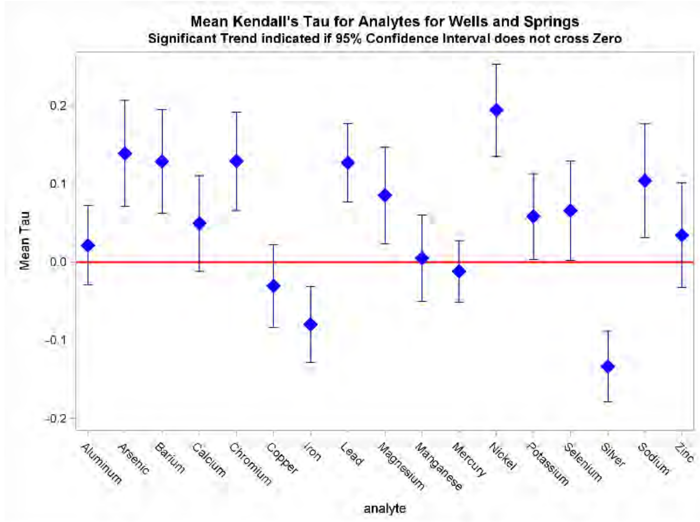
Metals --Descriptive Statistics (mg/L)							
Analyte	% NonDetect	n	25th Pctl	Median	75th Pctl	Max	Std Dev
Aluminum	15.11	2091	0.017	0.063	0.172	16.500	0.816
Arsenic	60.90	2097	-	-	0.002	0.021	0.001
Barium	0.10	2091	0.027	0.037	0.050	0.814	0.092
Calcium	0.05	2095	40.200	71.000	87.700	166.000	33.099
Chromium	32.20	2096	-	0.001	0.001	0.037	0.002
Copper	34.78	2093	-	0.001	0.002	0.591	0.021
Iron	15.36	2097	0.032	0.068	0.180	21.700	0.967
Lead	68.68	2101	-	-	0.002	0.044	0.003
Magnesium	0.05	2095	4.540	7.000	9.450	102.000	8.476
Manganese	6.55	2093	0.004	0.012	0.031	1.560	0.102
Mercury	97.22	2087	-	-	-	0.004	0.000
Nickel	34.30	2093	-	0.001	0.002	0.065	0.005
Potassium	0.43	2095	1.140	1.700	2.320	51.100	1.725
Selenium	70.38	2093	-	-	0.002	0.038	0.002
Silver	97.98	2083	-	-	-	40.000	0.876
Sodium	0.05	2095	2.770	6.250	16.900	542.000	34.117
Zinc	35.74	2093	-	0.007	0.015	6.220	0.179

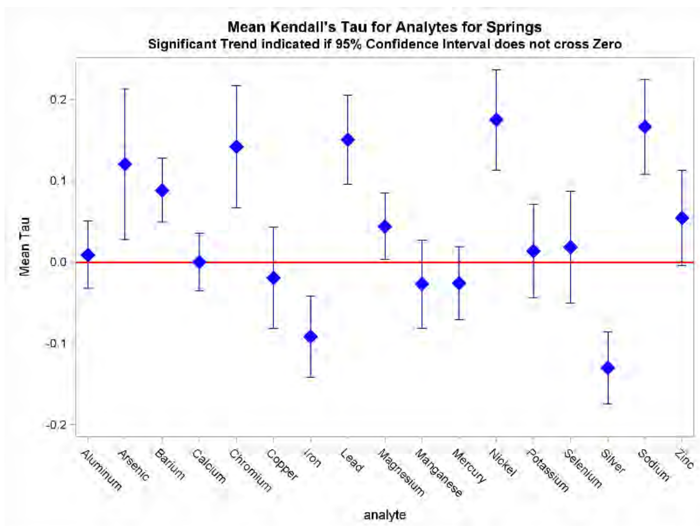
Table 17. Trends for metals for all stations, and wells and springs separately.

Trends for Metals for Wells and Springs									
	All			Springs			Wells		
Analyte	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL
Aluminum	-0.030	0.021	0.072	-0.032	0.009	0.051	-0.080	0.041	0.162
Arsenic	0.071	0.139	0.207	0.028	0.121	0.213	0.070	0.172	0.274
Barium	0.063	0.129	0.195	0.049	0.088	0.128	0.029	0.192	0.356
Calcium	-0.012	0.049	0.111	-0.035	0.000	0.036	-0.023	0.127	0.277
Chromium	0.066	0.129	0.192	0.067	0.142	0.217	-0.025	0.103	0.231
Copper	-0.084	-0.030	0.023	-0.082	-0.019	0.043	-0.151	-0.048	0.055
Iron	-0.128	-0.080	-0.031	-0.142	-0.092	-0.041	-0.165	-0.061	0.044
Lead	0.077	0.127	0.177	0.096	0.151	0.205	-0.010	0.091	0.191
Magnesium	0.024	0.085	0.147	0.003	0.044	0.085	0.002	0.150	0.299
Manganese	-0.050	0.005	0.060	-0.081	-0.027	0.027	-0.062	0.055	0.173
Mercury	-0.051	-0.012	0.027	-0.070	-0.026	0.019	-0.068	0.029	0.126
Nickel	0.135	0.194	0.253	0.113	0.175	0.237	-0.006	0.124	0.254
Potassium	0.003	0.058	0.113	-0.043	0.014	0.071	0.020	0.129	0.238
Selenium	0.002	0.066	0.130	-0.050	0.019	0.088	0.018	0.145	0.271
Silver	-0.179	-0.134	-0.089	-0.174	-0.130	-0.086	-0.271	-0.142	-0.013
Sodium	0.031	0.104	0.177	0.108	0.166	0.225	-0.158	0.005	0.168
Zinc	-0.032	0.034	0.101	-0.004	0.054	0.113	-0.156	-0.001	0.154

Significantly increasing trend
Significantly decreasing trend

Figure 23. Trends for metals for all stations, and wells and springs separately.





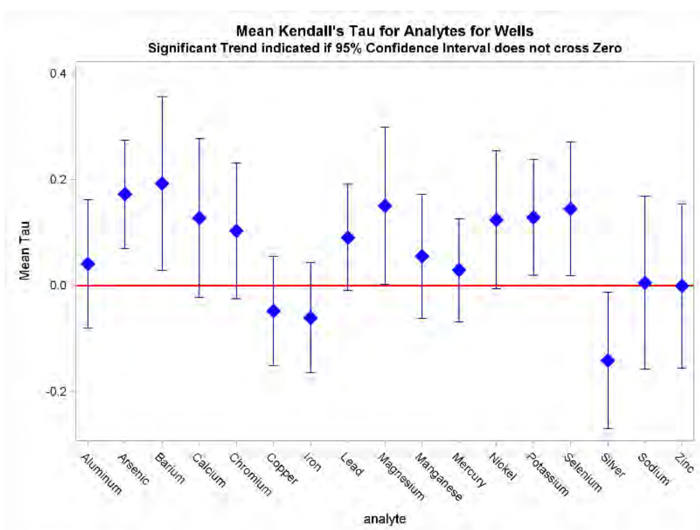


Table 18. Trends for metals for all stations by physiographic region.

Kendall's Tau by Physiographic Region																		
	Bluegrass			E. Coal Field			Jackson Purchase			Mississippian Plateau			Ohio River Alluvium			W. Coal Field		
Analyte	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL	LCL	Kendall's Tau	UCL
Aluminum	-0.035	0.032	0.099	-0.197	0.128	0.453	-0.308	-0.023	0.262	-0.030	0.033	0.097	-0.206	-0.069	0.068	-0.517	-0.051	0.416
Arsenic	-0.013	0.031	0.075	-0.240	0.005	0.249	-1.017	0.126	1.269	0.028	0.129	0.229	-0.050	0.189	0.427	-0.698	0.250	1.198
Barium	-0.011	0.081	0.173	-0.393	-0.109	0.175	-0.273	0.222	0.717	0.062	0.106	0.149	0.069	0.308	0.546	-2.533	0.380	3.292
Calcium	-0.010	0.029	0.068	-0.160	0.019	0.198	-0.575	-0.123	0.330	-0.025	0.023	0.071	-0.091	0.214	0.518	-0.543	0.364	1.271
Chromium	0.058	0.270	0.483	-0.300	0.011	0.322	-0.705	0.005	0.716	0.046	0.130	0.215	-0.114	0.106	0.327	.	0.119	.
Copper	-0.163	0.023	0.208	-0.340	-0.040	0.259	-0.410	-0.042	0.326	-0.112	-0.038	0.036	-0.138	-0.042	0.055	-0.350	0.030	0.410
Iron	-0.132	-0.026	0.080	-0.310	-0.049	0.213	-0.414	-0.066	0.283	-0.160	-0.102	-0.044	-0.288	-0.103	0.081	-0.301	0.037	0.376
Lead	0.122	0.180	0.238	-0.250	-0.019	0.211	-0.322	0.015	0.352	0.110	0.172	0.233	-0.073	0.099	0.271	-1.041	0.176	1.393
Magnesium	0.033	0.110	0.187	-0.113	0.065	0.243	-0.437	-0.019	0.398	-0.009	0.048	0.104	-0.137	0.201	0.539	0.193	0.392	0.591
Manganese	-0.215	-0.101	0.013	-0.255	-0.026	0.202	-0.326	0.049	0.425	-0.063	0.002	0.068	-0.187	0.068	0.322	-0.659	0.056	0.772
Mercury	-0.076	0.016	0.107	-0.510	0.023	0.557	.	0.031	.	-0.086	-0.032	0.022	-0.317	0.034	0.385	.	.	.
Nickel	0.090	0.220	0.351	-0.334	0.045	0.424	-0.306	-0.112	0.081	0.123	0.196	0.269	-0.104	0.079	0.262	-0.874	-0.004	0.865
Potassium	-0.168	-0.132	-0.096	-0.228	-0.046	0.137	0.022	0.206	0.389	-0.005	0.066	0.138	0.014	0.207	0.401	-2.852	0.006	2.864
Selenium	-0.254	-0.048	0.157	-0.127	0.009	0.145	0.184	0.307	0.430	-0.050	0.031	0.112	-0.173	0.146	0.466	-0.739	0.204	1.146
Silver	-0.242	-0.128	-0.014	-0.523	-0.213	0.097	-0.214	-0.007	0.200	-0.185	-0.139	-0.093	-1.061	-0.144	0.772	.	.	.
Sodium	0.206	0.317	0.429	-0.144	0.034	0.212	-0.641	-0.234	0.174	0.066	0.138	0.210	-0.124	0.191	0.506	-3.083	-0.092	2.900
Zinc	-0.087	-0.004	0.079	-0.200	0.068	0.336	-0.511	-0.068	0.376	-0.037	0.046	0.128	-0.256	0.028	0.312	-0.516	-0.119	0.277

Significantly increasing trend
Significantly decreasing trend

Figure 24. Trends for metals for all stations by physiographic region.

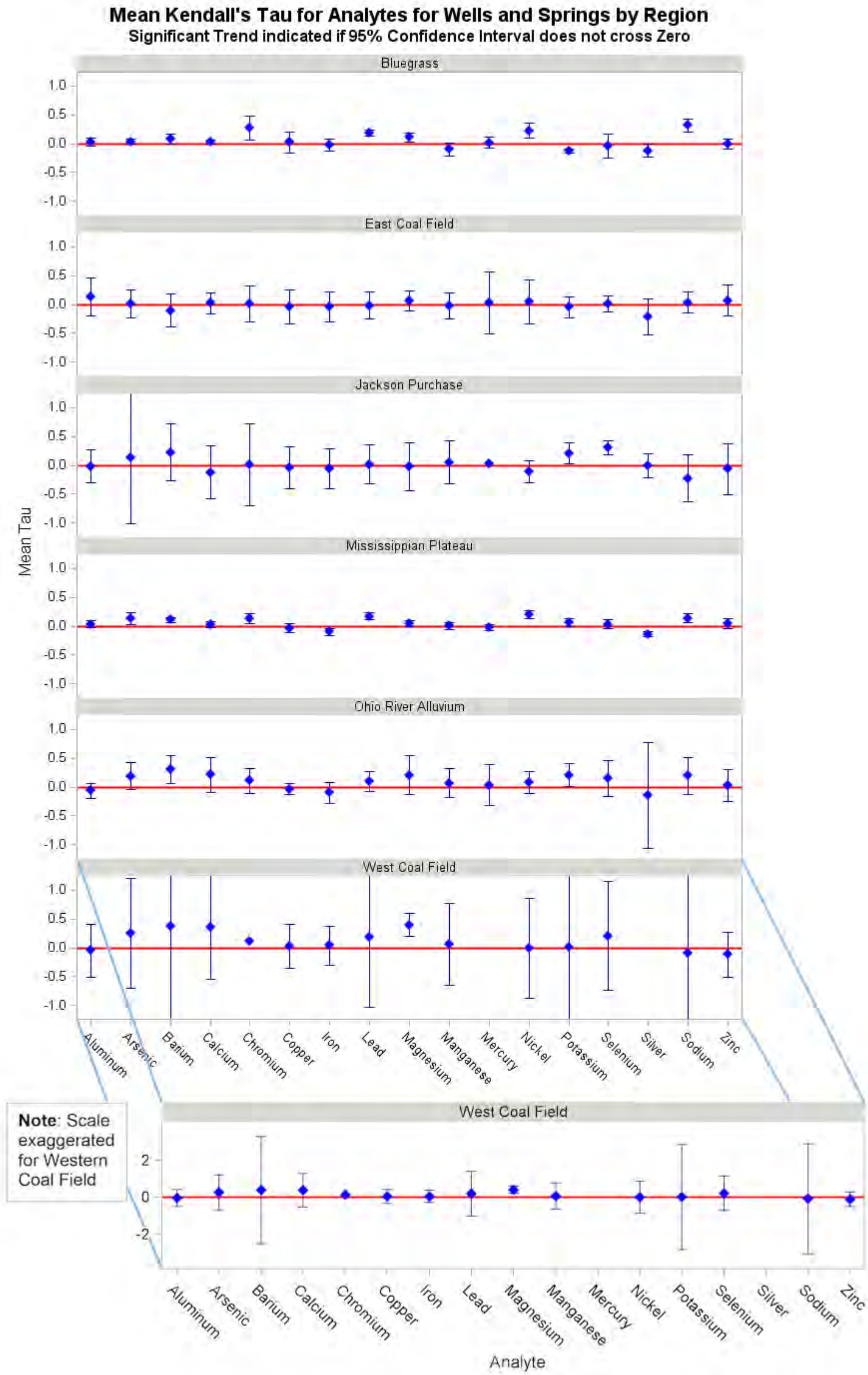
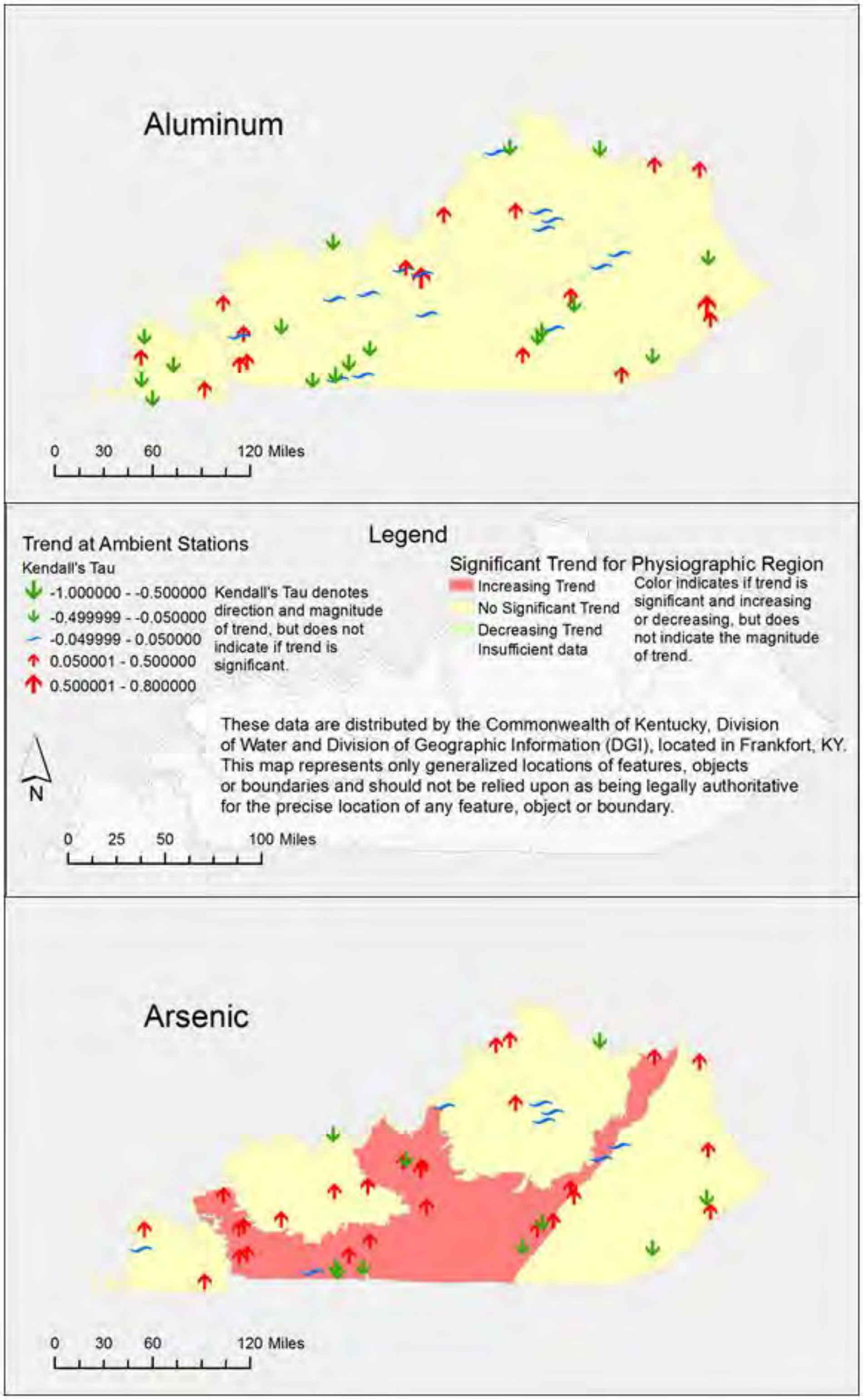
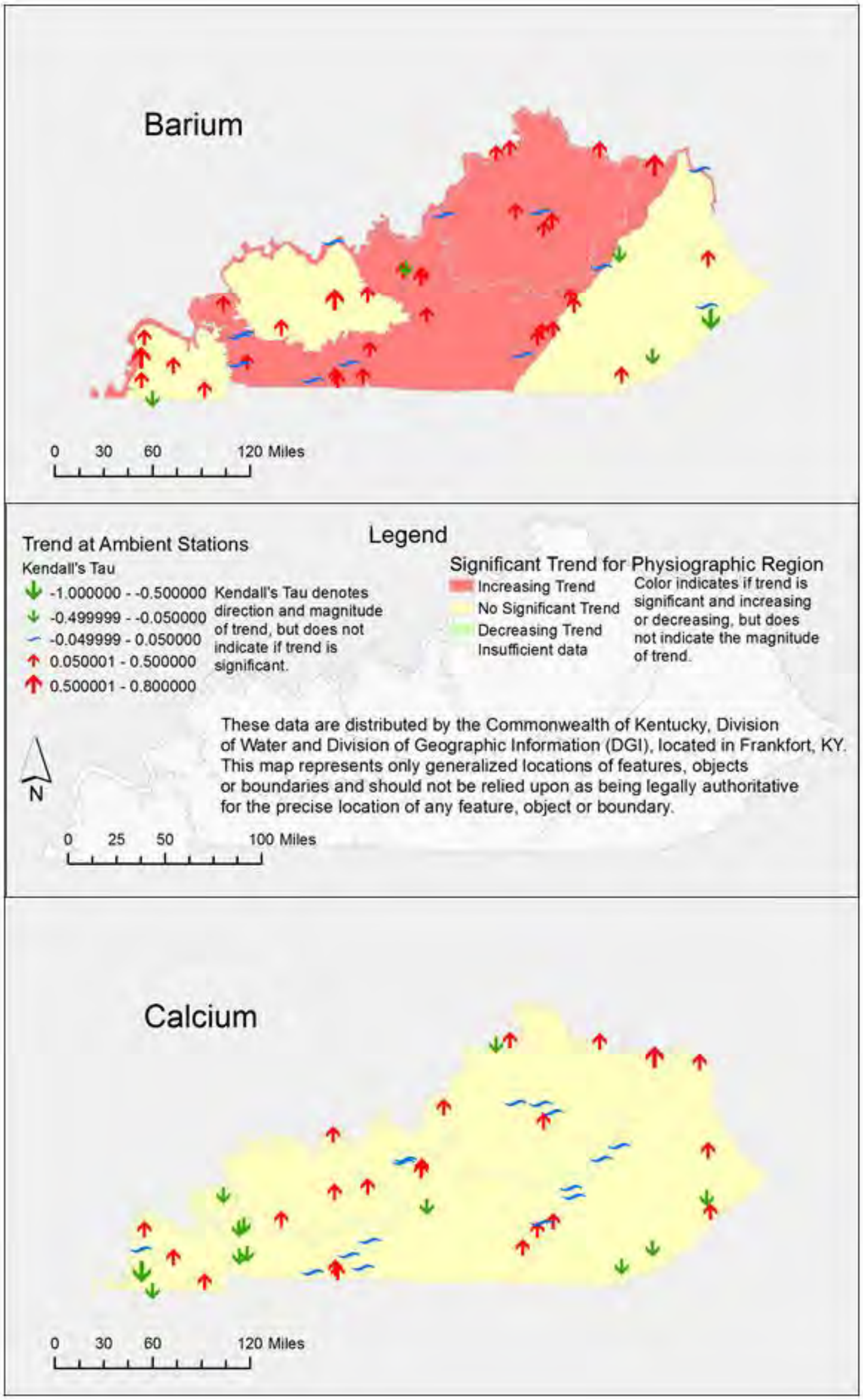
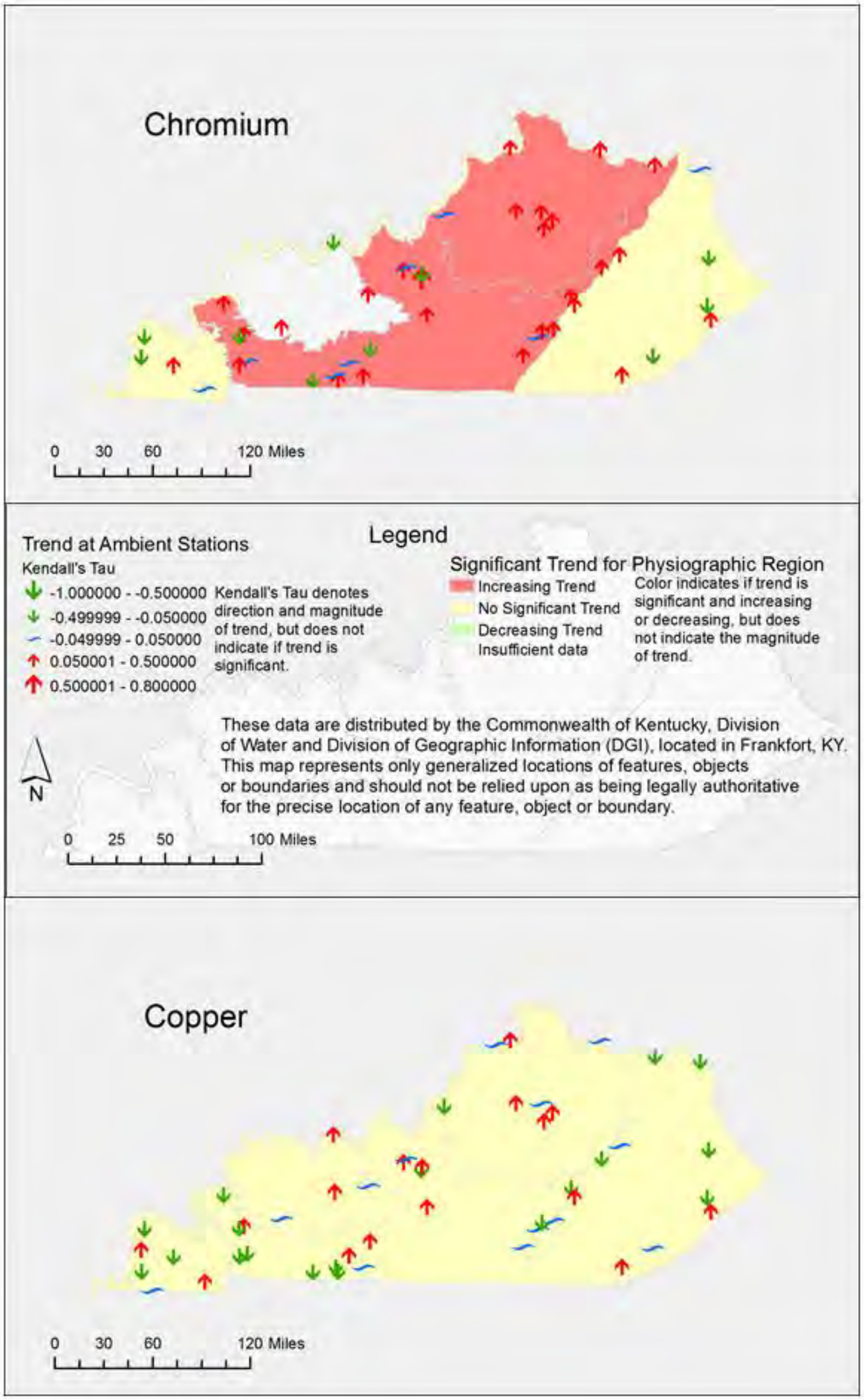
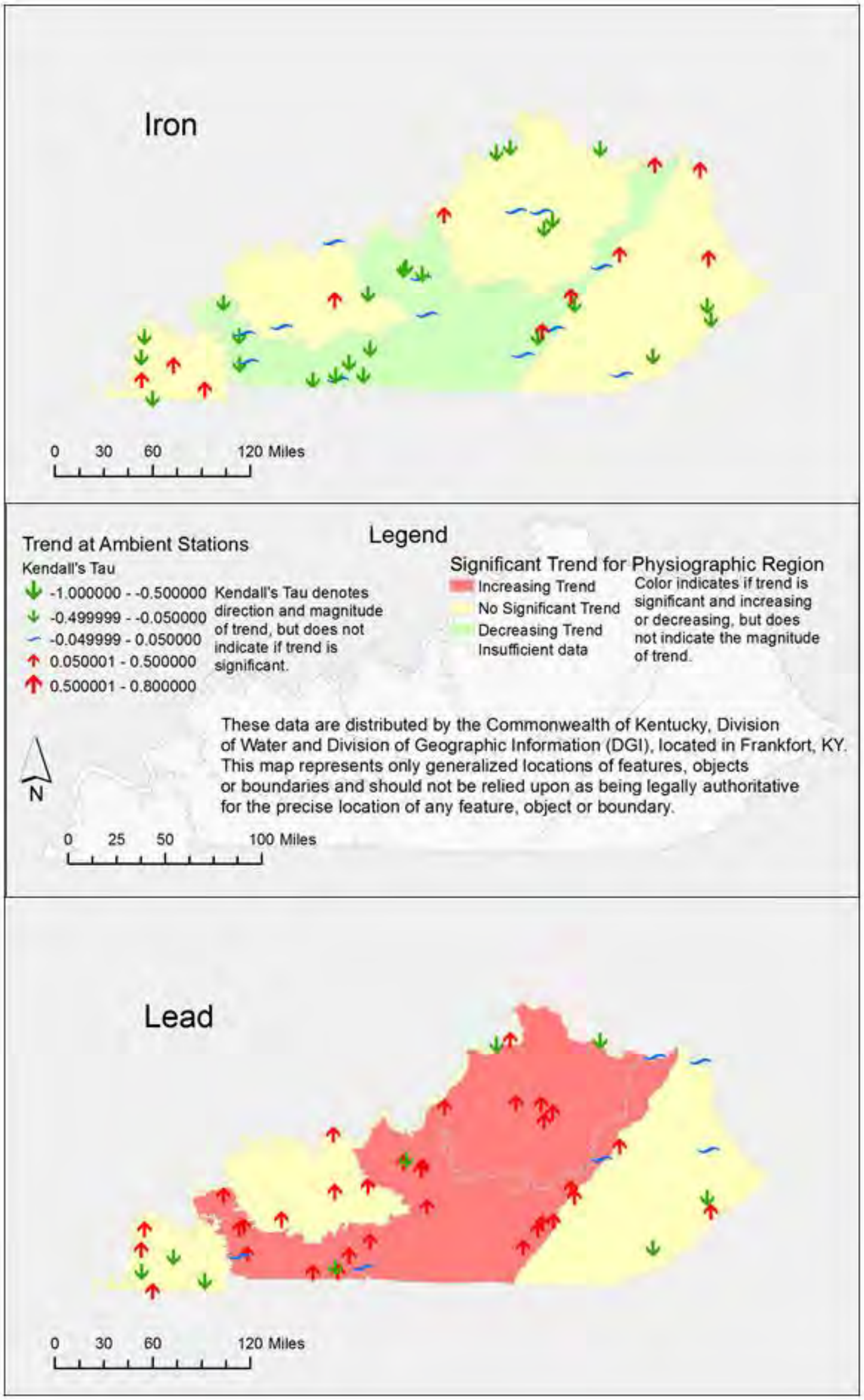


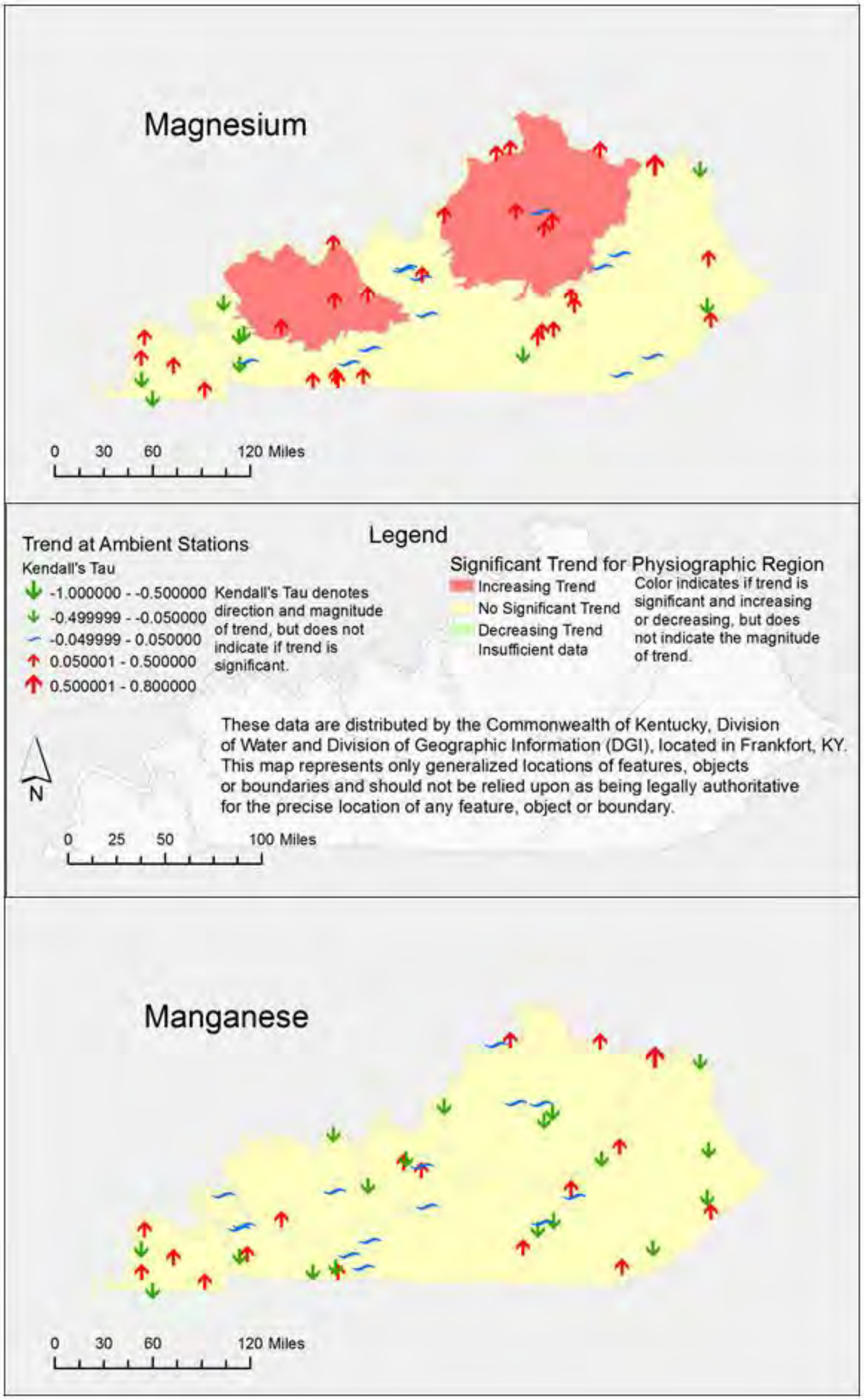
Figure 25. Maps of trends for metals for monitoring stations and physiographic regions.

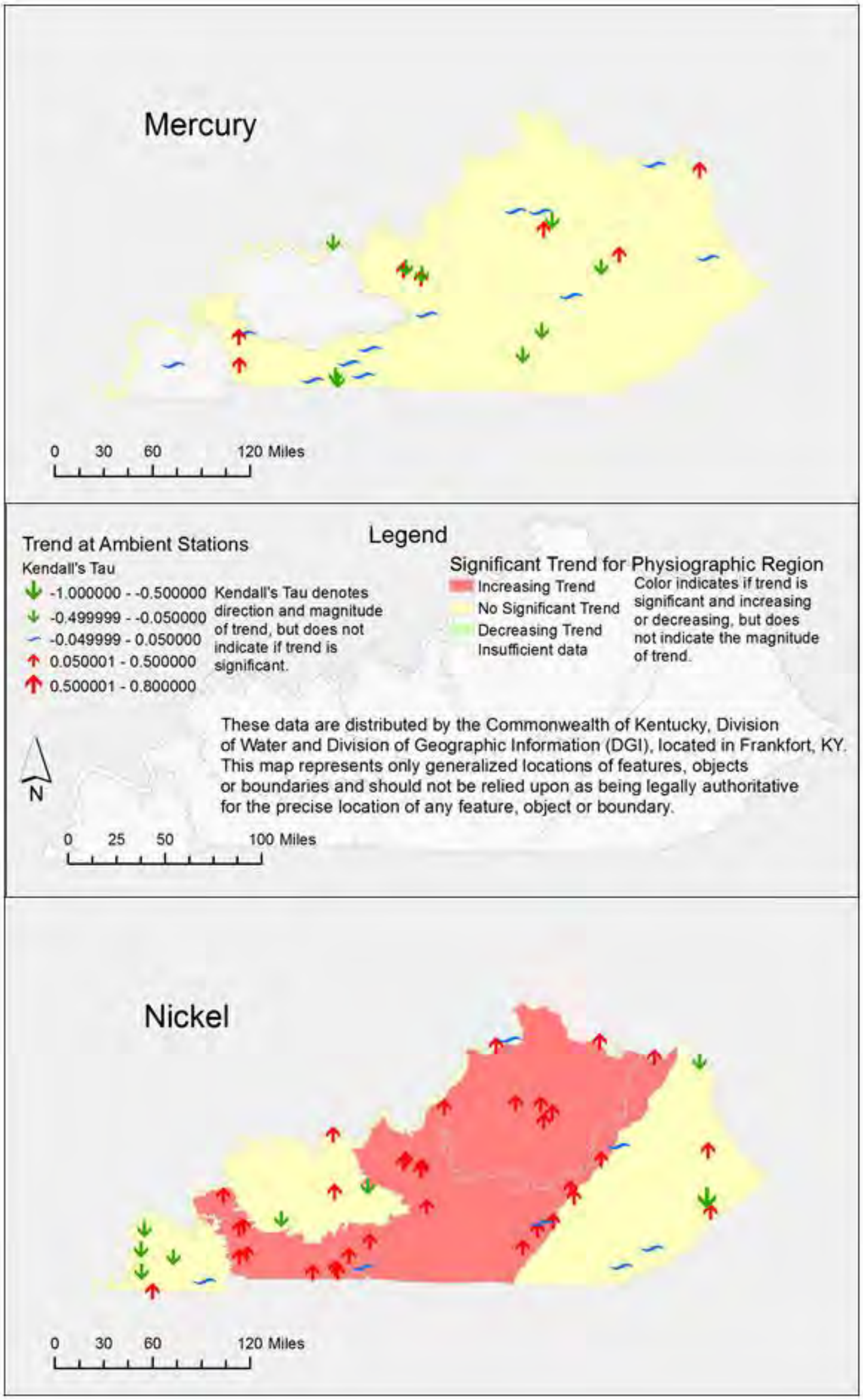


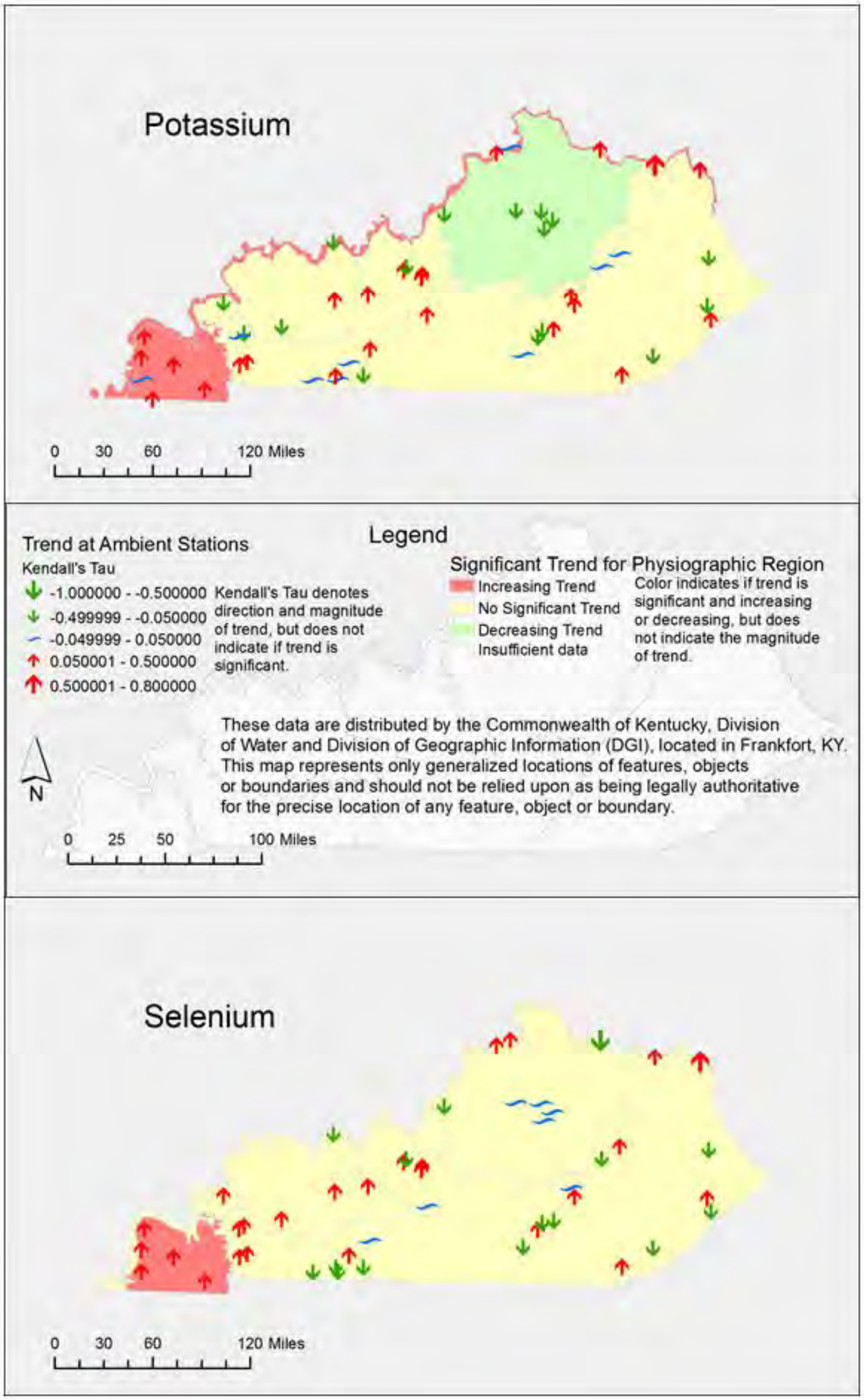

Barium
0 30 60 120 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles
Calcium
0 30 60 120 Miles

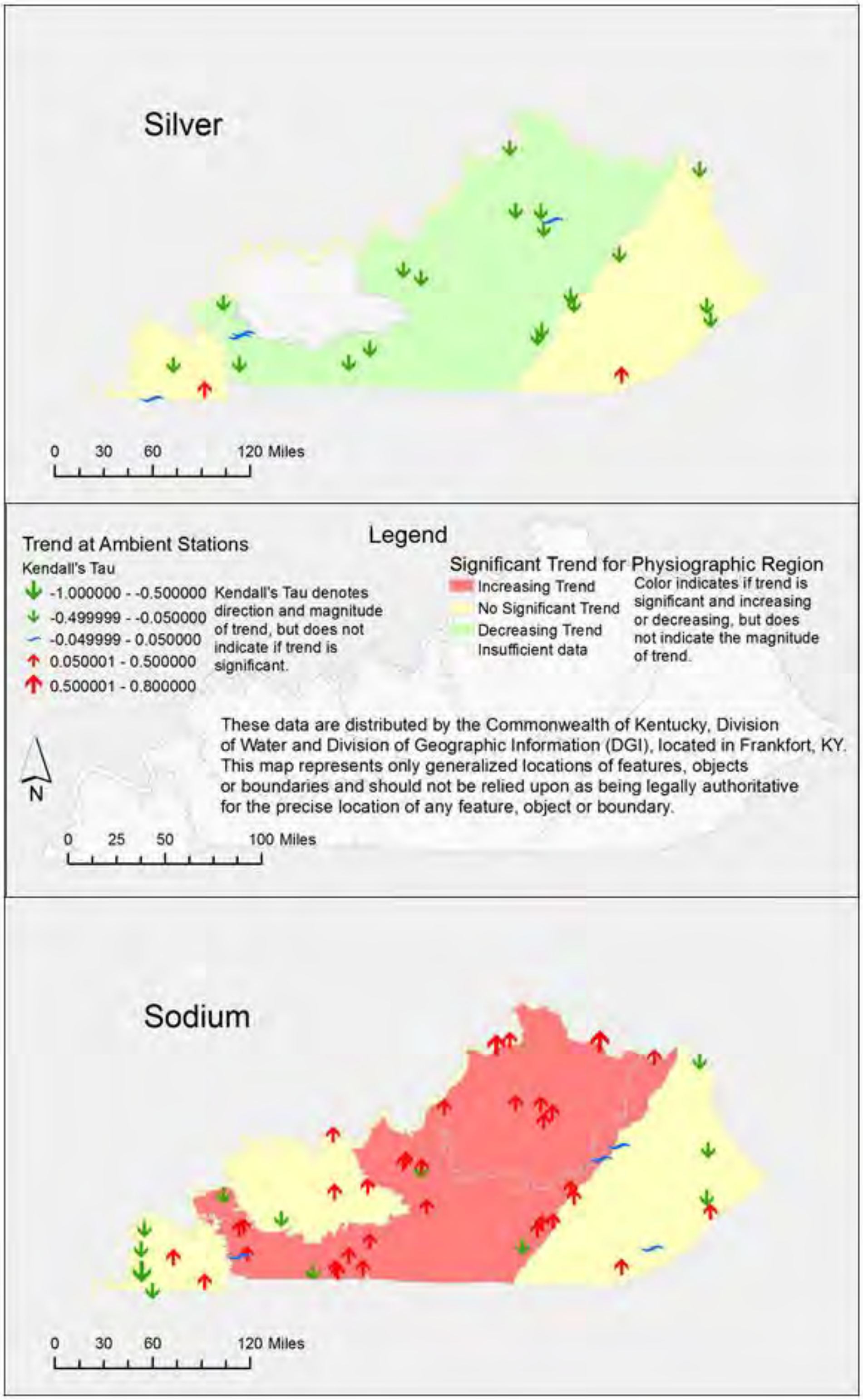

Chromium
0 30 60 120 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles
Copper
0 30 60 120 Miles

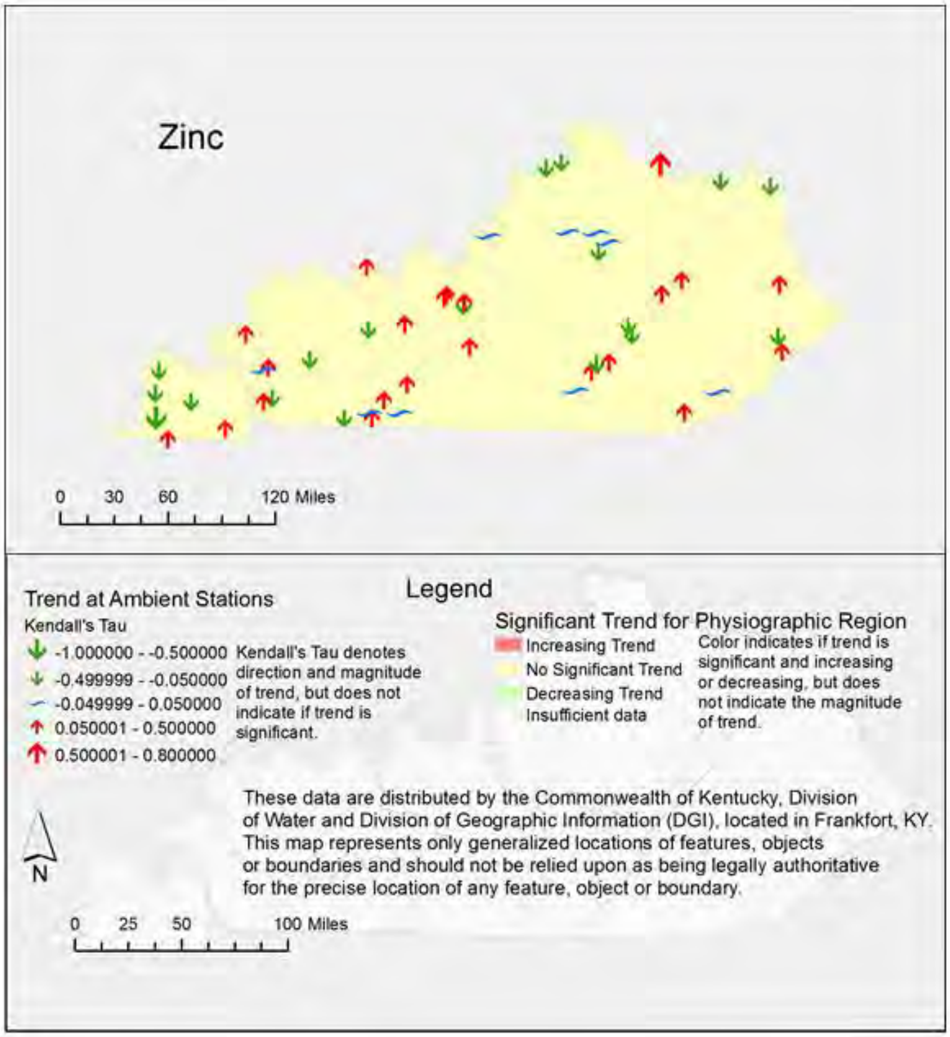

Iron
0 30 60 120 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles
Lead
0 30 60 120 Miles


Magnesium
0 30 60 120 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles
Manganese
0 30 60 120 Miles


Mercury
0 30 60 120 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles
Nickel
0 30 60 120 Miles


Potassium
0 30 60 120 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles
Selenium
0 30 60 120 Miles


Silver
0 30 60 120 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles
Sodium
0 30 60 120 Miles


Zinc
0 30 60 120 Miles
Legend
Trend at Ambient Stations
Kendall's Tau
-1.000000 - -0.500000
-0.499999 - -0.050000
-0.049999 - 0.050000
0.050001 - 0.500000
0.500001 - 0.800000
Kendall's Tau denotes direction and magnitude of trend, but does not indicate if trend is significant.
Significant Trend for Physiographic Region
Increasing Trend
No Significant Trend
Decreasing Trend
Insufficient data
Color indicates if trend is significant and increasing or decreasing, but does not indicate the magnitude of trend.
These data are distributed by the Commonwealth of Kentucky, Division of Water and Division of Geographic Information (DGI), located in Frankfort, KY. This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
N
0 25 50 100 Miles

Pesticides and Volatile Organic Compounds

For pesticides and Volatile Organic Compounds (VOCs), no trend analysis was possible with > 75% of all cases being non-detects. Instead, pesticide hits were plotted for each monitoring site, and maps were generated for all sites with > 2 detections, showing the geospatial distribution of pesticide and VOC detections. The data time distribution was from April 1, 1994 through December 31, 2015.

Pesticides do not naturally occur and theoretically should not be present in groundwater at background levels. Therefore, the high percentages of non-detects were to be expected (Table 19). Atrazine is one of the most commonly used herbicides, it had the most detections. Glyphosate, another commonly used pesticide, had only three detections throughout the state, and those were at three different monitoring sites.

The VOCs examined include benzene, toluene, ethylbenzene and xylenes (commonly called BTEX) and methyl tertiary butyl ether (MTBE), all of which are associated with fuels. A common source for these VOCs is from leaking fuel storage tanks (Zogorski et al, 2006).

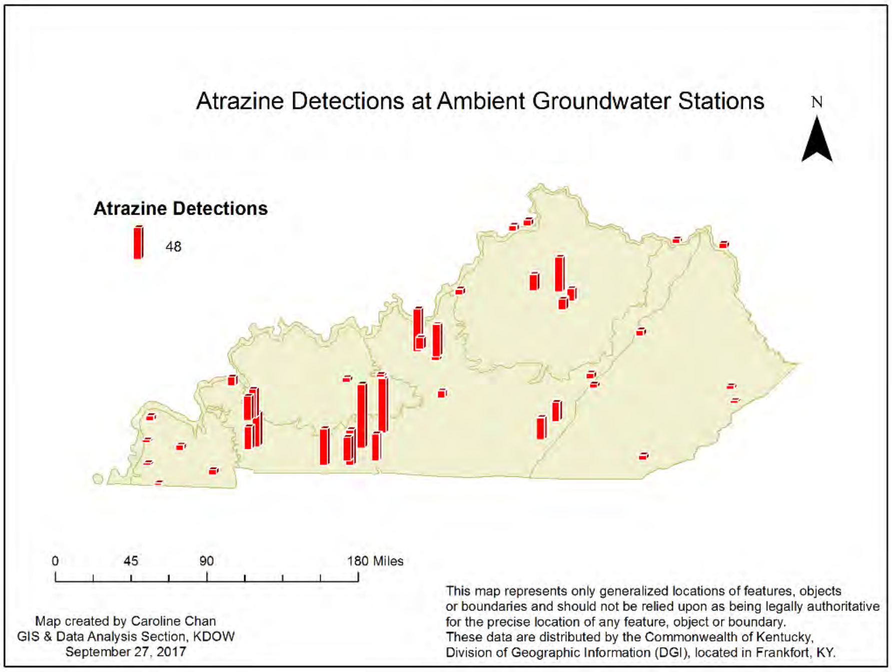
Table 19. Descriptive statistics for pesticides.

Pesticides and Volatile Organic Compounds								
	Analyte (mg/L)	% NonDetect	n	25th Pctl	Median	75th Pctl	Max	Std Dev
Pesticides	Alachlor	99.30	2421	-	-	-	0.000234	0.000015
	Atrazine	69.20	2425	-	-	0.000050	0.041900	0.000953
	Cyanazine	98.64	1894	-	-	-	0.000059	0.000014
	Glyphosate	99.78	1383	-	-	-	0.009090	0.003132
	Metolachlor	84.14	2421	-	-	-	0.004780	0.000125
	Simazine	92.65	2353	-	-	-	0.007200	0.000183
Volatile Organic Compounds	Benzene	99.01	2128	-	-	-	0.005000	0.000217
	Ethylbenzene	99.95	2128	-	-	-	0.005000	0.000209
	Toluene	97.70	2128	-	-	-	0.008600	0.000311
	Xylenes	99.35	1991	-	-	-	0.042800	0.001136
	MTBE	99.29	2108	-	-	-	0.200000	0.005034

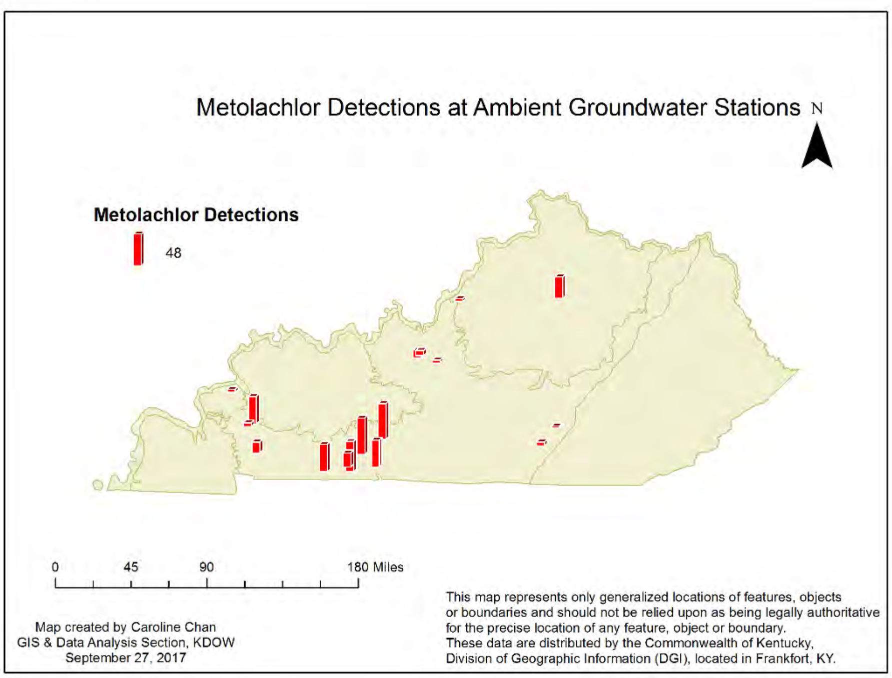
Table 20. Number of detections for each physiographic region. Note, table includes all detections; all graphics were produced on monitoring stations with greater than 2 detections.

Number of Detections by Physiographic Region							
	Analyte	Bluegrass	E. Coal Field	Jackson Purchase	Mississippian Plateau	Ohio River Alluvium	W. Coal Field
Pesticides	Alachlor	-	-	-	13	-	-
	Atrazine	122	30	32	773	46	8
	Cyanazine	1	-	-	6	-	-
	Glyphosate	1	-	-	2	-	-
	Metolachlor	-	-	-	93	-	-
	Simazine	4	-	-	170	-	-
Volatile Organic Compounds	Benzene	-	-	-	4	-	-
	Ethylbenzene	-	-	-	-	-	-
	Toluene	4	-	-	5	-	5
	Xylenes	6	-	-	5	-	-
	MTBE	13	-	-	-	-	-

Figure 26. Geospatial distribution of pesticide detections (>2 detections at a station).



Bar height indicates number of detections.



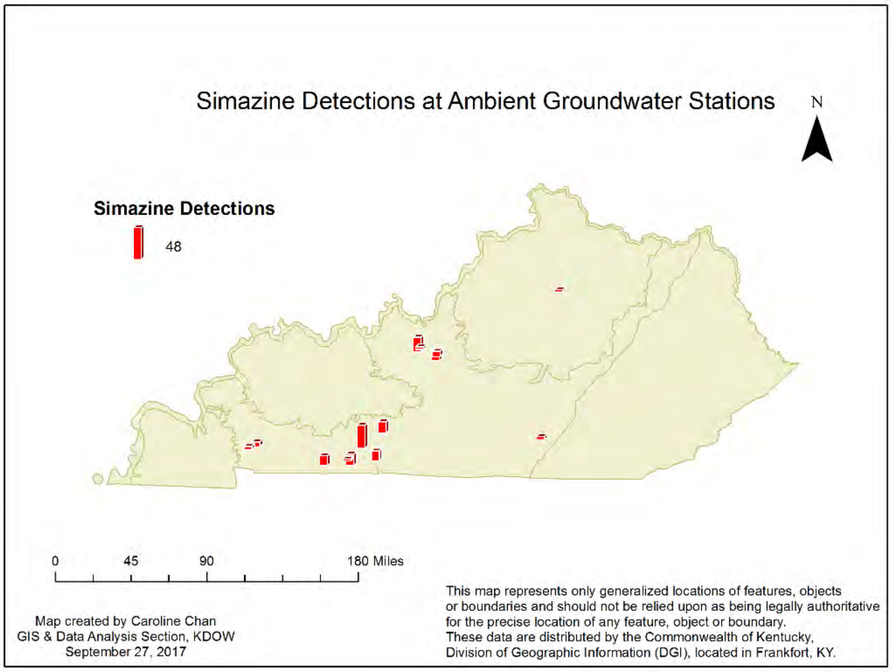
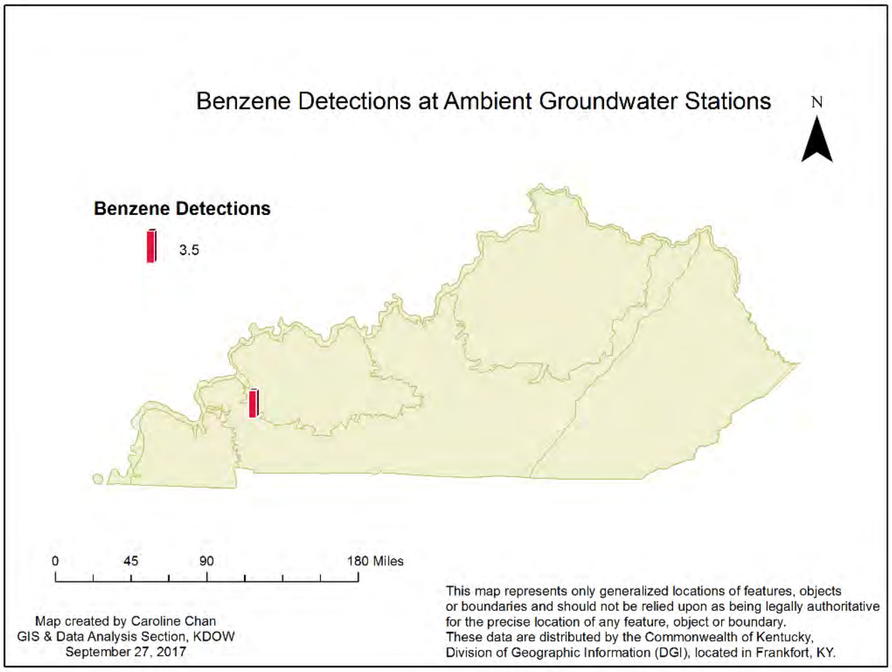
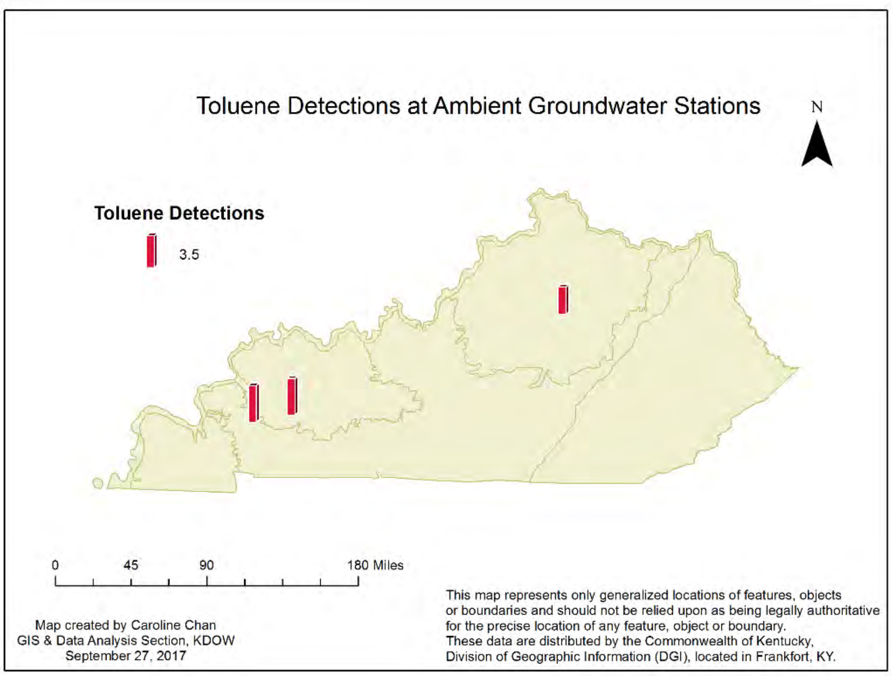
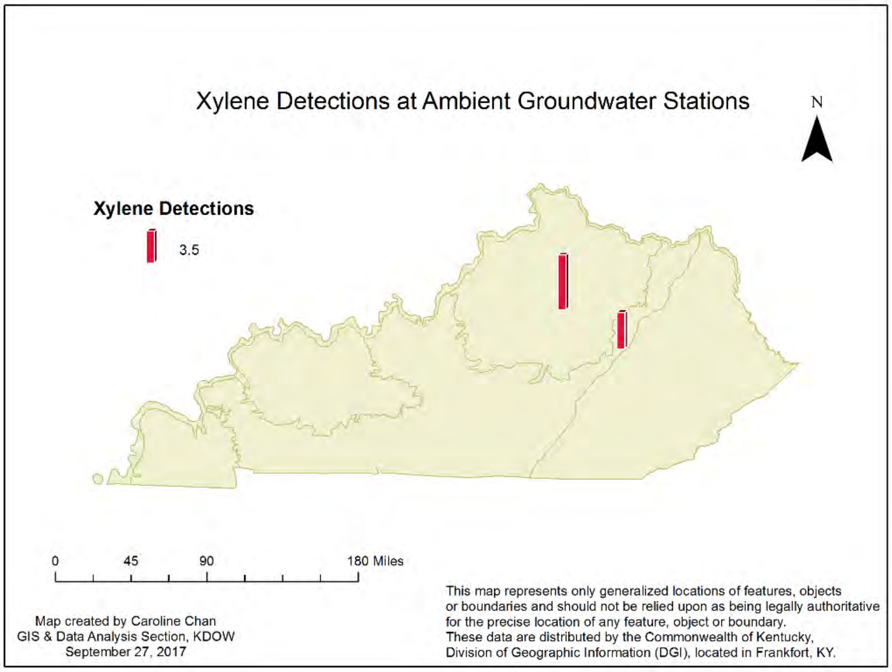

Simazine Detections at Ambient Groundwater Stations
N
Simazine Detections
48
0
45
90
180 Miles
Map created by Caroline Chan
GIS & Data Analysis Section, KDOW
September 27, 2017
This map represents only generalized locations of features, objects
or boundaries and should not be relied upon as being legally authoritative
for the precise location of any feature, object or boundary.
These data are distributed by the Commonwealth of Kentucky,
Division of Geographic Information (DGI), located in Frankfort, KY.

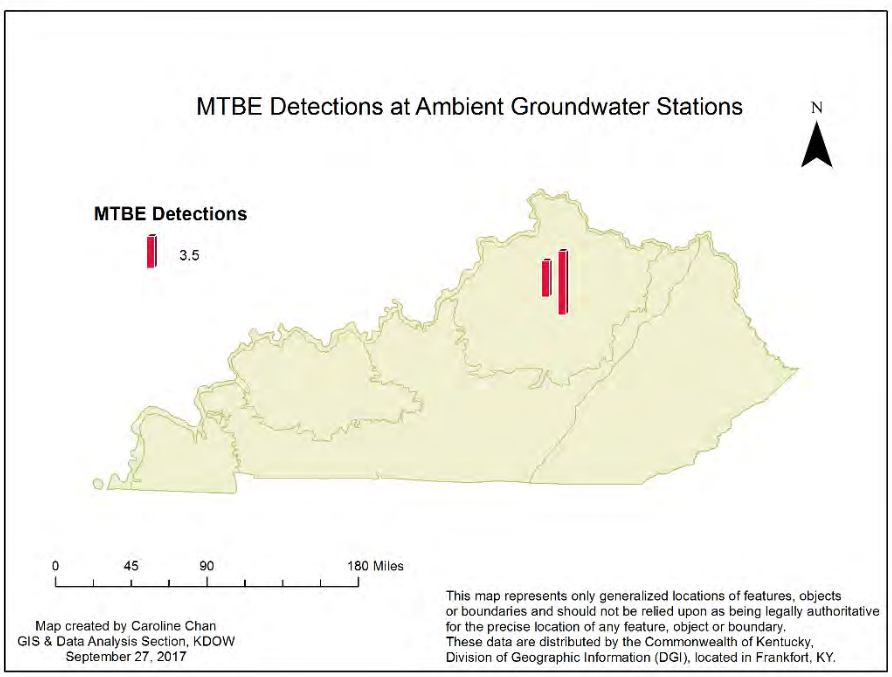
Figure 27. Geospatial distribution of VOC detections (>2 detections at a monitoring station).



Bar height indicates number of detections.




Xylene Detections at Ambient Groundwater Stations
N
Xylene Detections
3.5
0
45
90
180 Miles
Map created by Caroline Chan
GIS & Data Analysis Section, KDOW
September 27, 2017
This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
These data are distributed by the Commonwealth of Kentucky, Division of Geographic Information (DGI), located in Frankfort, KY.


MTBE Detections at Ambient Groundwater Stations
N
MTBE Detections
3.5
0
45
90
180 Miles
Map created by Caroline Chan
GIS & Data Analysis Section, KDOW
September 27, 2017
This map represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object or boundary.
These data are distributed by the Commonwealth of Kentucky, Division of Geographic Information (DGI), located in Frankfort, KY.

Conclusions

This report represents the initial examination of statewide trends in groundwater quality based on data collected through the Network. In general, data indicate that groundwater quality in Kentucky continues to be suitable for many purposes and that trends are observed for several analytes. Springs account for the majority of monitoring stations and exhibited the strongest trends.

In general, increasing trends were more frequent in the Mississippian Plateau physiographic region and in stations that were springs, as opposed to wells. An obvious contributor to this result is the power found in detecting trends with a larger number of samples or stations. Of the six physiographic regions, the Mississippian Plateau has 24 of the 49 stations. The sample size difference between wells and springs is large, but not as marked – 20 wells versus 29 springs. Interestingly, 22 of the 29 springs are in the Mississippian Plateau. The question then arises whether these trends are the result of influences specific to that region, whether global stresses are impacting springs more rapidly because they are closer to the surface and less insulated from these impacts, or whether the trends are detected because there is more power to do so. Adding monitoring stations in the under-represented physiographic regions as well as more wells to the Network would be needed to resolve this issue.

Trends were found within each analyte group. Additionally, trends for analytes varied for each physiographic region evaluated. For Bulk Parameters, statewide tests showed increasing trends for conductivity and pH for springs, while the more robust regression showed significant increases for all stations and wells and springs separately. No trends were detected for temperature. Kendall's tau performed for physiographic regions found conductivity and pH increased in two out of six regions, while temperature showed no increases. Springs tend to have higher amounts of dissolved calcium and magnesium, and therefore, greater hardness. An increasing trend for hardness was observed for the Bluegrass Region only. Of the six nutrients analyzed, three exhibited decreasing trends. This may be an indication of successful statewide nutrient management strategies. The major inorganic anions of chloride, fluoride and sulfate showed limited trends in just a few regions. A total of 17 metals were evaluated with nine showing increasing trends, three decreasing trends and five with no trend observed. Pesticide detections were scattered across the state and were more common in springs. Although no pesticides were detected at levels of concern, their presence is indicative of nonpoint source pollution. The volatile organic compounds evaluated (BTEX and MTBE) are associated with fuel and their detections were infrequent and at low concentrations.

The Kentucky Interagency Groundwater Monitoring Network was established to meet three major goals relative to groundwater resources: 1) provide baseline data; 2) characterize the resource; and 3) disseminate the information collected. While these goals have been met in various ways, they are an on-going process that should continue. Baseline geochemical and groundwater quality data have been collected for each physiographic region and aquifer type in the state. This has allowed researchers to characterize groundwater resources on varying scales from local to regional and statewide scales. The information collected has been made available through numerous reports, publications and maps, and via The Kentucky Groundwater Data Repository at KGS.

This report meets the Network's goal of disseminating information. While baseline data have been gathered and groundwater resources have been characterized, continued and expanded monitoring will further our understanding of groundwater in Kentucky. The finding of trends points to ongoing changes in this resource which have implications regarding protection, conservation, public health and economic development. With vigilance, stresses on this resource can be addressed and rectified before negative outcomes are realized.

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Appendix A: Data Distribution over Time

Figure 28. Distribution of field measures over time. Data within the green lines used for trend tests.

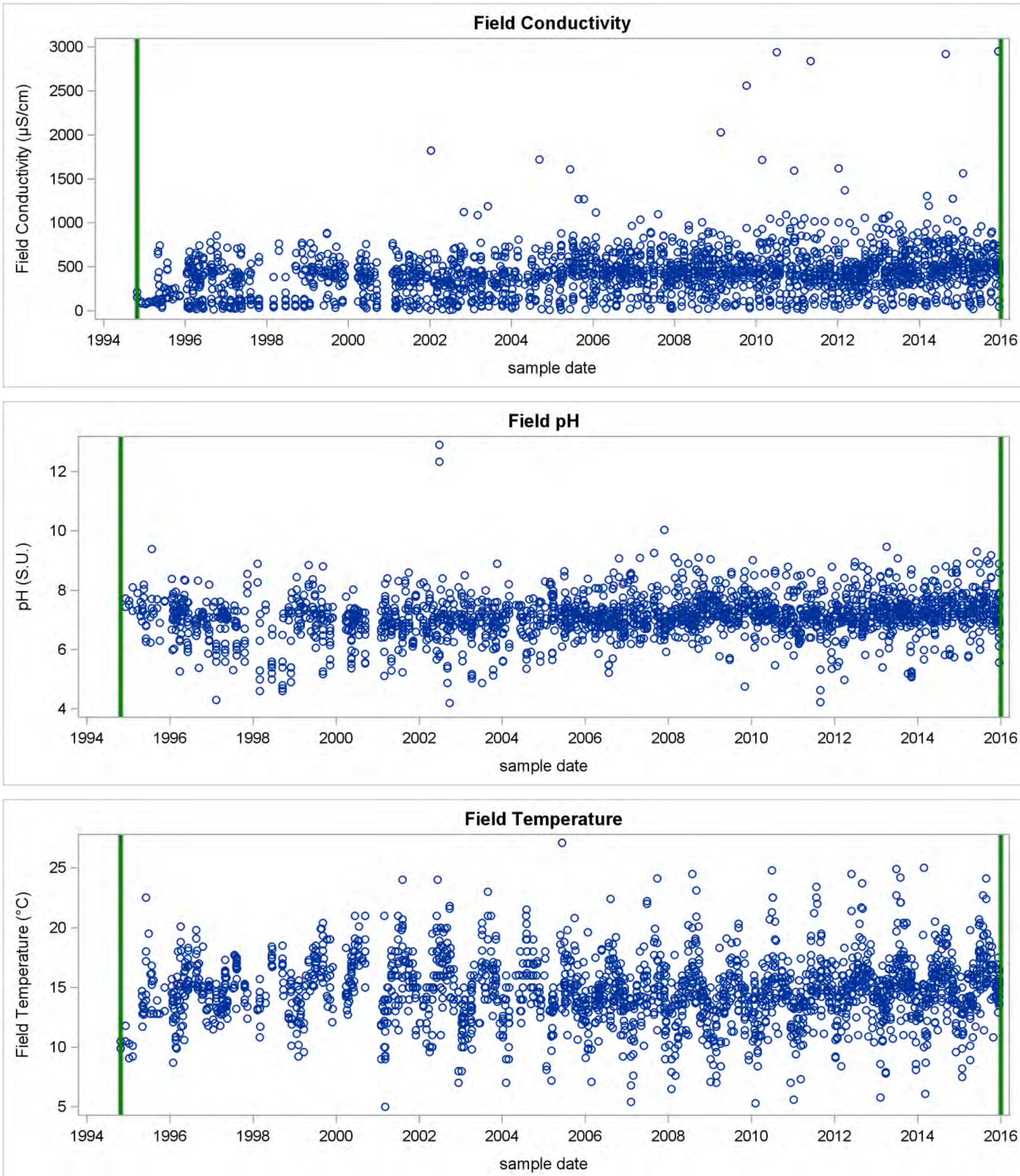


Figure 29. Distribution of total hardness over time.

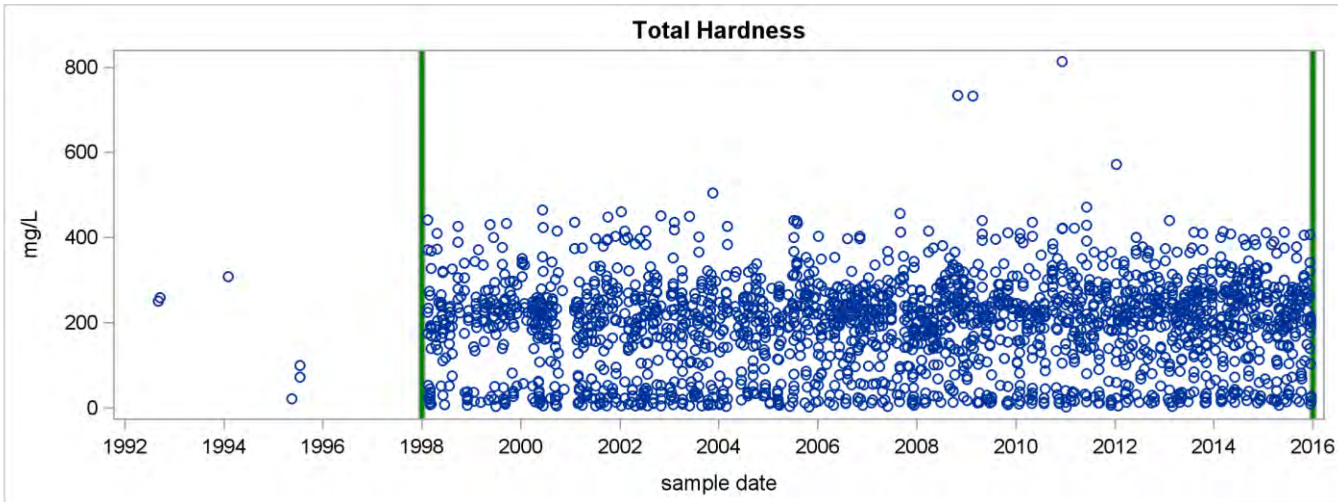


Figure 30. Distribution of nutrients over time.

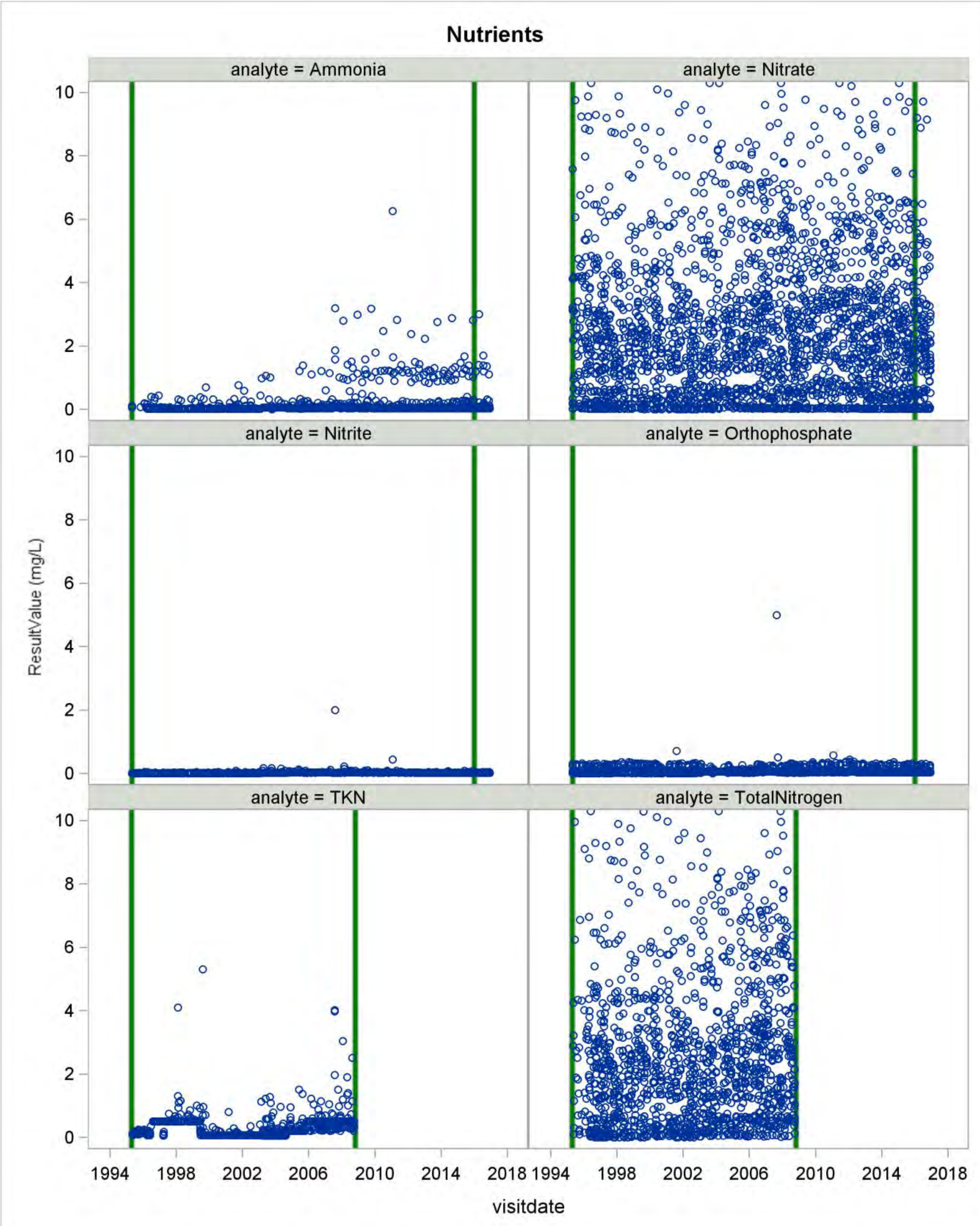


Figure 31. Distribution of metals over time.

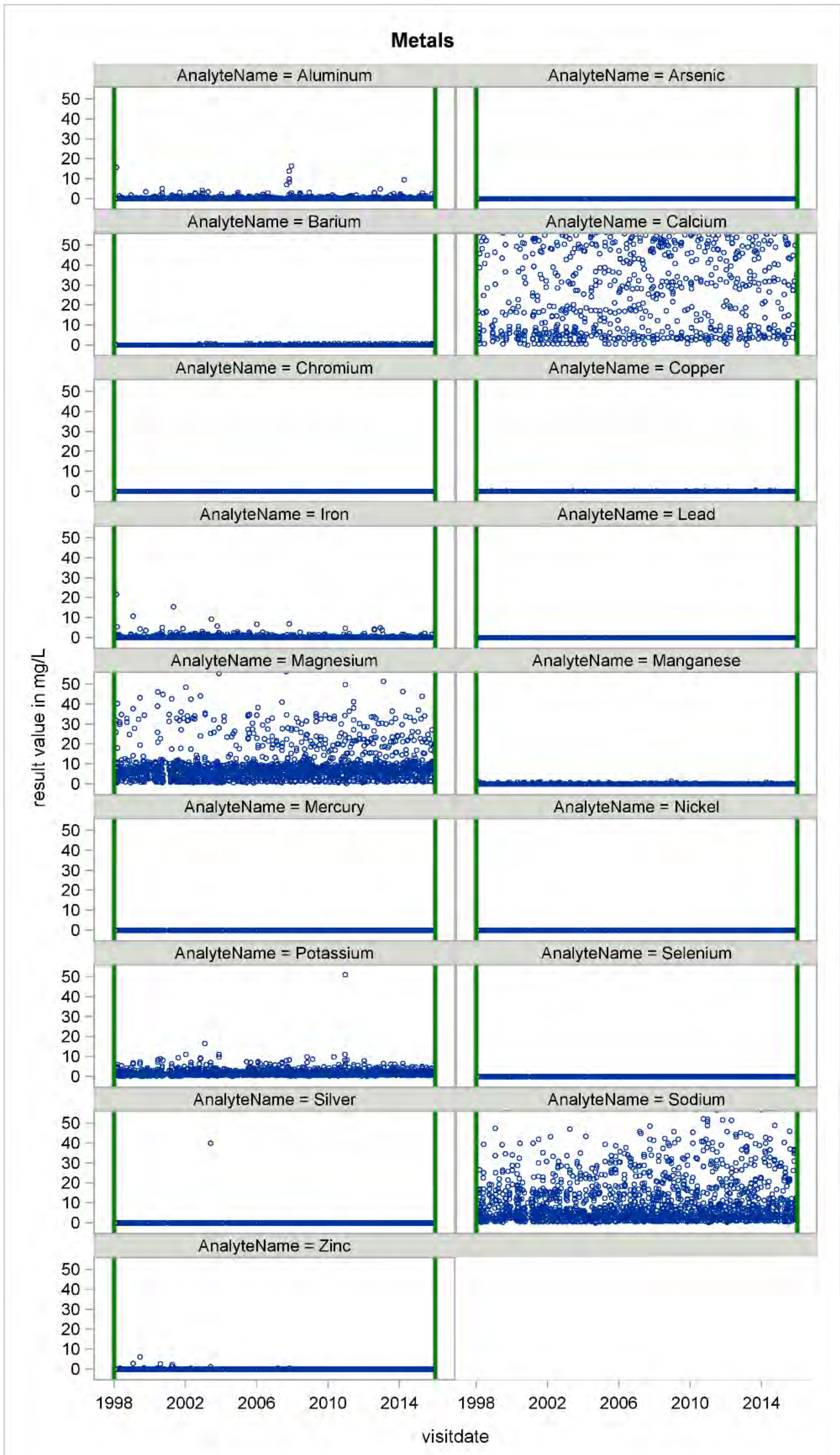
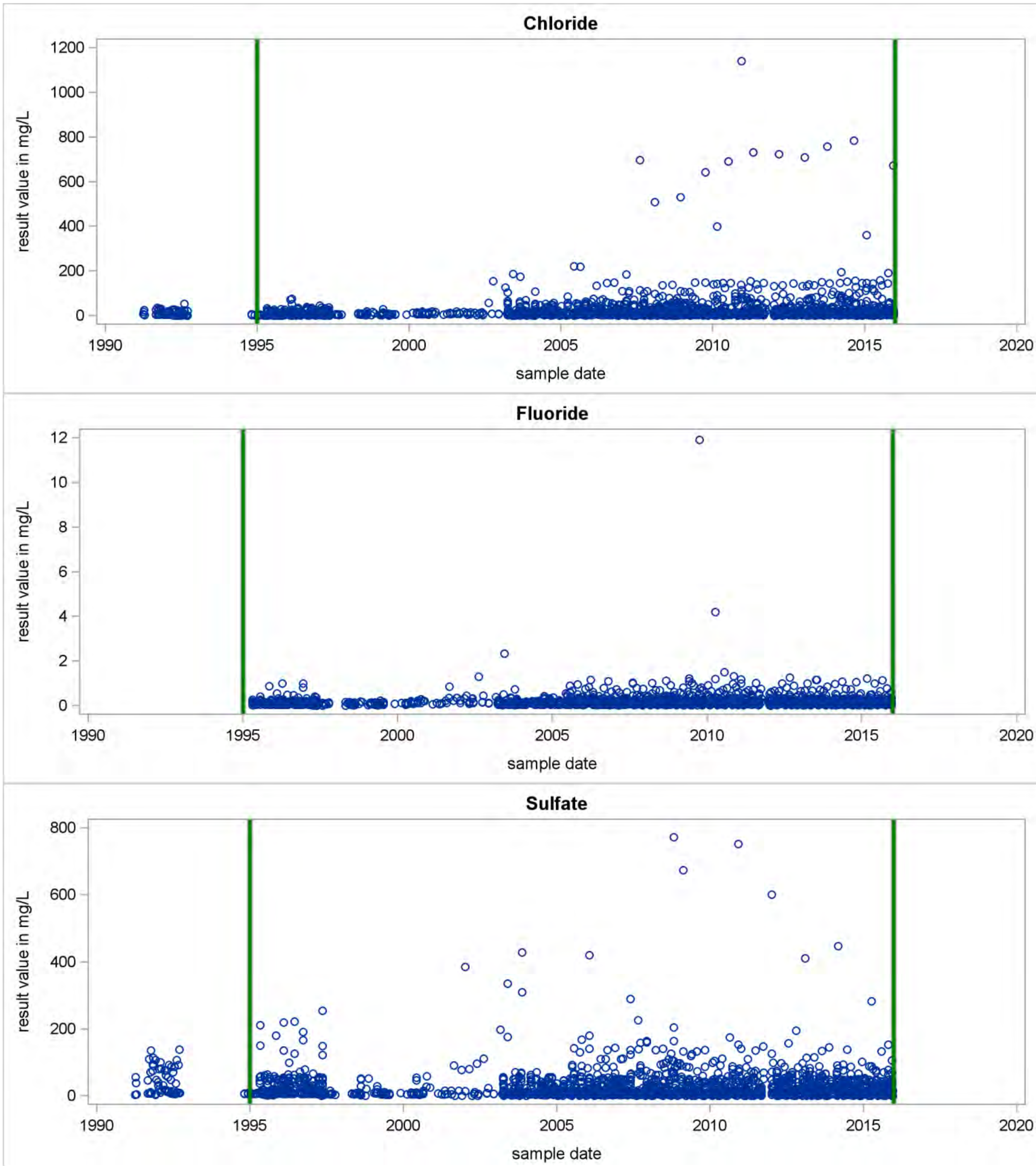
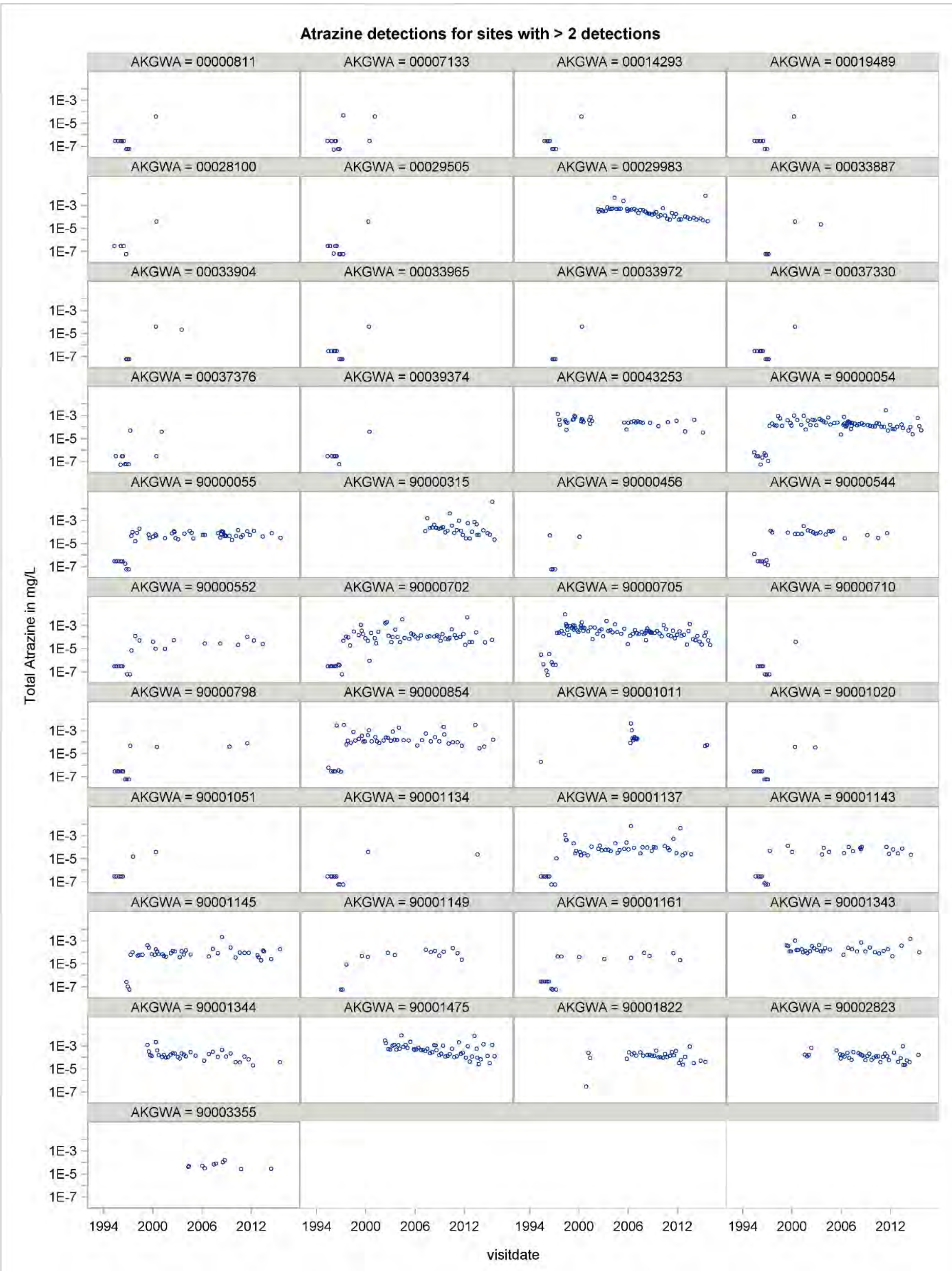
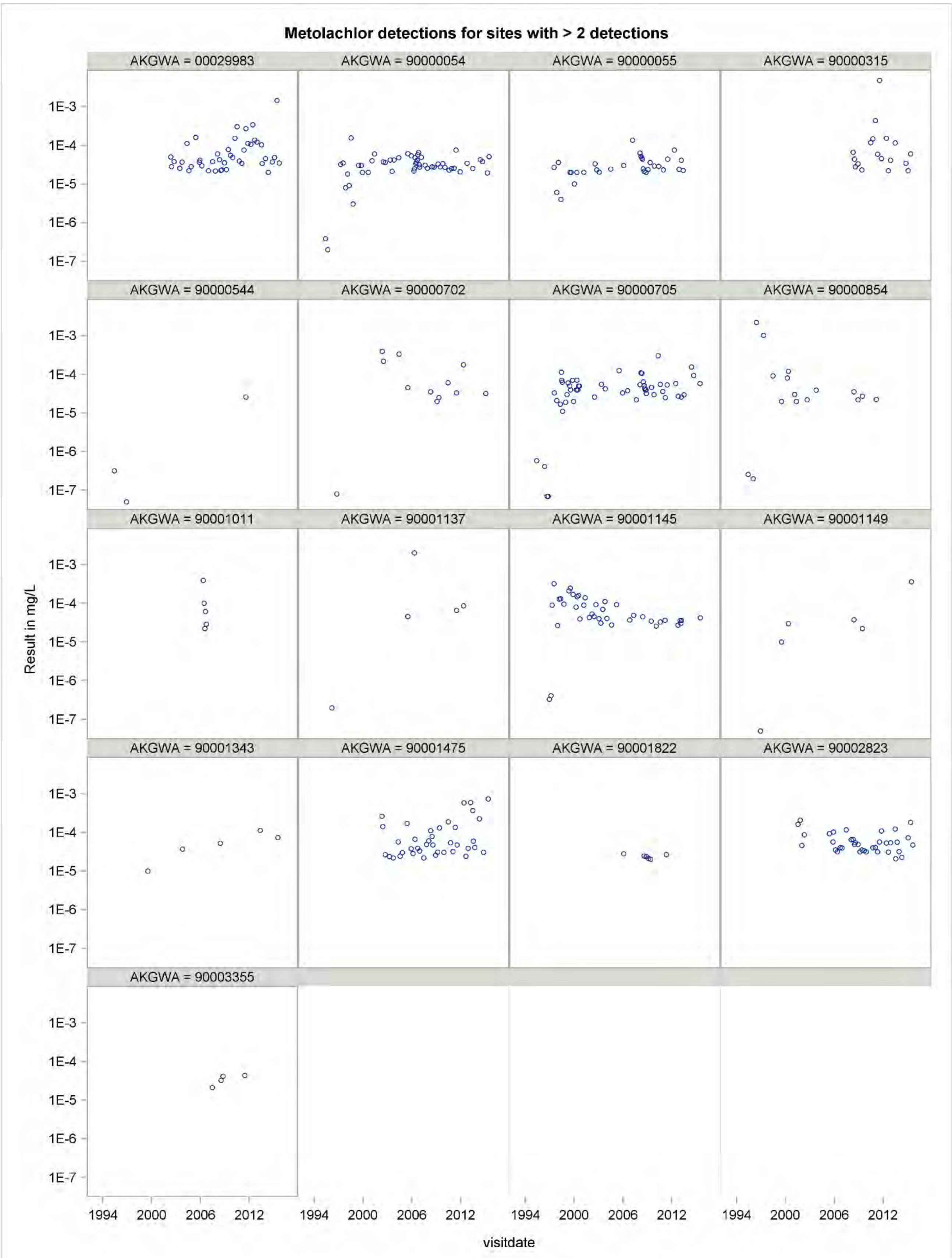


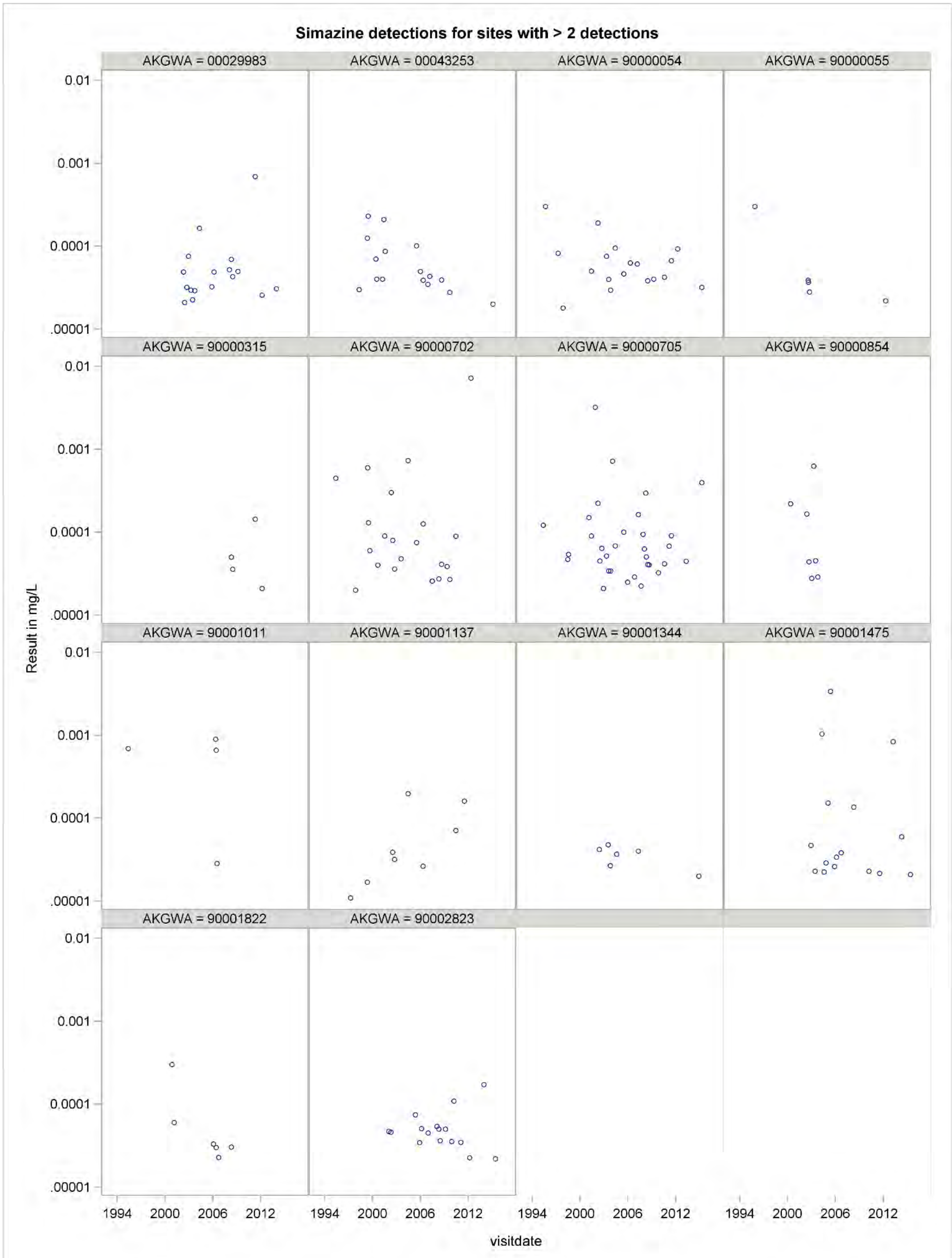
Figure 32. Distribution of major inorganic ions over time.

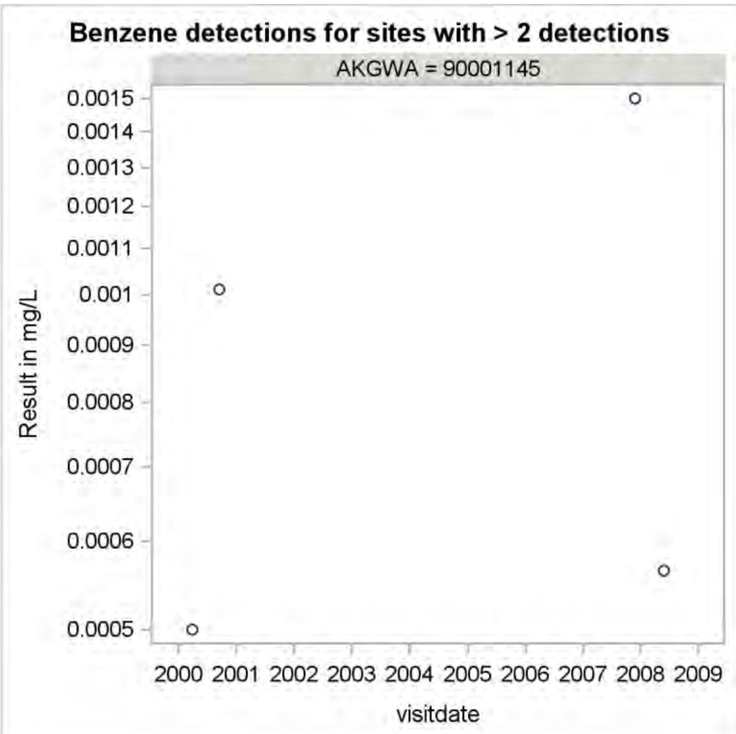


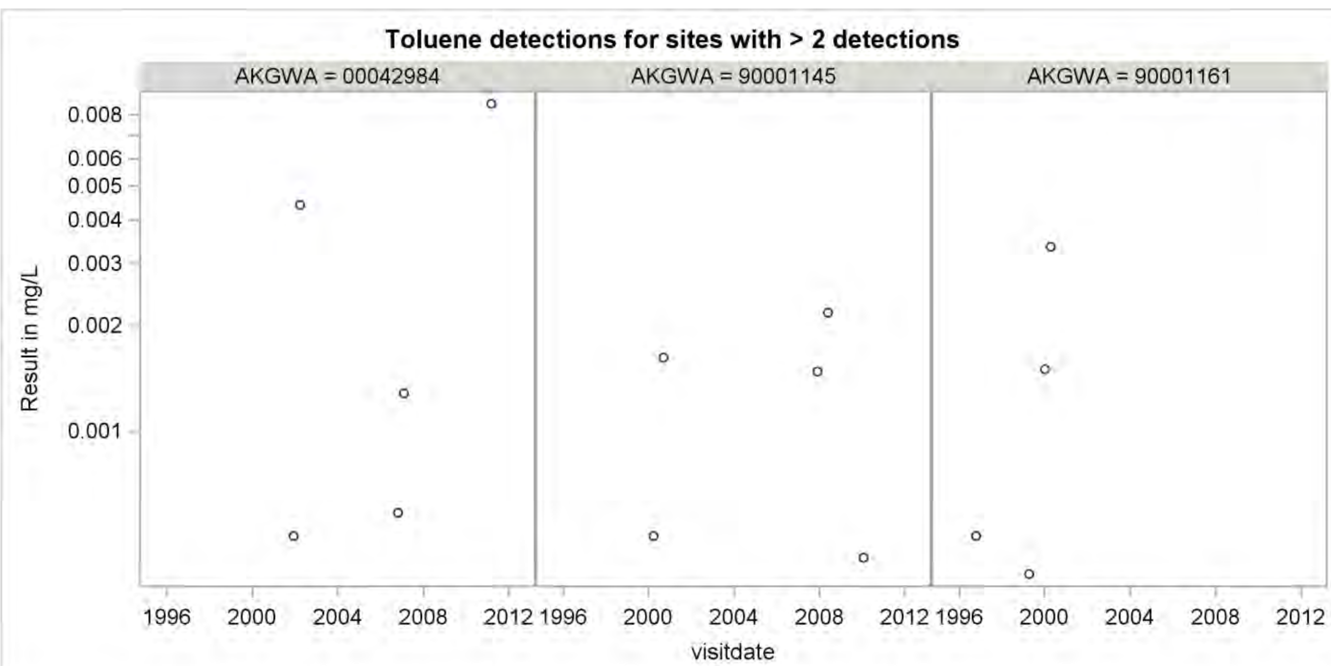
Appendix B: Pesticide and Volatile Organic Compound Detections

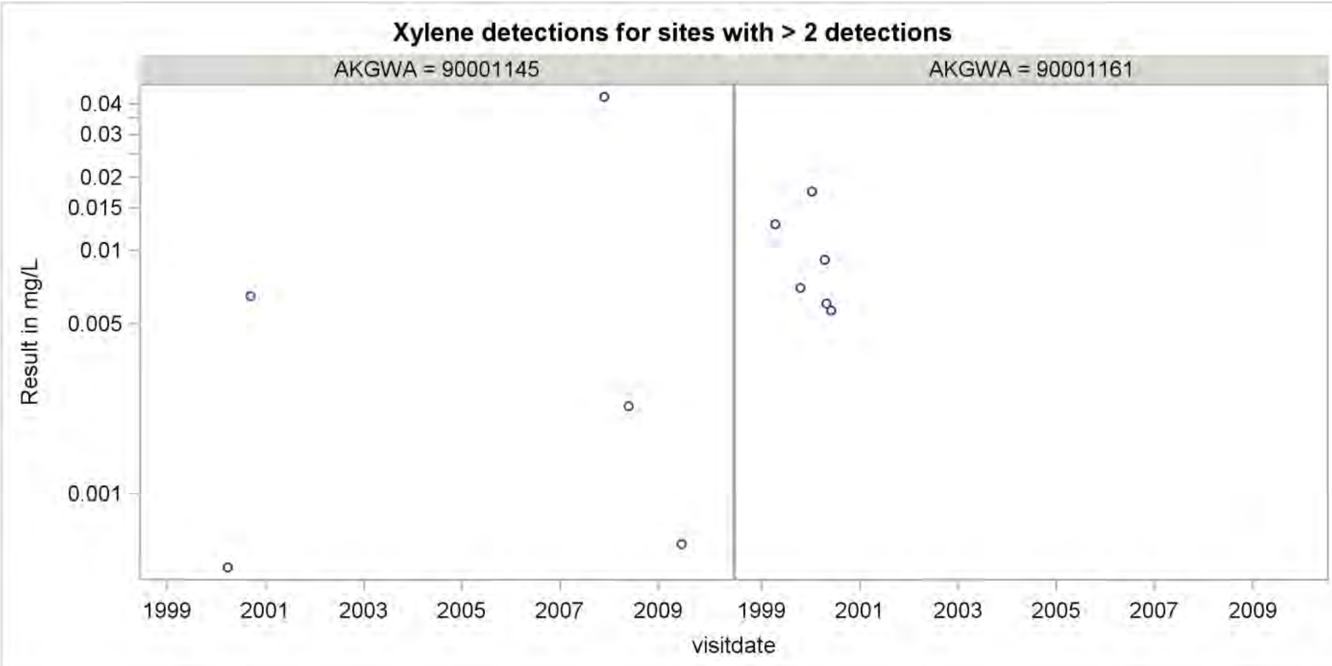


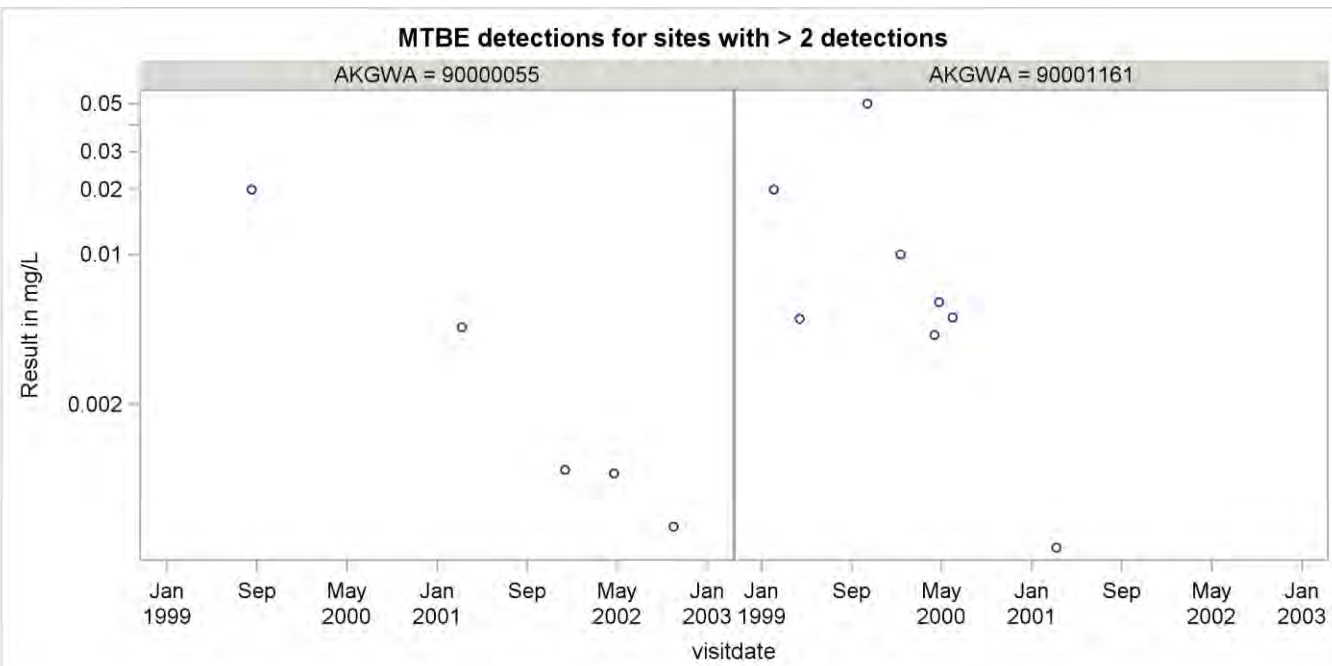

Metolachlor detections for sites with > 2 detections
AKGWA = 00029983
AKGWA = 90000054
AKGWA = 90000055
AKGWA = 90000315
AKGWA = 90000544
AKGWA = 90000702
AKGWA = 90000705
AKGWA = 90000854
AKGWA = 90001011
AKGWA = 90001137
AKGWA = 90001145
AKGWA = 90001149
AKGWA = 90001343
AKGWA = 90001475
AKGWA = 90001822
AKGWA = 90002823
AKGWA = 90003355
Result in mg/L
1E-3
1E-4
1E-5
1E-6
1E-7
1994
2000
2006
2012
visitdate


Simazine detections for sites with > 2 detections
AKGWA = 00029983
AKGWA = 00043253
AKGWA = 90000054
AKGWA = 90000055
AKGWA = 90000315
AKGWA = 90000702
AKGWA = 90000705
AKGWA = 90000854
AKGWA = 90001011
AKGWA = 90001137
AKGWA = 90001344
AKGWA = 90001475
AKGWA = 90001822
AKGWA = 90002823
Result in mg/L
0.01
0.001
0.0001
.00001
1994
2000
2006
2012
visitdate


Benzene detections for sites with > 2 detections
AKGWA = 90001145
Result in mg/L
0.0015
0.0014
0.0013
0.0012
0.0011
0.001
0.0009
0.0008
0.0007
0.0006
0.0005
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
visitdate


Toluene detections for sites with > 2 detections
AKGWA = 00042984
AKGWA = 90001145
AKGWA = 90001161
Result in mg/L
0.008
0.006
0.005
0.004
0.003
0.002
0.001
1996 2000 2004 2008 2012 1996 2000 2004 2008 2012 1996 2000 2004 2008 2012
visitdate


Xylene detections for sites with > 2 detections
AKGWA = 90001145
AKGWA = 90001161
Result in mg/L
0.04
0.03
0.02
0.015
0.01
0.005
0.001
1999
2001
2003
2005
2007
2009
visitdate


MTBE detections for sites with > 2 detections
AKGWA = 90000055
AKGWA = 90001161
Result in mg/L
0.05
0.03
0.02
0.01
0.002
Jan 1999
Sep
May 2000
Jan 2001
Sep
May 2002
Jan 2003
visitdate