Expanded Groundwater Monitoring

For Nonpoint Source Pollution Assessment

In the Salt and Licking River Basins:

Final Report

By

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EXECUTIVE SUMMARY

In order to conduct a more adequate assessment of groundwater resources in the Salt and Licking River basins, Kentucky Watershed Basin Management Unit Number 2 (BMU 2), the Groundwater Branch of the Kentucky Division of Water (KDOW) collected 120 raw-water samples at 37 wells and springs in BMU 2. Sites selected represented ambient groundwater conditions and the various hydrogeologic flow regimes found in the basin. Samples were analyzed for pesticides (including the most commonly used herbicides), total and dissolved metals, nutrients, major inorganic ions, residues, and volatile organic compounds, including trichloroethylene (TCE), benzene, toluene, ethylbenzene, xylenes, and methyl-tert-butyl ether (MTBE). Additionally, data from 33 other ambient groundwater monitoring sites were data analyzed for this project. The Division of Water sampled these other sites for various other projects, most commonly, the Division's Ambient Groundwater Monitoring Program.

Ambient groundwater quality in BMU 2 is generally good, with land-use the primary determining factor. At some sites naturally occurring constituents, including iron and manganese, impair groundwater quality. Additional naturally occurring constituents that may also impact groundwater include nitrate-nitrogen, ammonia, total phosphorus, and ortho-phosphate. Because these nutrients occur both naturally and through anthropogenic activity, the impact of man's contribution to naturally occurring groundwater chemistry is difficult to assess.

Constituents not naturally occurring that have impacted groundwater in BMU 2 are several common agricultural herbicides, including atrazine and metolachlor, and volatile organic compounds, including benzene and MTBE. In BMU 2, the occurrence of herbicides is the result of nonpoint source pollution. The occurrence of volatile organic compounds occurs via point source releases or from nonpoint sources such as urban storm-water runoff.

INTRODUCTION and BACKGROUND

The Kentucky Division of Water has adopted an integrated approach to the management of water resources. The approach, known as the Kentucky Watershed Framework, is ". . . a means for coordinating and integrating the programs, tools, and resources of stakeholders to better protect, maintain, and restore the ecological composition, structure, and function of watersheds and to support the sustainable uses of watersheds for the people of the Commonwealth" (KDOW, 2002a). Under this system, the watersheds of the state are sub-divided into five Basin Management Units (BMU's). As part of the data gathering and assessment efforts of the watershed approach, the Division of Water-Groundwater Branch assessed nonpoint source pollution impacts to groundwater within the Salt and Licking River basins (BMU 2).

Before 1995, ambient groundwater quality data throughout the state was inadequate to assess groundwater quality on a regional, basin-wide or statewide scale. In order to correct this situation, the Division of Water 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, which formalized groundwater assessment efforts. Oversight for this network is through the Interagency Technical Advisory Committee on Groundwater, which includes the Division of Water.

The Division of Water regularly collects ambient groundwater samples throughout the state. To date, the Division has collected more than 2000 samples from approximately 330 sites. The information from these samples is used for a variety of purposes, including: 1) assessment and characterization of local and regional baseline groundwater quality, 2) documentation of spatial and temporal variations in groundwater quality 3) support of public water systems, especially through source water characterization and Wellhead Protection, 4) development of Total Maximum Daily Loads (TMDL) for surface water in areas where groundwater directly influences this resource, 5) support of the state's pesticide management plan, 6) development of groundwater quality standards and aquifer classification, and 7) to address compliance and nonpoint source issues. The Division of Water forwards analytical data to the Kentucky Geological Survey (KGS) Ground-Water Data Repository where it is available to the public. Data requests can be made via their website (http://kgs.edu/KGS/home.htm), by phone at (859) 257-5500, or by mail at 228 Mining and Minerals Resources Building, University of Kentucky, Lexington, KY 40506-0107.

Project Description

This project provides additional groundwater quality data in areas lacking adequate information. The objective of this project was to sample 30 groundwater sites in BMU 2 on a quarterly basis for one year, beginning in April 1999. However, because drought affected some low-flow springs, alternate sites had to be selected and therefore 37 sites were eventually included to meet this grant commitment (Appendix D, Table 1). In addition, data from 33 other sites sampled for various other ambient monitoring efforts from 1993 through 2001 are also included in this report. The Groundwater Branch selected wells and springs to provide good geographical representation of the diverse physiographic and hydrogeologic characteristics, and dominant land uses in BMU 2. Samples were analyzed for numerous parameters including nutrients, pesticides, total/dissolved metals, residues, major inorganic ions, and volatile organic compounds, as shown in Table 1. Data were compared to various existing standards and to data from unimpacted ("pristine") reference springs (Table 2), to determine possible nonpoint source pollution impacts or other water quality problems, as well as to identify outstanding resources.

Previous Investigations

Comprehensive discussions of groundwater quality within the Salt and Licking River basins were not found in the literature. Faust and others (1980) compiled groundwater quality data on a limited number of parameters for the entire state, but did not analyze or summarize the data. The United States Geological Survey has prepared Hydrologic Atlases (HA's) and 7.5 minute Geological Quadrangle maps

Table 1. Parameters and Standards for Comparison

Parameter	*Standard*	*Source/Discussion **
Hydroparameters		
Conductivity	800 μmho	No MCL, SMCL, or HAL; this roughly corresponds to 500 mg/L TDS, which is the SMCL
Hardness (Ca/Mg)	0-17 mg/L = soft 17-120 mg/L = moderate > 120 mg/L = hard	No MCL, SCML, or HAL; scale modified from USDA (date)
PH	6.5 to 8.5 pH units	SMCL
Inorganics		
Chloride	250 mg/L	SMCL
Fluoride	4 mg/L	MCL
Sulfate	250 mg/L	SMCL
Metals		
Arsenic	.010 mg/L	MCL
Barium	2 mg/L	MCL
Iron	.3 mg/L	SMCL
Manganese	.05 mg/L	SMCL
Mercury	.002 mg/L	MCL
Nutrients		
Ammonia	.110 mg/L	DEP
Nitrate-n	10 mg/L	MCL
Nitrite-n	1 mg/L	MCL
Orthophosphate	.04 mg/L	No MCL, SMCL, or HAL; Texas surface water standard
Total phosphorous	.1 mg/L	No MCL, SMCL, or HAL; level recommended by USGS NAWQA Program
Pesticides		
Alachlor	.002 mg/L	MCL
Atrazine	.003 mg/L (0.00067 mg/L)	MCL (DEP)
Cyanazine	.001 mg/L	HAL
Metolachlor	.1 mg/L	HAL
Simazine	.004 mg/L	MCL
Residues		
Total Dissolved Solids	500 mg/L	SMCL
Total Suspended Solids	35 mg/L	No MCL, SMCL, or HAL; KPDES permit requirement for sewage treatment plants
Volatile Organic Compounds		
Benzene	.005 mg/L	MCL
Ethylbenzene	.7 mg/L	MCL
Toluene	1 mg/L	MCL
Xylenes	10 mg/L	MCL
MTBE	.050 mg/L	DEP

* Abbreviations:

MCL = Maximum Contaminant Level
SMCL = Secondary Maximum Contaminant Level
HAL = Health Advisory Level
KPDES = Kentucky Pollutant Discharge Elimination System
NAWQA = National Water-Quality Assessment Program (USGS)
DEP = Kentucky Department for Environment Protection risk-based number

Table 2. Reference Springs Analytical Data Summary (Cameron Spring/Lewis County; Nada Spring/Powell County; F. Mullin Spring/Rockcastle County).

NPS REFERENCE SITES SUMMARY STATISTICS						
	START DATE	END DATE	NUMBER OF SAMPLES	MEDIAN	MIN	MAX
Conductivity	04/27/95	10/04/00	48	111.25	46.0	448.0
Hardness	07/14/95	12/03/01	28	52.3015	14.039	140.29
pH	04/27/95	10/04/00	44	7.31	6.01	8.12
Chloride	04/27/95	03/07/00	19	1.9	0.6	16.7
Fluoride	04/27/95	03/07/00	33	0.05	< 0.023	0.253
Sulfate	04/27/95	03/07/00	36	7.425	< 5.0	69.4
Arsenic	06/03/98	12/03/01	34	0.002	< 0.002	0.0045
Barium	06/03/98	12/03/01	34	0.0305	0.0040	0.073
Iron	07/14/95	12/03/01	34	0.056	< 0.001	0.337
Manganese	06/03/98	12/03/01	34	0.0035	< 0.001	0.208
Mercury	06/03/98	12/03/01	34	0.00005	< 0.00005	< 0.00005
Ammonia	04/27/95	10/04/00	42	0.02	< 0.02	0.11
Nitrate-n	04/27/95	03/07/00	36	0.1805	< 0.01	0.888
Nitrite-n	04/27/95	03/07/00	21	0.005	< 0.002	0.006
Orthophosphate	04/27/95	10/04/00	43	0.011	< 0.003	0.069
Total Phosphorus	04/27/95	03/07/00	19	0.019	< 0.005	0.019
Alachlor	04/27/95	12/03/01	55	0.00004	< 0.00002	< 0.00006
Atrazine	04/27/95	12/03/01	55	0.00004	< 0.00004	< 0.0003
Cyanazine	05/03/95	12/03/01	48	0.00004	< 0.00004	< 0.0001
Metolachlor	04/27/95	12/03/01	55	0.00004	< 0.00004	< 0.0002
Simazine	04/27/95	12/03/01	52	0.00004	< 0.00004	< 0.0003
TDS	04/27/95	10/04/00	48	63.0	< 10.0	266.0
TSS	04/27/95	10/04/00	48	3.0	< 1.0	13.0
Benzene	04/12/00	12/03/01	20	< 0.0005	< 0.0005	< 0.0005
Ethylbenzene	04/12/00	12/03/01	20	< 0.0005	< 0.0005	< 0.0005
Toluene	04/12/00	12/03/01	20	< 0.0005	< 0.0005	< 0.0005
Xylenes	04/12/00	12/03/01	20	< 0.0005	< 0.0005	< 0.0005
MTBE	04/12/00	12/03/01	20	< 0.001	< 0.001	< 0.001

(GQ's) for the entire state. The Kentucky Geological Survey (1969, 2002) has indexed these publications. Geochemical data in the HA's is limited, and generally includes only common metals and major inorganic ions. However, the atlases usually provide information that is somewhat more detailed for areas including the Ohio River alluvium. In general, groundwater found in the Ohio River alluvium is hard and may contain high amounts of iron, especially from areas adjacent to valley walls.

Several investigators have mapped karst groundwater basins within BMU 2, and Currens and others (1998, 2002) have compiled the results. Carey and Stickney (2001) have prepared county groundwater resource reports, including general descriptions of groundwater quality. Ray and others (1994) have interpreted groundwater sensitivity to contamination for the entire state. Carey and others (1993) study examined data from 4,859 samples collected throughout the state for ammonia, nitrate-nitrogen, nitrite-nitrogen, chloride, sulfate, conductivity, alachlor, and triazine. For three important nonpoint source parameters, they found: 1) 4.6% of the samples for nitrate-n exceeded the Maximum Contaminant Level (MCL) of 10.0 mg/L, 2) 0.9% exceeded the MCL of 0.002 mg/L for alachlor, and 3) 0.3% exceeded the atrazine MCL of 0.003 mg/L. (Note that this study measured total triazines and did not differentiate between various triazine herbicides, including atrazine, simazine, and cyanazine. Additionally, this study applied, perhaps inappropriately, the MCL for atrazine for the entire triazine group.)

Conrad and others (1999) described the occurrence of nitrate-n and fluoride in the state and Fisher (2002) described the occurrence of arsenic. In their study of nitrate-n, Conrad and others (1999) found that MCL exceedances decreased with well depth, and that for fluoride less than 1% of 2,363 analyses exceeded the MCL of 2.0 mg/L. Fisher (2002) concluded that "arsenic in Kentucky groundwater generally does not exceed the MCL and there are no widespread occurrences of high arsenic concentrations."

Currens (1979) compiled a bibliography of karst publications for the state and several researchers, including Kipp and Dinger (1991) and Minns (1993) have studied groundwater in eastern Kentucky. These studies, and others, have found that groundwater in eastern Kentucky is generally hard, and that naturally occurring water quality problems commonly include iron, manganese, sodium chloride, and sulfate. Keagy and others (1993) conducted some smaller scale studies in the Licking River watershed and Keagy found that pesticide concentrations in an epikarst area of the Inner Bluegrass peaked about two weeks after application and then rapidly decreased, indicative of the quick flow nature of karst.

PHYSIOGRAPHIC and HYDROGEOLOGIC SETTING

BMU 2 covers more than 9,000 square miles, and includes the Salt and Licking River basins, as well as several other direct Ohio River tributaries. For the purposes of this report, the terms "Licking River Basin" or "Salt River Basin" will also include those adjacent areas that drain directly to the Ohio River. Figure 1 illustrates the location of BMU 2, and the sites included in this study.

Licking River Basin

The Licking River rises in Magoffin County within the Eastern Coal Field physiographic region. The river flows northwesterly for approximately 320 miles to its confluence with the Ohio River between Newport and Covington, and has a drainage basin of 3,670 square miles, approximately 10% of the state (ORSANCO, 2002). From south to north, the Licking River and its tributaries flow through the following physiographic regions (Figure 2): the Eastern Coal Field, the Mississippian Plateau, the Knobs, the Outer Bluegrass, and the Inner Bluegrass. In addition, the area drains portions of the Ohio River Alluvium. Although the alluvium along the Ohio River is not technically a true physiographic province, it is nevertheless an important aquifer within this region and is discussed separately. Groundwater flow in the Licking River basin varies according to the local geology. After initial runoff of precipitation, groundwater provides base flow to surface water streams, thereby sustaining stream flow during periods without rain.

Principal tributaries are the North Fork, which joins the main stem near Milford in Bracken County, and the South Fork, which joins at Falmouth in Pendleton County. Other tributaries include Hinkston and Stoner Creeks, which form the South Fork at Ruddels Mill in Bourbon County, and Fleming Creek. An additional 1,195 sq. miles of area draining directly to the Ohio River is included in BMU 2. Some of these more important watersheds include Kinniconick Creek, Salt Lick Branch, and Gunpowder Creek. The largest impoundment in BMU 2 is Cave Run Lake, operated by the Army Corps

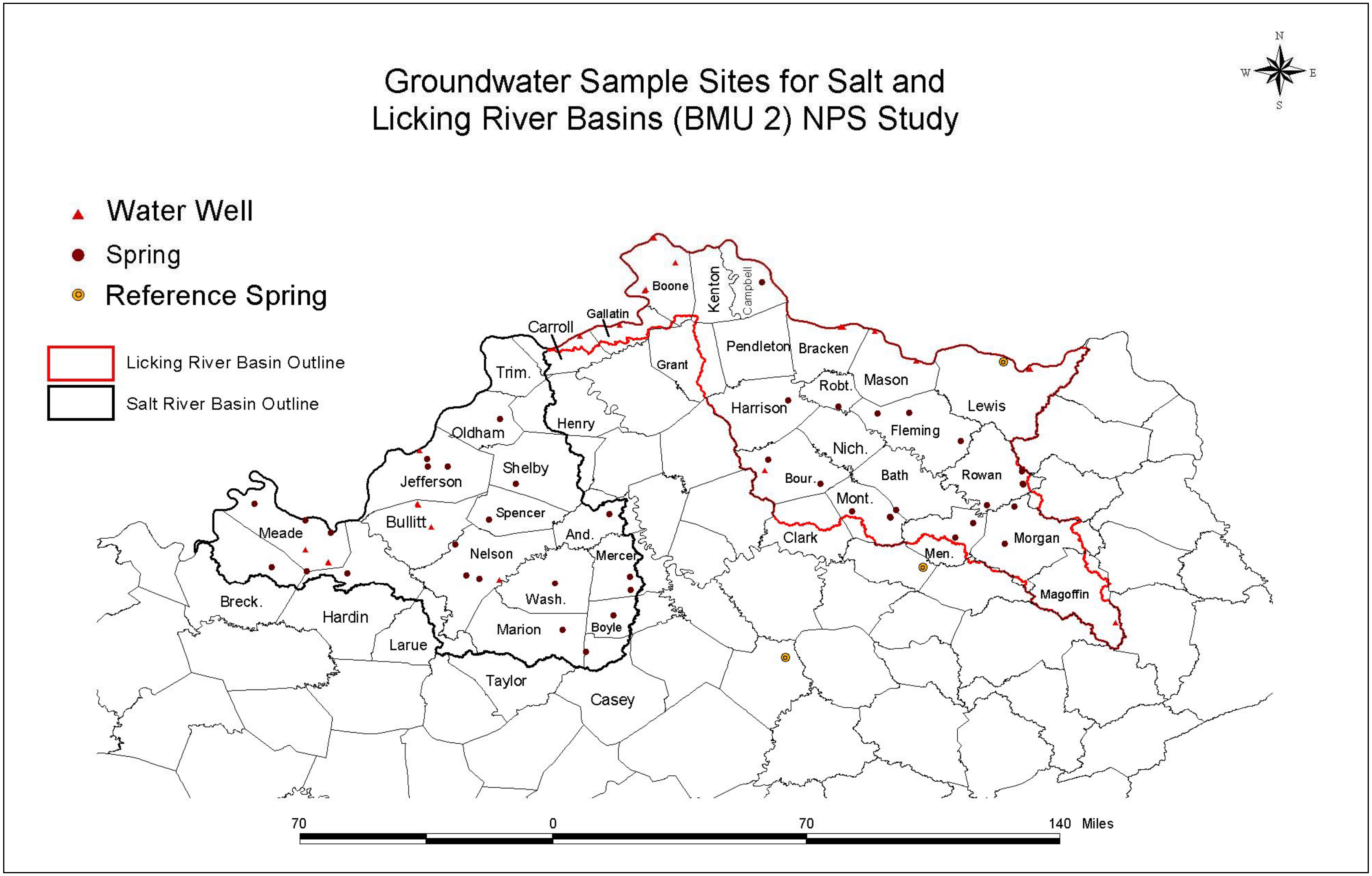


Figure 1. Salt River and Licking River basin boundaries and Groundwater Sample Sites in BMU 2

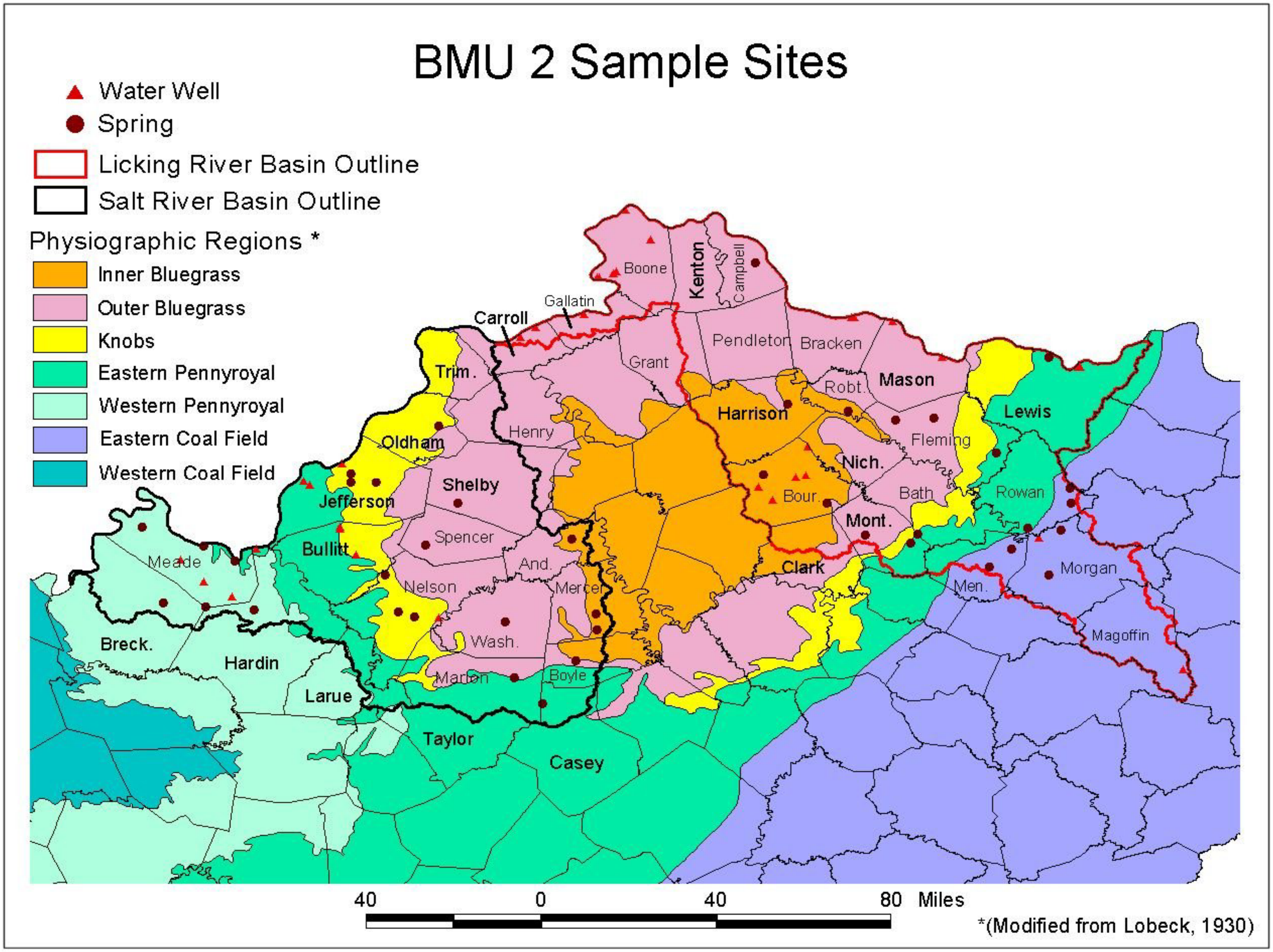


Figure 2. Physiographic Provinces

of Engineers. A dam south of Farmers in Rowan County forms Cave Run Lake, which has a summer pool of about 8,300 acres.

Salt River Basin

The Salt River rises in Boyle County and flows generally northwesterly to its confluence with the Ohio River at West Point in Hardin County. The Salt River is approximately 125 miles long and drains 2,890 square miles (ORSANCO, 2002), or about 7% of the state. The Salt River watershed drains portions of several physiographic provinces, including the Inner and Outer Bluegrass, the Knobs, and the Mississippian Plateau. In the Salt River portion of BMU 2, the Ohio River Alluvium is also an important aquifer.

Groundwater flow in the Salt River basin varies according to local geology. As in the Licking River basin, after initial runoff of precipitation, groundwater provides base flow to surface water streams, thereby sustaining stream flow during periods without rain.

Principal tributaries of the Salt River include the Rolling Fork and the Chaplin Rivers. Tributaries discharging directly to the Ohio River drain an additional 1,260 square miles adjacent to the Salt River Basin proper. Larger Ohio River tributaries in this area include Sinking, Otter, and Beargrass creeks. The largest impoundment in the basin is Taylorsville Lake in Spencer, Nelson, and Anderson Counties. The dam is located about four miles from Taylorsville and has a surface area (summer pool) of 3,050 acres.

Groundwater Sensitivity

Based upon variations in geology, topography, and hydrologic regime, groundwater underlying Kentucky's various physiographic regions has varying sensitivity to contamination from activities conducted on the surface. Groundwater sensitivity to potential impacts is based upon three primary hydrologic components: recharge, flow velocity, and dispersion. Sensitivity ranges from low (1) to high (5). In general, the quicker the recharge, the faster the flow, and the more extensive the dispersion, then the greater the sensitivity. Figure 3 illustrates generalized interpretation of groundwater sensitivity in BMU 2. Ray and others (1994) discuss this topic in detail.

In BMU 2, groundwater sensitivity ranges from high in the well-developed karst of the Mississippian Plateau and Inner Bluegrass, to low in the Eastern Coal Field, Outer Bluegrass, and Knobs regions.

Physiographic Provinces

Physiographic provinces (Figure 2) are differentiated on the basis of geology and hydrology, and therefore the physiographic map is used as a base map to present analytical data on each parameter. Five physiographic provinces occur in BMU 2: the Eastern Coal Field, the Outer Bluegrass, the Inner Bluegrass, the Mississippian Plateau, and the Ohio River Alluvium. Because each province differs in physiography and subsurface flow regime, sensitivity to contamination from nonpoint source pollution also differs. The information below is summarized from Noger (1988), McDowell (2001), and Ray and others (1994).

Generally, flat-lying Pennsylvanian-age clastic sedimentary rocks, sandstone, siltstone, shale and clay, with significant coal beds characterize the **Eastern Coal Field**, also known as the Cumberland Plateau. Erosion of this plateau has produced steeply incised, narrow valleys, with narrow ridges. Maximum local topographic relief within this portion of the study area is about 400 ft. Groundwater flow is primarily through shallow stress-relief fractures, rather than through primary porosity and permeability. Well yields are usually sufficient for domestic water supplies, and range from one to several gallons per minute (gpm) when larger fractures are encountered. High-yield municipal or industrial supply wells are rare. Springs tend to have low flows, and are usually perched on impermeable shales. Large-flow, base-level springs are rare. The Eastern Coal Field exhibits the lowest hydrogeologic sensitivity in the state, and is rated as a "1."

The **Mississippian Plateau**, also known as the Pennyroyal or Pennyrile, is characterized by flat-lying Mississippian-age carbonate rocks, primarily limestone with some dolostone. Well-developed karst

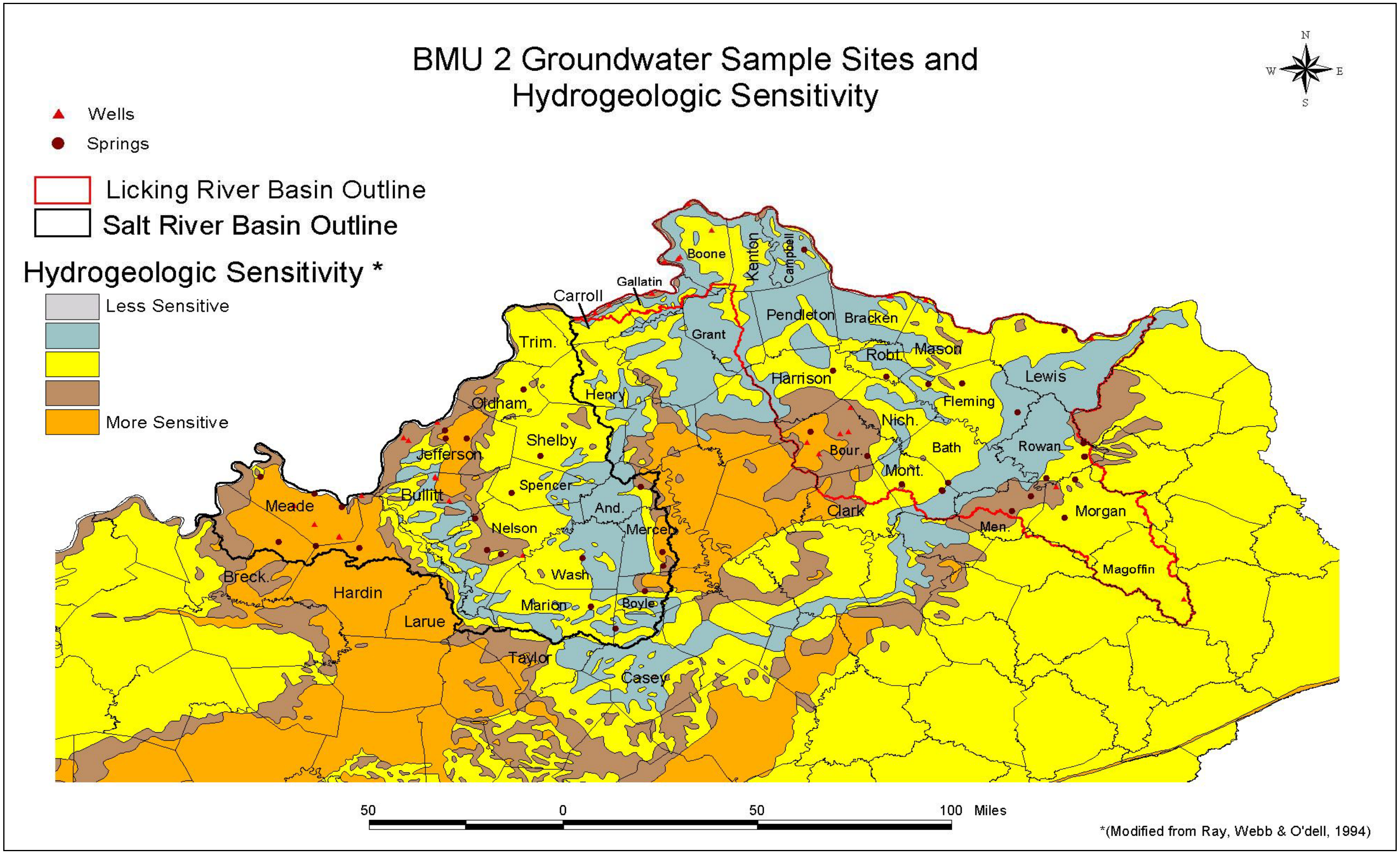


Figure 3. Monitoring sites overlain on Groundwater Sensitivity Map for Kentucky (after Ray, and others, 1994)

topography occurs in this province, with an abundance of sinkholes, caves, and sinking streams. Groundwater flow is primarily through solutionally enlarged conduits, but fracture flow and flow along bedding planes also occurs, and can be locally important. In general, yields from wells varies widely according to the size of any enlarged water-filled conduits encountered by the well-bore, and can range from less than one gallon per minute to more than one hundred. Springs developed on these thick and generally pure carbonate sedimentary rocks tend to have larger flows than other areas within the watershed, with base flow discharges ranging up to several cubic feet per second (cfs). The Mississippian Plateau is very sensitive to contamination from surface activities and rates a "5."

The **Knobs** physiographic region consists of conical hills forming a horseshoe belt almost surrounding the Bluegrass on the east, south and west. This narrow belt of hills is approximately 10 to 15 miles wide, and consists of generally flat-lying sedimentary rocks of Ordovician through Mississippian age. These hills are the eroded remnants of the Pottsville Escarpment in the Licking River watershed and Muldraughs Hill in the Salt River basin. In the Knobs, resistant Mississippian-age limestone or sandstone overlies more easily eroded shale and siltstone. Knobs are generally circular in plan view, and are characterized by ". . . symmetrical concave-upward slopes. . .[that]. . . steepen upward into cliffs on knobs with resistant caprocks. Knobs that have lost their protective caps have rounded crests." (McDowell, 2001). Groundwater flow in this region is primarily through stress relief fractures. Groundwater in this province is less vulnerable to surface contamination (Ray, and others, 1994) and generally rates a "2." Springs in this province tend to be gravity springs, perched on stratigraphic contacts, with low and commonly intermittent flows.

Generally thin-bedded, flat-lying Ordovician and Silurian-age limestones, dolostones, and shale underlie the **Outer Bluegrass** physiographic province. 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, non-integrated karst conduits and stress relief fractures. In general, Ray and others (1994) found that sensitivity in this region is low to moderate, usually rating a "2" or "3". Springs are typically low-flow (0.1 cfs or lower) and often seasonal.

The **Inner Bluegrass** is underlain predominantly by Ordovician-age limestone and shale. In general, relief is low and the area is characterized by gently rolling hills with shallow sinkholes and thick soils. Although some karst topography, such as sinkholes, caves, and sinking streams, occurs in this province, most terrain is moderately dissected by surface streams. As in the Mississippian Plateau, groundwater yield is highly variable, and for wells, depends on the number and size of water-filled fractures and conduits that are intersected by the well bore. Most wells yield one or more gallons per minute, which is sufficient for domestic supplies; however, large municipal or industrial wells and springs are rare. An exception to this is Royal Spring in Scott County, which supplies water to about 18,000 people in Georgetown. Ray and others (1994) assigned high to extreme sensitivity for the Inner Bluegrass province, rating it as "4" and "5."

The **Ohio River Alluvium** is comprised of unconsolidated sand, gravel, silt and clay deposits adjacent to the Ohio River. These deposits consist of Pleistocene age glacial-outwash sediments and modern alluvial sediments. Coarse sand and gravel beds in these deposits supply large volumes of water to industrial, municipal, and domestic wells. Large diameter conventional wells commonly produce yields of 2000 gallons per minute, and radial collector wells can produce even greater amounts of water. Because groundwater can travel quickly through these coarser sediments, Ray and others (1994) rated sensitivity as high, or "4."

In addition, some alluvium deposits thick enough to serve as viable aquifers are also present along the larger rivers in this BMU, especially on lower reaches. However, these alluvial aquifers are generally thinner and finer-grained than the Ohio River Alluvium, but are nevertheless also highly sensitive to contamination. Note that although alluvial areas do not show up at the scale used for the maps in this report, these aquifers are nevertheless important along the Ohio River as well as along some other major drainages, particularly in their lower reaches.

Land Use

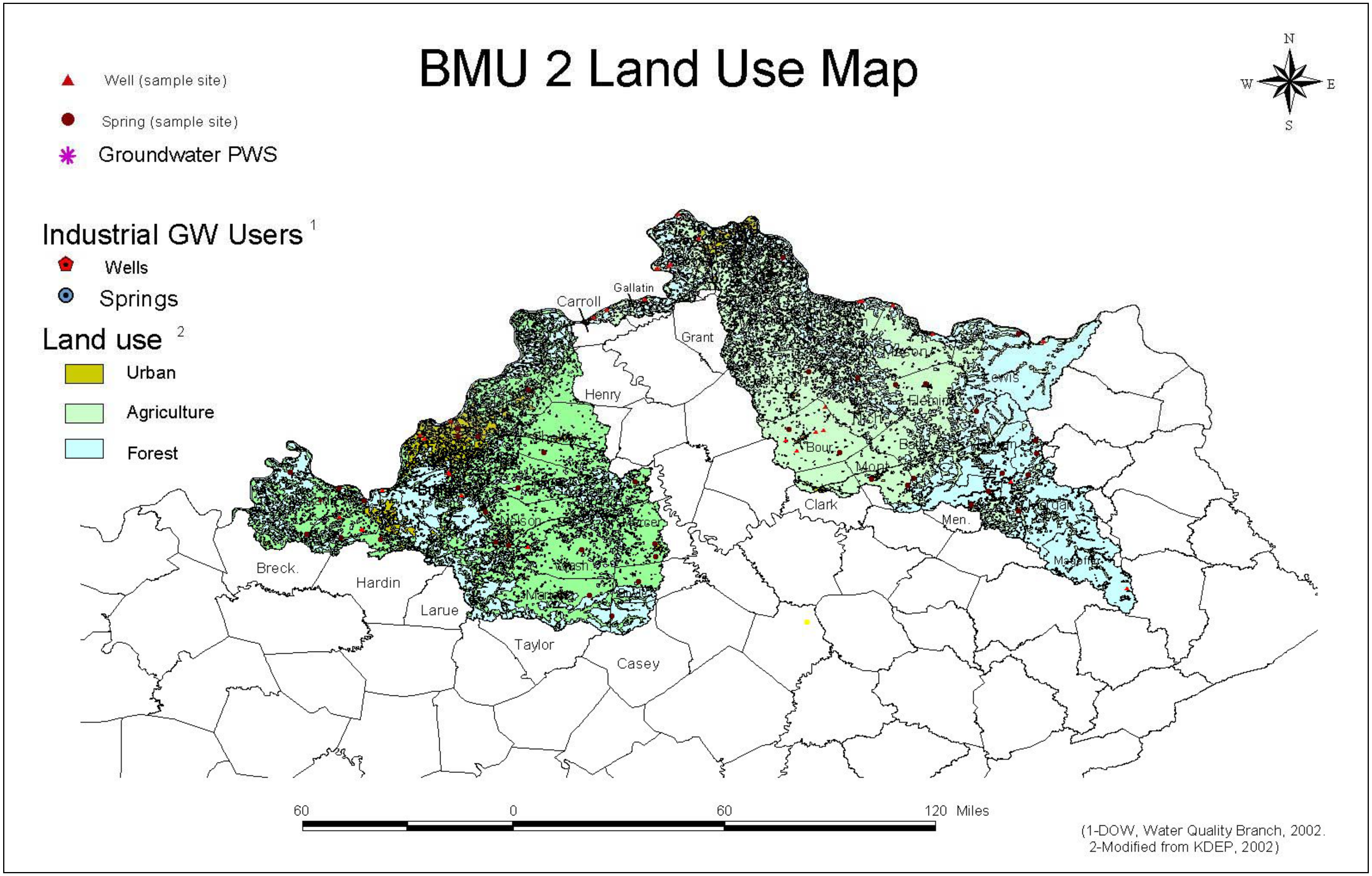
Land use is an important consideration regarding potential impacts to groundwater quality (Figure 4). Approximately 7% of the surface area in BMU 2 is urban, 54% is agricultural (row crop or pasture), and 39% is forest. In order to simplify the map, forest usage is combined with the relatively insignificant amount of surface area covered by wetlands, lakes and reservoirs, and reclaimed strip mines. Little active coal mining has occurred the last six years in BMU 2, according to the Kentucky Department of Mines and Minerals (2002). The two primary coal-producing counties in BMU 2 are Magoffin and Morgan. Magoffin County reported two small surface-mining operations and Morgan County four (one underground and three surface) during this period. The Magoffin County mines were inactive by 1999 and neither county reported any active mining for 2001. Table 3 illustrates potential nonpoint source impacts to groundwater from varying land use.

Table 3. Land Use and Potential Nonpoint Source Contaminants

Land Use	% in BMU 2	Potential Contaminants
Agriculture, including row crop production, livestock grazing, fuel/pesticide storage	54	Pesticides, nutrients (esp. nitrate-n), salts/chloride, volatile organics, bacteria
Urban	7	Pesticides, volatile organics, chlorides
Forested, including mining, logging, silviculture	39	Metals, pesticides, nutrients, sediment, pH

Groundwater Use

Groundwater is an important resource in BMU 2, providing private and public drinking water, as well as water for industrial and agricultural purposes. Additionally, groundwater recharge provides water to maintain base flow to surface water streams after run-off from precipitation events. In BMU 2, groundwater is widely used for industrial purposes, as well as for both publicly-supplied and private drinking water. Permitted industrial users and larger public water supply systems are concentrated along the Ohio River and utilize the alluvial aquifer, as shown in Figure 4. Public water systems, serving 68,713 people, that use groundwater in BMU 2 are shown in Table 4. In addition, the Louisville Water



(1-DOW, Water Quality Branch, 2002.
2-Modified from KDEP, 2002)

Figure 4. Land Use Map for BMU

Table 4. Public Water Systems in BMU 2 With Groundwater Source (KDOW, 2002b)

Public Water System	County	Population Served
Trapp Water Company	Boone	450
Arlinghaus Property	Boone	36
Birkle Water Supply	Boone	260
Bullitsburg Baptist Assembly	Boone	25
Camp Turnabout	Boone	429
Cincinnati Gas & Electric	Boone	150
River Ridge Park	Boone	150
Rivershore Sports Complex	Boone	25
Riverland Park	Boone	50
Kelley Elem. School	Boone	355
Potters Ranch	Boone	100
Augusta Regional WTP	Bracken	1,369
Addison Well	Breckinridge	14
Grahm Mobile Home Park	Bullitt	18
St. Anne Convent	Campbell	150
Grove Trailer Court	Campbell	12
Wren Road Campsites	Campbell	24
Thomas More College	Campbell	45
Nienaber Property	Campbell	9
H and H Farms	Campbell	15
The Roost Mobile Home Park	Campbell	23
Tiemeier Fishing Lake	Campbell	24
Doyle Club and Camp	Campbell	52
Carroll Co. WD #1	Carroll	5,085
Carrollton Utilities	Carroll	6,366
K. U. Ghent Station	Carroll	245
Dow Corning Corp.	Carroll	511
Ameriform Manufacturing	Carroll	127
Warsaw Water Works	Gallatin	2,310
River's Edge Campground	Gallatin	132
Far-Vue Farm	Gallatin	20
I 75 Campers Village	Grant	145
West Point Water Dept.	Hardin	1,200
Wallace Farm	Jefferson	50
Hosbrau Haus	Jefferson	15
Garrison/Quincy Heights WD	Lewis	2,836
Vanceburg Elec. Plant Board	Lewis	6,184
W. Lewis/Rectorville WD	Mason	4,627
W. Mason Co. WD	Mason	2,247
Brandenburg Water Works	Meade	4,214
Ekron Water System	Meade	244
Kozy Corners Trailer Park	Meade	20
Arch Chemicals	Meade	650
Salem Baptist Camp	Meade	23
Aqua Source/Goshen	Oldham	5,877
Oldham County WD	Oldham	13,860
Milton Water/Sewer Dept.	Trimble	3,630
Trimble Co. WD #1	Trimble	4,310
TOTAL		68,713

Company, which supplies drinking water to more than 750,000 people, produces 12% of its total daily production from groundwater. Groundwater from wells or springs provides private drinking water to approximately 31,350 people in the Salt River portion of BMU 2 and about 28,770 people in the Licking River portion, for a total of 61,120 (KGS, 2002). No figures are available for the agricultural use of groundwater, which does not require a permit. This use includes irrigation, livestock watering, and general farm use. Although no figures are available, field observations indicate that such use is significant. Principal aquifers within the Salt and Licking River basins are shown in Table 5.

Table 5. Simplified Aquifer Characteristics in BMU 2

Geologic Age of Aquifer	Predominant Rock Type	Predominant Sub-Surface Flow	Characteristic of Physiographic Province
Pennsylvanian	Sandstone, siltstone, shale & coal	Fracture	Eastern Coal Field
Mississippian	Limestone & dolostone	Well-developed Conduits	Mississippian Plateau
Silurian, Devonian	Limestone, shale	Fractures, Conduits	Knobs
Ordovician	Limestone, shale	Fractures, Conduits	Bluegrass (Inner and Outer)
Quaternary	Unconsolidated Sand, silt, & gravel	Granular	Ohio River Alluvium

MATERIALS and METHODS

Introduction

Parameters that are most indicative of nonpoint source pollution, as well as those parameters necessary to characterize naturally occurring groundwater chemistry, and the values against which the raw data were compared, are shown in Table 1. Basic water quality chemistry can be determined from common, naturally occurring major inorganic ions, metals, residues, conductivity and pH. Parameters that are not naturally occurring are the best indicators of nonpoint source pollution and include pesticides and volatile organic compounds. Reference values used for comparison are from a variety of sources and there is no consensus regarding the appropriateness of comparing ambient groundwater with these standards. Therefore, the derivation of these standards and the applicability of them to groundwater are discussed below.

Sample results from this study were compared to a variety of existing standards, referred to as "reference values" in this report. Many of the parameters have limits established by the United States Environmental Protection Agency (USEPA, 2000) for treated drinking water supplied to the public. The USEPA defines three types of drinking water standards: Maximum Contaminant Levels, Secondary Drinking Water Regulations, and Health Advisories:

Maximum Contaminant Level (MCL) is defined (USEPA, 2000) as "the highest level of a contaminant that is allowed in drinking water." MCLs are legally enforceable limits applied to "finished" public drinking water based on various risk levels, ability to treat, and other cost considerations. MCL standards are health-based and are derived from calculations based on adult life-time exposure, with drinking water as the only pathway of concern. These standards are also based upon other considerations, including the efficacy and cost of treatment.

Secondary Drinking Water Regulations (SDWR) are defined by the USEPA (2000) as "non-enforceable Federal guidelines regarding cosmetic effects (such as tooth or skin discoloration) or aesthetic effects (such as taste, odor, or color) of drinking water." In common usage, this is often referred to as **S**econdary **M**aximum **C**ontaminant **L**evel (**SMCL**), and this usage has been adopted for this report.

Health Advisory (HA) is defined (USEPA, 2000) as "an estimate of acceptable drinking water levels for a chemical substance based on health effects information; a Health Advisory is not a legally enforceable Federal standard, but serves as technical guidance to assist Federal, state, and local officials." Again, reflecting common usage, this term has been modified slightly and is referred to in this document as the **H**ealth **A**dvisory **L**evel (**HAL**).

Many parameters discussed in this report have no MCL, SMCL, or HAL. These parameters were compared to a variety of existing standards. These include proposed, but not adopted, Department for Environmental Protection (DEP) standards for **m**ethyl ***tert*-b**utyl **e**ther (**MTBE**), atrazine, and ammonia; the Kentucky Pollution Discharge Elimination System (KPDES) standard for total suspended solids discharged to surface waters; and the USGS recommended surface water standard for total phosphorous.

Although established water quality standards provide a valid window through which to view the data, perhaps the most important tool is to compare data with water quality from sites known to have minimal impact from anthropogenic activities. Adopting the language used for similar surface water areas, these sites are informally called "reference springs" or "reference reach springs." Unfortunately, such sites are rare, and may not truly exist, given that atmospheric deposition from automobiles, power plants, and other sources, is ubiquitous throughout the Commonwealth. Reference reach springs that represent the least impacted groundwater in the state are nevertheless considered important for comparison. These sites drain forested areas unimpacted by routine surface land uses, such as recent logging, agricultural, industrial, or residential use. References springs include Cameron Spring in Lewis County (located in BMU 2), and two springs outside of this study area: Fred Mullin Spring in Rockcastle County and Nada Spring in Powell County.

Reference reach *wells* in BMU 2 are virtually non-existent, given that wells are typically installed adjacent to homes, farm areas, or businesses and therefore inherently reflect anthropogenic influences. In addition, wells in BMU 2 usually produce from shallow, unconfined aquifers. Wells completely cased through shallower aquifers and that produce from deep, confined aquifers protected from surface influences could be considered for reference purposes. However, these wells are rare in BMU 2.

Although some parameters, such as pesticides, can only come from anthropogenic sources, others, such as metals, inorganics, and many organic compounds, can be both naturally occurring and from man-made sources. Therefore, reviewing land-use in conjunction with geochemical data, as well as comparing data with that from reference reach springs, can help differentiate between anthropogenic and natural sources.

Statistical and Graphical Methods

Project data were evaluated with summary statistics, summary tables, box and whisker plots, cumulative frequency curves, and graduated-size maps. **Summary statistics** list simple statistics, including minimum and maximum values, median and mode. **Summary tables** list number of samples, numbers of detections, and the number of detections above the particular standard of comparison for that parameter, such as MCL. **Graduated size** maps show analytical results as symbols that increase in size as values increase. These maps show the highest value for each site.

According to Hall (2002), a **box and whisker plot**, or simply "boxplot," is ". . .a graphical representation of dispersions and extreme scores. Represented in this graphic are minimum, maximum, and quartile scores in the form of a box with 'whiskers.' The box includes the range of scores falling into the middle 50% of the distribution (**I**nter **Q**uartile **R**ange [IQR] = 75th percentile **-** 25th percentile) and the whiskers are lines extended to the minimum and maximum scores in the distribution or to the mathematically defined (+/- 1.5* **IQR**) upper and lower fences." For a full discussion of boxplots, see Appendix D.

Analyte samples for which there was no detection, based on analyte-specific testing methods and test-specific detection limits, are referred to as "censored observations" in the boxplots. A conservative approach was taken regarding these censored observations by plotting these data at their detection limit. The boxplot provides a pictorial representation of the data, showing the distribution of the data set. The censored data have values between zero and the detection limit, and since the detection limit is typically low, the clustering of uncensored observations at this detection limit does not provide an unrealistic interpretation of the overall data set.

Cumulative frequency curves are graphs that show the cumulative totals of a set of values up to each of the points on the graph. The horizontal, or x-axis, shows the values for the parameter, and the vertical, or y-axis, shows that percent, from 0 up to 100. Therefore, this curve represents a "running total" of the values found. Curves that are long on the horizontal axis indicate a wide range of values; conversely, frequency curves that are more nearly vertical indicate a narrow range of values.

In order to simplify the boxplots and summary tables, data for sites in the Knobs and Outer Bluegrass Physiographic Provinces are included in the Bluegrass category. The graduated size maps are overlain on a physiographic map that differentiates these provinces, so variations in the results, if any, between these similar terranes can be noted. Additionally, at the map scale used in this report the Ohio River Alluvium cannot be effectively illustrated. Therefore, care must be exercised in the interpretation of sites along the northern border of the study area. A good rule of thumb is that *wells* located on the northern edge of the area are likely in the Ohio River Alluvium, whereas springs are not.

Boxplots comparing data from the various physiographic provinces represented in BMU 2 and graduated size maps are presented and discussed in the body of this report. Cumulative frequency curves, summary statistics, summary tables, and additional boxplots are presented in Appendix C.

Site Selection

The Groundwater Branch selected sites by a modified probabilistic approach in order to provide representative geographical distribution throughout the two basins. Under this approach, sites in thirty 7.5 minute quadrangles were chosen randomly for inclusion in this study. The distribution of sites selected using this method therefore provided un-biased monitoring sites representative of various land-uses, each with characteristic nonpoint source threats, as well as varying aquifer types of differing inherent groundwater sensitivity. This probabilistic approach was modified because in addition to selecting sites randomly through the use of 7.5 minute quadrangle maps, numerous other maps and data were used to facilitate site selection, including Hydrologic Atlases, the Division for Environmental Protection's (DEP) Groundwater data base, and field reconnaissance.

In general, previously sampled 7.5 minute quadrangles were omitted from this study. Public water supplies using groundwater were given preference over private supplies and unused sources. Some easily accessed springs (commonly called "road-side" springs) that are used locally for drinking water were selected for this study and are noted as "unregulated public access springs". Little information is available regarding the number of people using such springs, however, observations by DOW personnel indicate that some of these springs are used by a significant number of people. Springs were given preference over wells, because generally the drainage area of a spring can be more easily determined and because of the shallow and quick flow systems typical of springs, they are usually more susceptible than wells to nonpoint source pollution.

Because this study was designed to assess ambient groundwater conditions, those areas with known point source discharges were eliminated from consideration. For example, sites affected by leaking underground storage tanks or landfills were not sampled as part of this study. Finally, other important considerations included accessibility of the site and permission to access the site.

A unique eight-digit identification number catalogs wells and springs maintained in the DEP's database. If a well or spring selected for this study had not been assigned an eight-digit identification number, a well inspection or spring inventory form was completed and a unique identification number was assigned. The inspection or inventory form notes details of the site, including owner's name and address, location, well construction or spring development data, yield, and topographic map location. The data are then entered into DEP's electronic database and forwarded to the Ground Water Data Repository at the Kentucky Geological Survey. Site locations are plotted on 7.5 minute topographic quadrangle maps maintained by the Groundwater Branch and the forms are scanned and stored in a database as an indexed electronic image.

Sites selected specifically for this nonpoint source study, as well as other sites monitored for other programs included in the data analysis, are listed in Appendix D. Geochemical data from 80 sites were analyzed for this project. The entire study area consists of more than 9,000 square miles, or an average of one sampling site per 110 square miles. Although data are inadequate to fully characterize the groundwater geochemistry of the area, this data greatly expands the knowledge that was previously available, especially before 1995.

Sample Collection Methods

Consistent with the Division of Water's other ambient groundwater monitoring efforts, samples of fresh, untreated groundwater were collected at each spring or well and analyzed for: major inorganic ions; nutrients; volatile organic compounds; total organic carbon; pesticides, including the most commonly used herbicides, insecticides, and fungicides; and dissolved and total recoverable metals. The analytical methods, containers, volumes collected, preservation, and sample transport are consistent with the Division of Water's Kentucky Ambient/Watershed Water Quality Monitoring Standard Operating Procedure Manual, prepared by the Water Quality Branch (2002c). Parameters to be measured, volume required for analysis, container type, and preservative are shown on the attached Chain-of-Custody Form (Appendix F).

Major inorganic ions are used to establish background groundwater chemistry and also to measure impacts from nonpoint source pollutants such as abandoned mine lands and abandoned hydrocarbon production operations by measuring pH, alkalinity, chloride, sulfate, and fluoride. Nutrients and total organic carbon are used to measure impacts from agricultural operations (ammonia, nitrate-n, nitrite-n, total Kjeldhal nitrogen, total phosphorous, and orthophosphate) and/or improper sewage disposal (nitrates, ammonia). Where sewage was suspected as a nonpoint source pollutant, unbleached cotton fabric swatches were used to detect optical brighteners, the whitening agents used in laundry products and commonly found in sewage (Quinlan, 1986). Pesticides are measured to determine both rural agriculture and urban domestic- and commercial-use impacts on groundwater. Metals are useful to establish rock-groundwater chemistry, local and regional background levels, and to determine nonpoint source impacts from active or abandoned coal mining operations. Volatile organic compounds determine impacts from urban run-off, oil and gas production, or other point and nonpoint source impacts to groundwater.

Sampling for pathogens was not conducted because of logistical considerations. Sampling at numerous sites occurred over a one or two-day period, commonly in remote regions. Because of the short holding time for bacteria (6 hours for fecal coliform, 24 hours for total coliform) we were unable to sample efficiently and regularly collect bacteria samples and comply with the required holding times.

All samples collected to meet grant committments were analyzed by the Division of Environmental Services (DES) laboratory according to appropriate USEPA methods. Additional data included in this study are from samples analyzed by DES for other groundwater projects, as well as data from the Kentucky Geological Survey laboratory. Appropriate USEPA analytical methods were employed for all data used in this report.

RESULTS and DISCUSSION

Water Quality Results

General water quality information, including definitions and sources, were compiled from numerous sources, primarily Hem (1985), USGS (2002a), and Driscoll (1986). Potential impacts to human health were compiled from the United States Environmental Protection Agency (USEPA 2002a) and the Agency for Toxic Substances and Disease Registry (ATSDR, 2001).

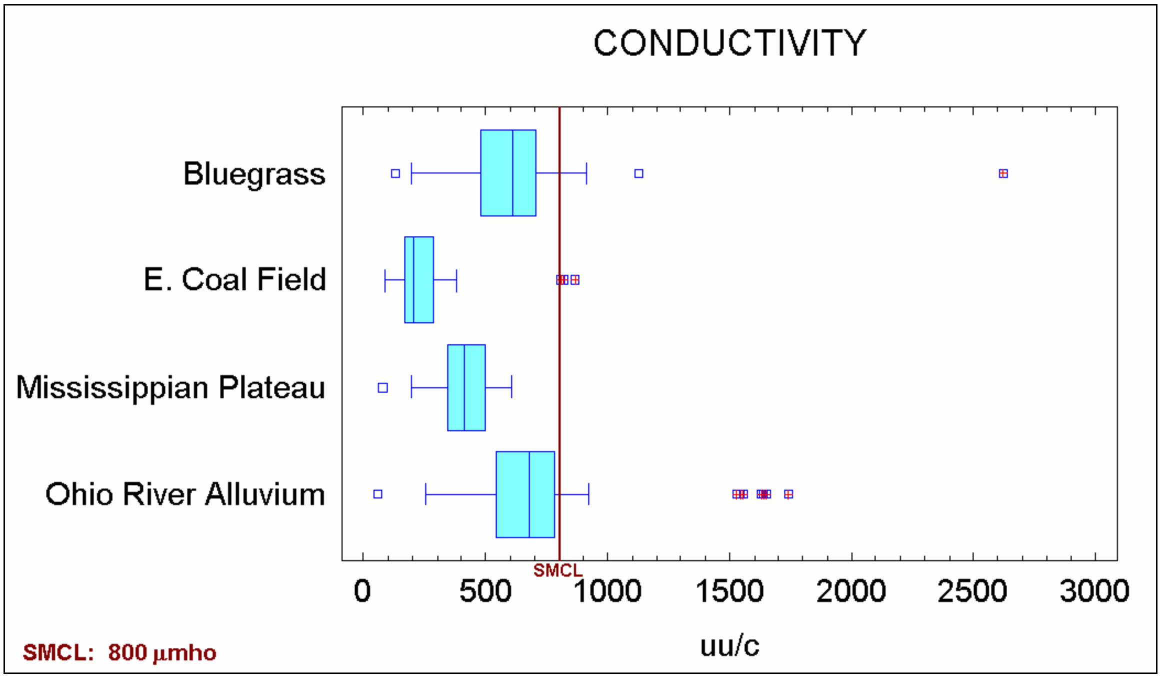
Parameters were divided into seven categories: hydroparameters (which includes conductivity, hardness, and pH), inorganic ions, metals, pesticides, residues, volatile organic compounds, and nutrients.

Hydroparameters (conductivity, hardness, and pH)

Conductivity, also known as specific conductance, is a measurement of the ability of water to conduct electrical current (Hem, 1985) and is reported in microsiemens (µS/cm). Since a microsiemen is the reciprocal of an **ohm**, the spelling of that latter unit has been reversed as an equivalent unit used to report conductivity. The term for a microsiemen reported in these units is "µ**mho**." Some laboratories report this as "uU/cm”. Therefore, 800 mS/cm = 800 µmho = 800 uU/cm. There is no MCL or other regulatory standard for conductivity; however, 800 µmho corresponds roughly to the 500 mg/L SMCL for Total Dissolved Solids, or TDS. Because conductivity increases as the amount of dissolved ions increases, it may be used as a general indicator of water pollution. However, caution should be exercised in the interpretation of conductivity results, as naturally occurring ions dissolved in water will result in elevated measurements. These ions include chloride, sulfate, iron, carbonate, calcium, and others.

The boxplot for conductivity (Figures 5 and 6) showed a wider variation in values for the Bluegrass and the Ohio River Alluvium than for the other physiographic provinces. In the Bluegrass, this is most likely the result of the natural variability of Total Dissolved Solids (TDS) in this system consisting largely of soluble carbonate bedrock. Lower values in the Eastern Coal Field most likely result from the prevalence of clastic sedimentary rocks, which are less soluble than the karstic, more readily dissolved carbonate rock predominating in the Bluegrass and Mississippian Plateau. Relatively high values in the Ohio River Alluvium may result from longer residence times of groundwater in these

Figure 5. Boxplot for Conductivity measurement distributions in BMU #2



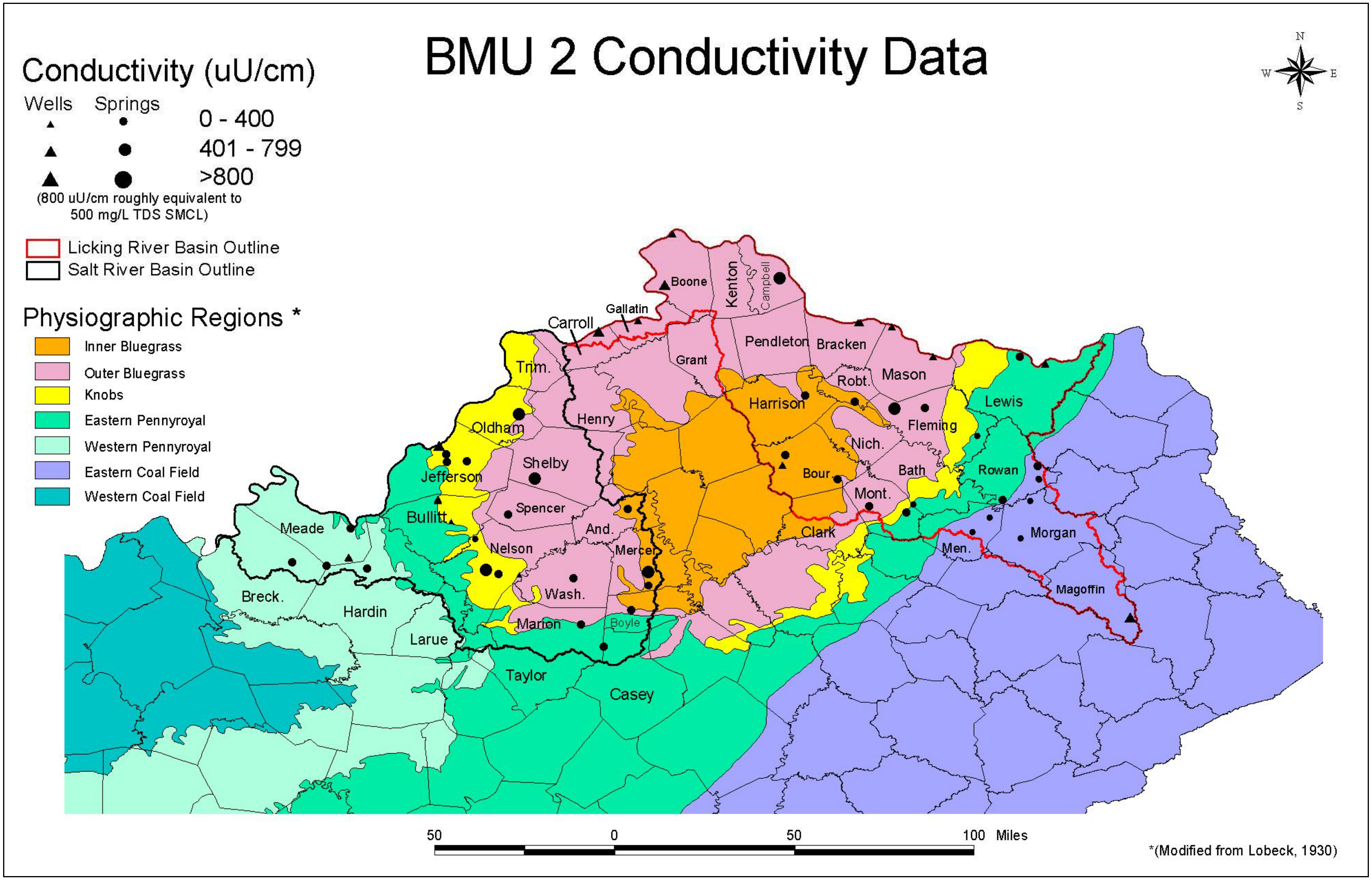


Figure 6. Map of conductivity data in BMU 2

heterogeneous, unconsolidated sediments. Conductivity values found in this study are comparable to those found by Carey and others (1993). In their study of 4,859 groundwater analyses throughout the state, an average value of 495 uU/cm was found, compared to a median value of 578 uU/cm for the 314 samples included in this study. Because conductivity measures a variety of ions, most of which are naturally occurring, the interpretation of this parameter alone as an indicator of nonpoint source pollution is difficult. Absent any direct evidence to the contrary, the range of values found in this study most likely reflect ambient conditions and are not necessarily indicative of nonpoint source pollution.

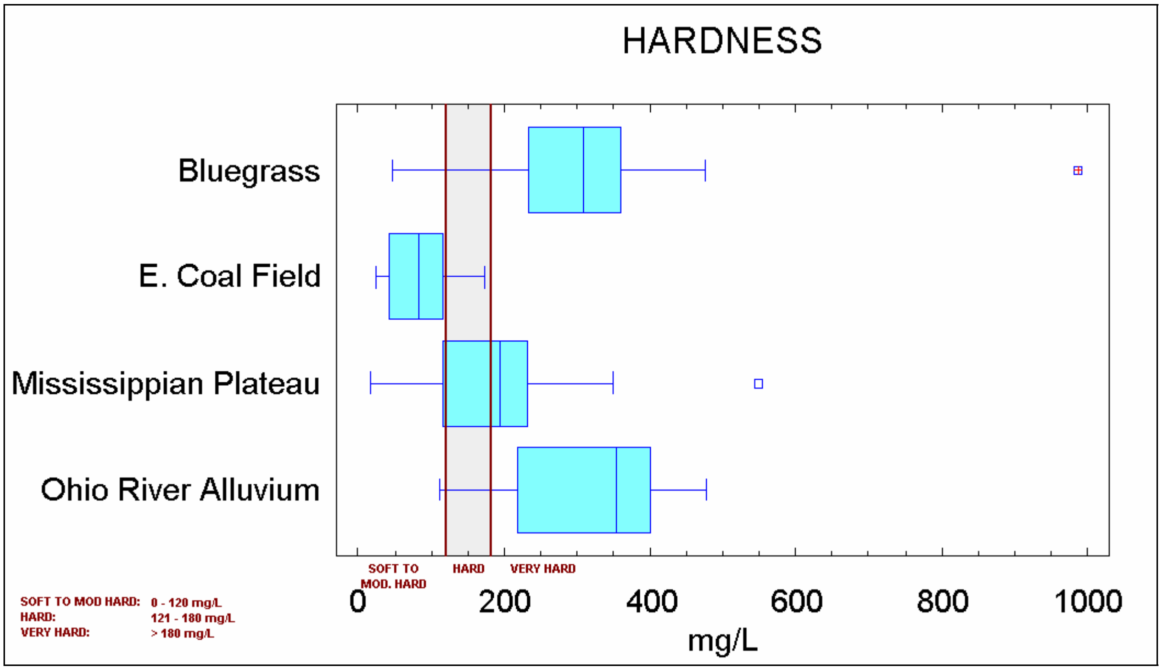
The term "hardness" was first used to describe water that was hard to lather. Water is made hard primarily from dissolved calcium and magnesium. Hardness measures the ability of water to produce soap lather, or suds, and is reported as equivalent $CaCO_3$ in mg/L derived from: (2.5 x mg/L Ca) + (4.1 x mg/L Mg). Hardness typically causes scaling on water pipes, boilers, and in cooking pans, causing problems in the laundry, kitchen, and bath. Water with excessive hardness may taste chalky, salty, or metallic, depending on the relative concentrations of various dissolved compounds. On the other hand, very soft water often has a flat, unpleasant taste. Most consumers, therefore, prefer to drink water of moderate hardness.

No regulatory standards exist for hardness. The Water Quality Association (2002) hardness scale has been modified for this report, where soft water is defined as less than 17 mg/L of calcium/magnesium, water from 17.1 to 120 mg/L is moderate, and more than 120 mg/L is hard.

The boxplot illustrating the distribution of hardness values (Figure 7) shows that median values for groundwater are very hard in all physiographic provinces of BMU 2, except the Eastern Coal Field. This reflects the abundance of calcium and magnesium, mostly derived from carbonate sedimentary rocks, in the Bluegrass, Mississippian Plateau, and Ohio River alluvial aquifer. This is indicative of ambient conditions, rather than of nonpoint source impacts.

Hardness values are generally high in both springs and wells throughout the study area (Figure 8). Lowest values are in the Eastern Coal Field in which clastic sedimentary rocks, generally low in calcium and magnesium, are dominant.

Figure 7. Boxplot for Hardness measurement distributions in BMU #2



pH is the negative log of the concentration of the hydronium ion and is essentially a measure of the relative acidity or alkalinity of water. The units of pH are dimension-less and the scale measures from 0 to 14. In this system, 7 represents neutral pH and values less than 7 are more acidic, values greater than 7 are more alkaline. The relative acidity/alkalinity of water is important in regard to water quality because this affects several qualities: the corrosiveness of the water, the ability to dissolve contaminants such as heavy metals, the taste of the water for human consumption, and in general the overall usefulness of water for various industrial functions. The pH range of normal aquatic systems is between 6.5 and 8.0. Low pH levels can indicate nonpoint source impacts from coal mining or other mineral extraction processes. High pH values for groundwater may indicate nonpoint source impacts to groundwater from brine intrusion from current or former oil and gas exploration and development activities. Concerning potability, pH is an aesthetic standard, with an SMCL range of 6.5 to 8.5 pH units.

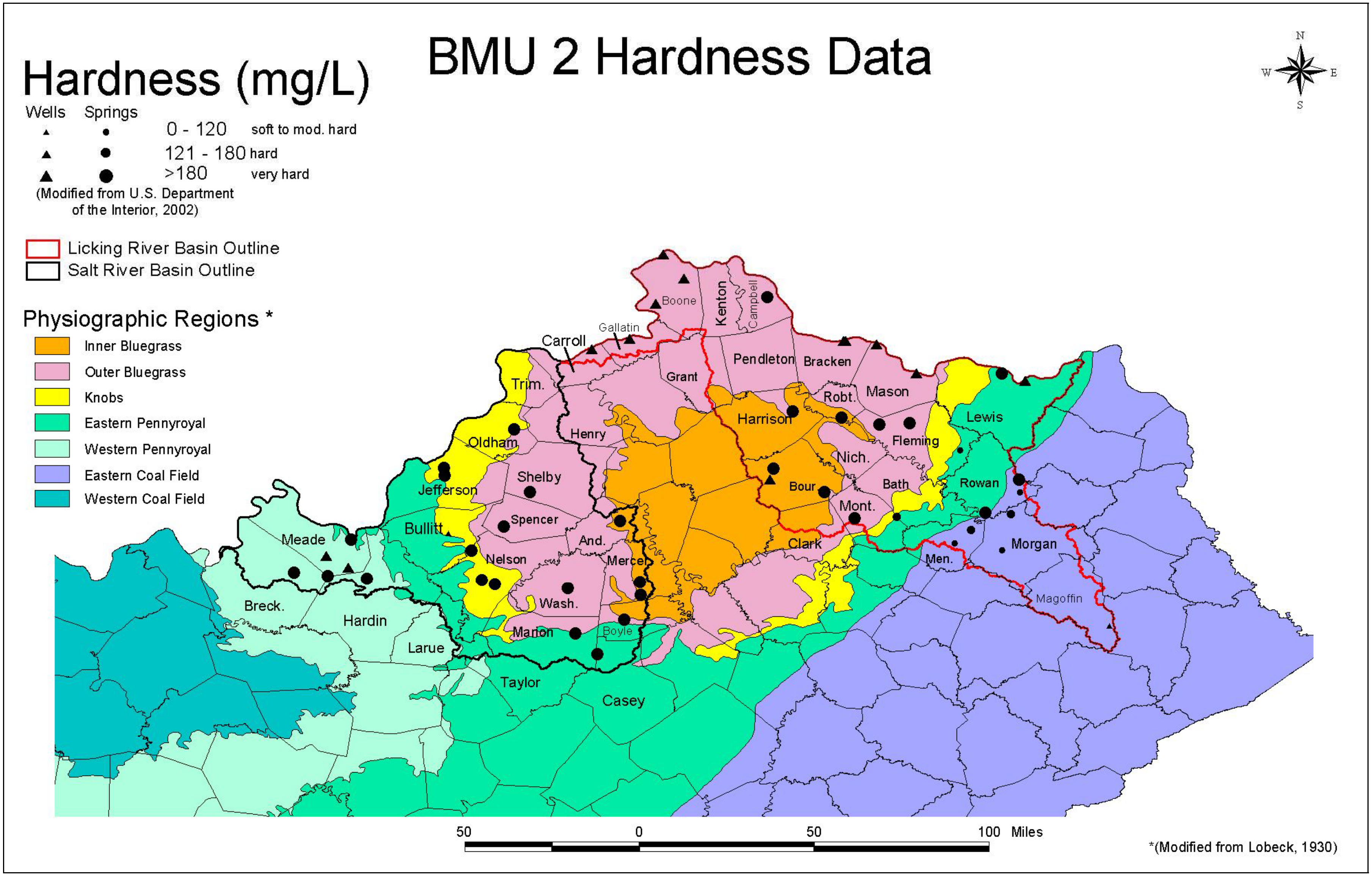
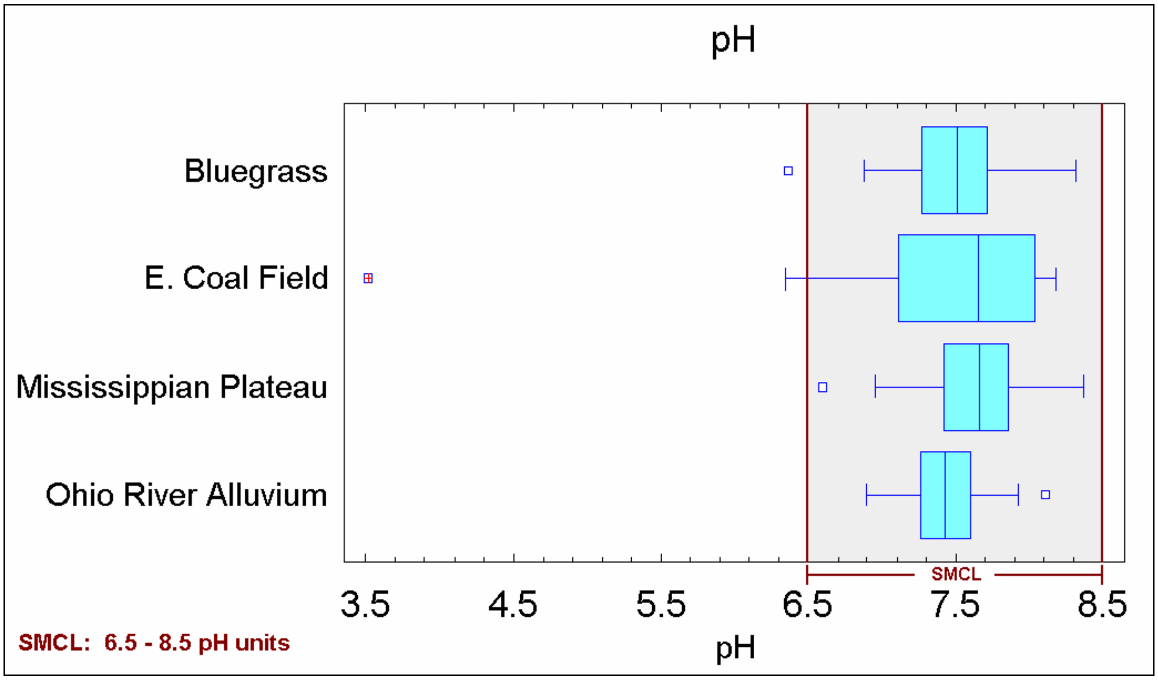


Figure 8. Map of hardness data in BMU 2

Figures 9 and 10 show that almost all pH values are within the SMCL range of 6.5 to 8.5 units. The greatest variability is in the Eastern Coal Field, with the outliers at approximately 3.5 and 6.4 pH units (from Magoffin and Rowan Counties). The first measurement is from a one time only sampling event at a site draining predominately carbonate rocks of Mississippian-age, and is anomalous and unexplained. The later site is in an un-mined area dominated by Pennsylvanian-age sedimentary rocks, including coal, and may represent naturally occurring conditions. Based on current knowledge of both sites, neither nonpoint source pollution. The other physiographic provinces show natural variability and because there is no direct evidence of nonpoint source influences on pH in areas adjacent to the studied sites, the conclusion is that there are no probable impacts from nonpoint source pollution. The outlier in the Bluegrass occurred at Humane Spring in Mercer County. This site has known impacts from a manufacturing facility point source. This site is monitored in support of the Kentucky Division of Waste Management's oversight of remediation at this facility and to provide additional long-term data from this source, as well as to document possible future impacts from further development in this area.

Figure 9. Boxplot for pH measurement distributions in BMU #2



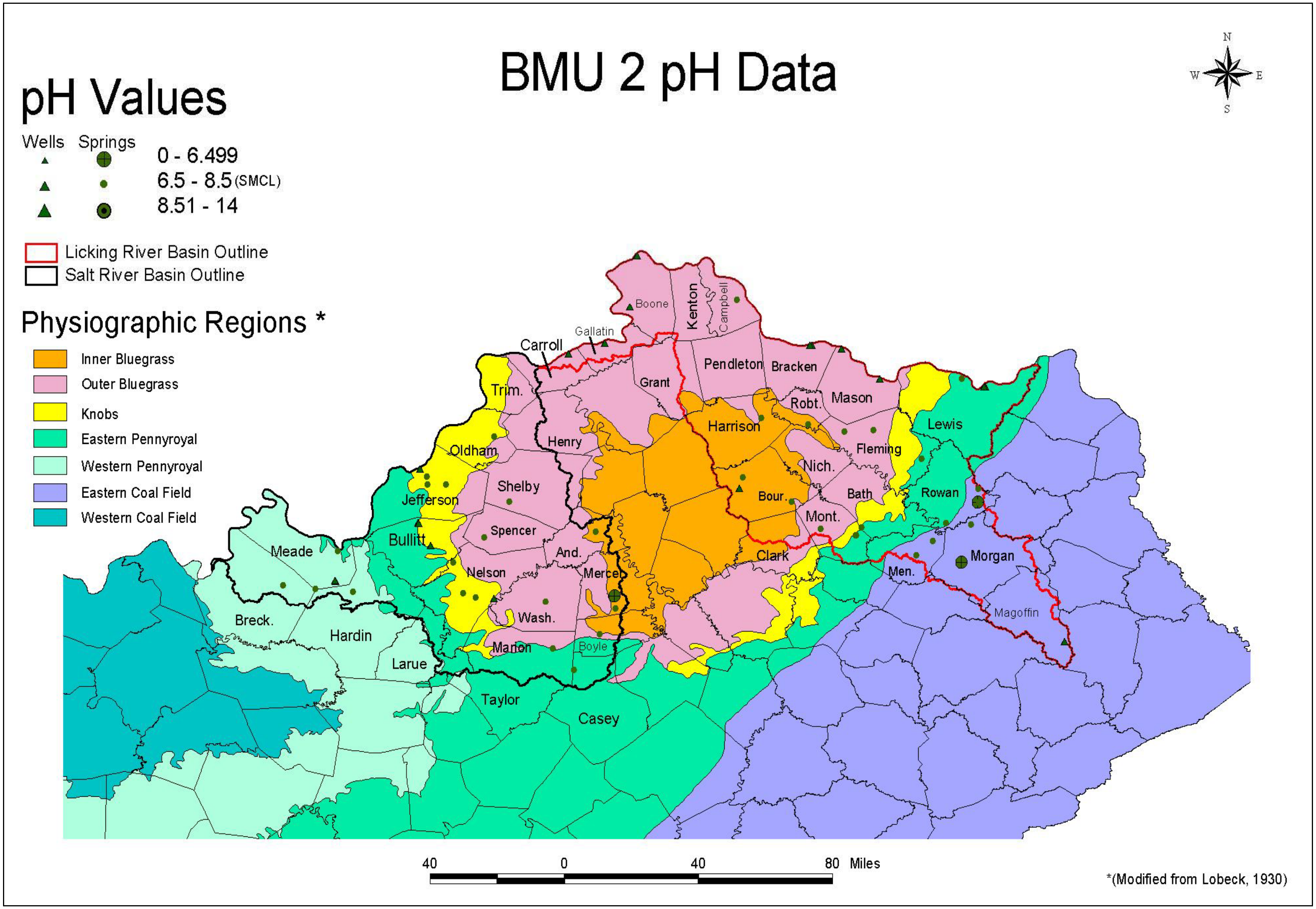


Figure 10. Map of pH Date for BMU 2

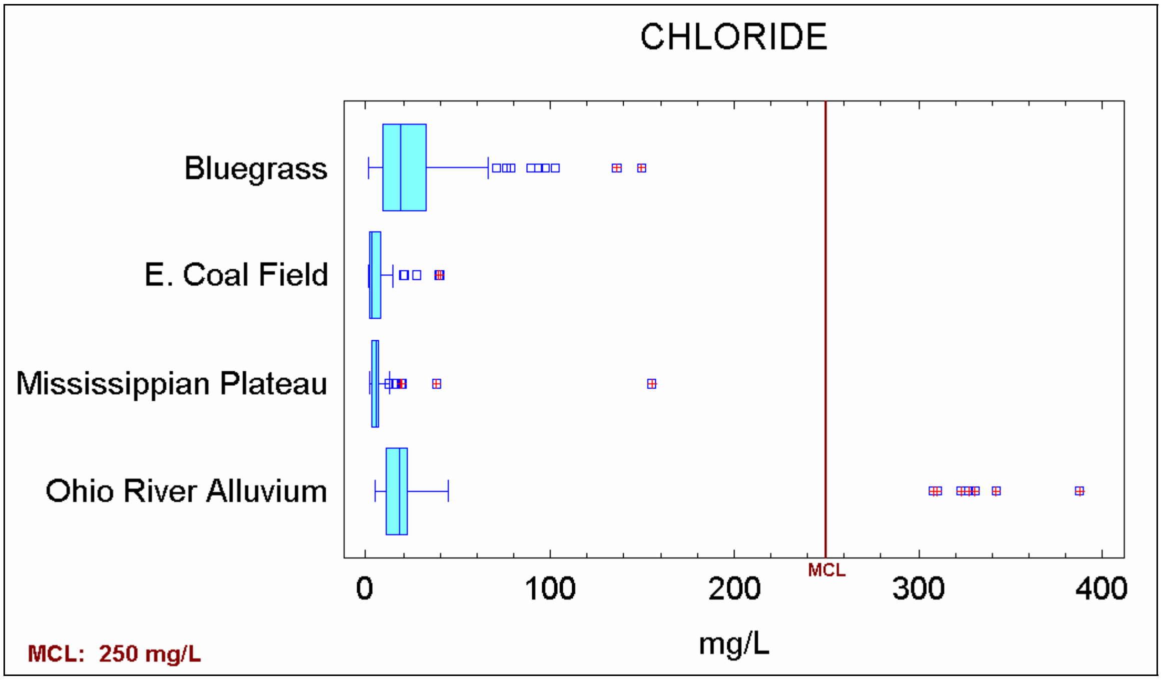
The low pH values discussed above occur in Magoffin and Rowan Counties, in the Eastern Coal Field, but do not appear to indicate nonpoint source pollution.

Inorganic Ions (chloride, fluoride, and sulfate)

Chloride (Cl) is naturally occurring in most rocks and soils, and is the primary constituent that makes water "salty". Chloride also occurs in sewage, industrial brines, and in urban run-off from the application of road salt. Brine water, or "connate water", occurs in the pore spaces and fractures of rocks and is sometimes found at shallow depths, especially in eastern Kentucky. Typically, however, water gradually becomes saltier as the depth increases. Over-pumping of fresh water in some wells can induce chloride-rich brines which occur at depth to move, or "up well", toward the discharge point. This phenomenon is known as "salt water intrusion". As nonpoint source pollutants, chlorides are also associated with crude oil and are commonly produced as a by-product when oil is pumped to the surface. For disposal, these brines are typically re-injected into very deep, and already briny, formations. Further, chloride-rich brines can contaminate fresh-water aquifers through improperly cased or abandoned oil production wells.

In general, the boxplot for chloride (Figure 11) shows low chloride values in BMU 2. In Kentucky, high chlorides sometimes occur at shallow depths, and because no specific point sources of chlorides occur adjacent to the sites sampled in this study, the variation observed is probably natural. The highest values found in this study were for a test well pumped continuously for long periods in the Ohio River Alluvium at Louisville (Figure 12). High chloride values in this well may result from the intrusion of chloride-rich water from underlying aquifers, which as previously noted can "up well" during over-pumping of shallower aquifers. Lower chloride values, well under the MCL, are distributed throughout the study area.

Figure 11. Boxplot for Chloride measurement distributions in BMU #2



Fluoride (Fl) commonly occurs in trace quantities in many soils and rocks, including coal. Fluorite (CaF_2) is the primary fluorine mineral. Additionally, fluoride in the form of hydrogen fluoride enters the environment through atmospheric deposition from coal-fired power plants and from some manufacturing processes, especially aluminum smelting. Because small amounts of fluoride (1 ppm) in water help prevent tooth decay, public water systems often add this to their water. Some researchers claim this practice is potentially harmful, and therefore the efficacy of drinking water fluoridation is a widely debated issue. The MCL for fluoride is 4 mg/L. Exposure to excessive amounts of fluoride can result in dental and skeletal fluorosis. Brittle, mottled, and discolored tooth enamel characterizes dental fluorosis. Skeleton fluorosis causes a wide range of muscle and bone problems, including osteoporosis.

Figures 13 and 14 indicated that fluoride showed a narrow range of values for most of the data. Because no apparent nonpoint sources of fluoride other than possible effects from atmospheric deposition were noted, outliers may be indicative of natural variability. No sample analysis results exceeded the MCL, and no specific sites are known to have been impacted by nonpoint source pollution. Since

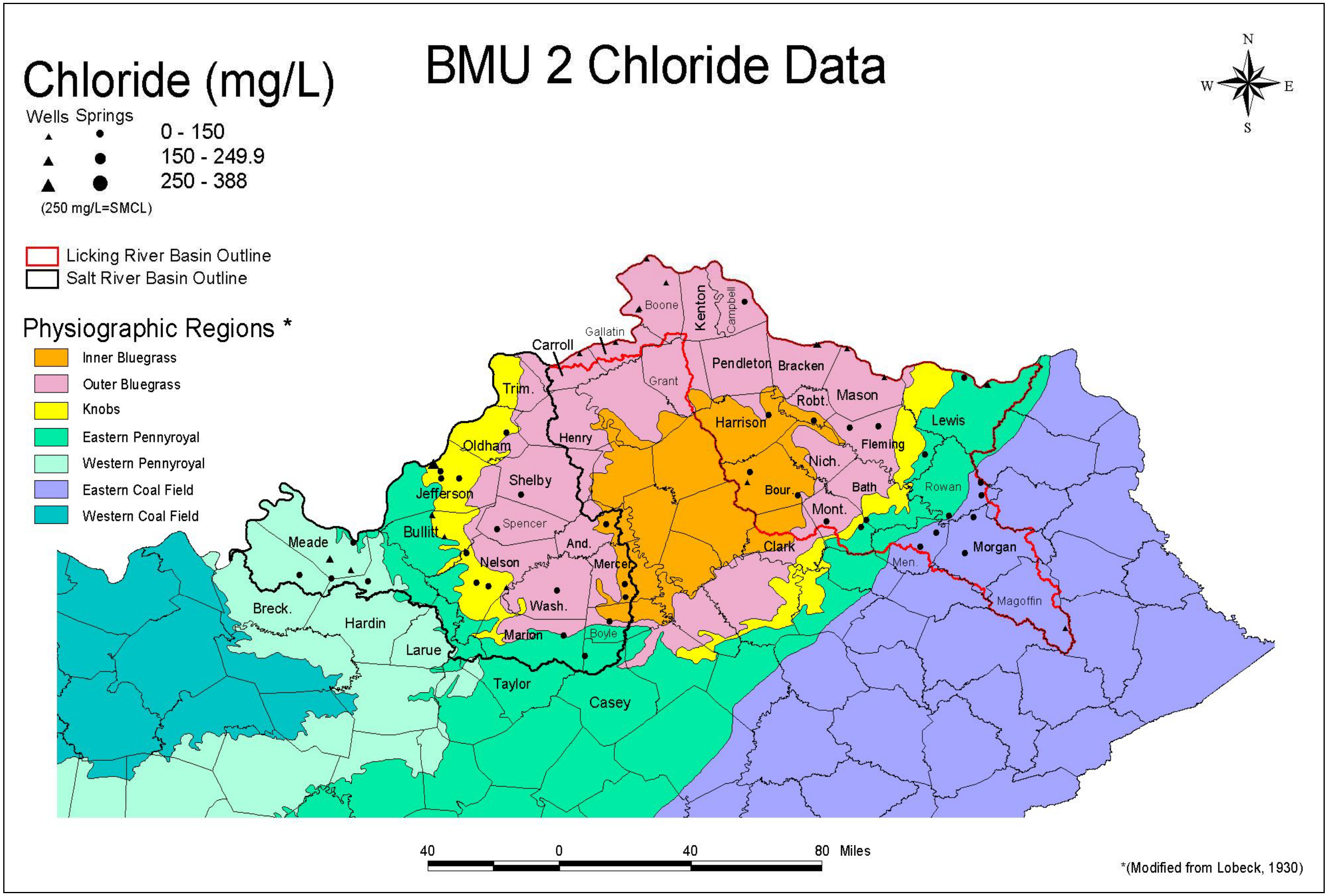
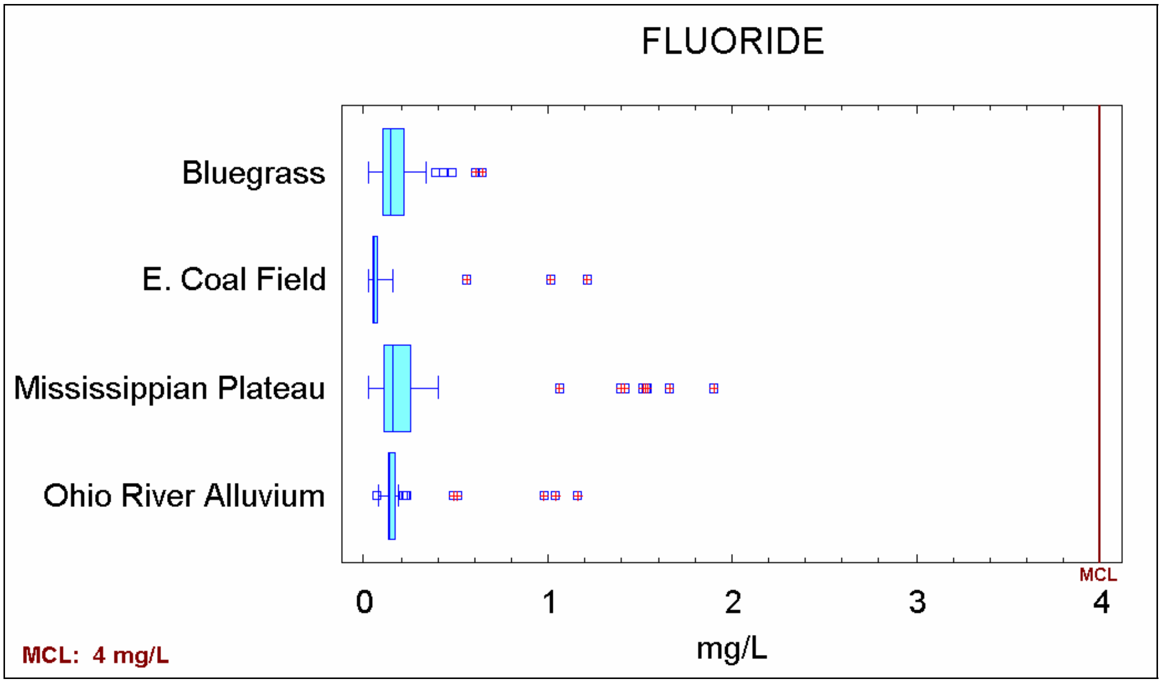


Figure 12. Map of Chloride Data for BMU 2

Figure 13. Boxplot for Fluoride measurement distributions in BMU #2



reference sites may also be impacted by possible atmospheric deposition, comparison with these sites may be invalid.

Conrad and others (1999a) compiled and analyzed statewide fluoride data. They reviewed 4,848 records from 2,630 sites and found only 24 analyses from 16 sites that exceeded the MCL. Two of these sites were in BMU 2, one in Mercer County and one in Gallatin County. Sites in this study in those counties failed to confirm the values found in the 1999 study, but does not necessarily indicate an improvement in groundwater quality.

Sulfate (SO_4) typically dissolves into groundwater from gypsum (hydrous calcium sulfate), anhydrite (calcium sulfate), from the oxidation of several iron sulfides, such as pyrite (FeS), and from other sulfur compounds. In project area sulfate is common and naturally occurring. Because of this, it is not a good indicator of nonpoint source pollution. Sulfate has an SMCL of 250 mg/L and amounts greater than this impart distasteful odor and taste to the water and commonly have a laxative effect.

In general, Figure 15 illustrates a narrow range of sulfate values, well under the SMCL, especially

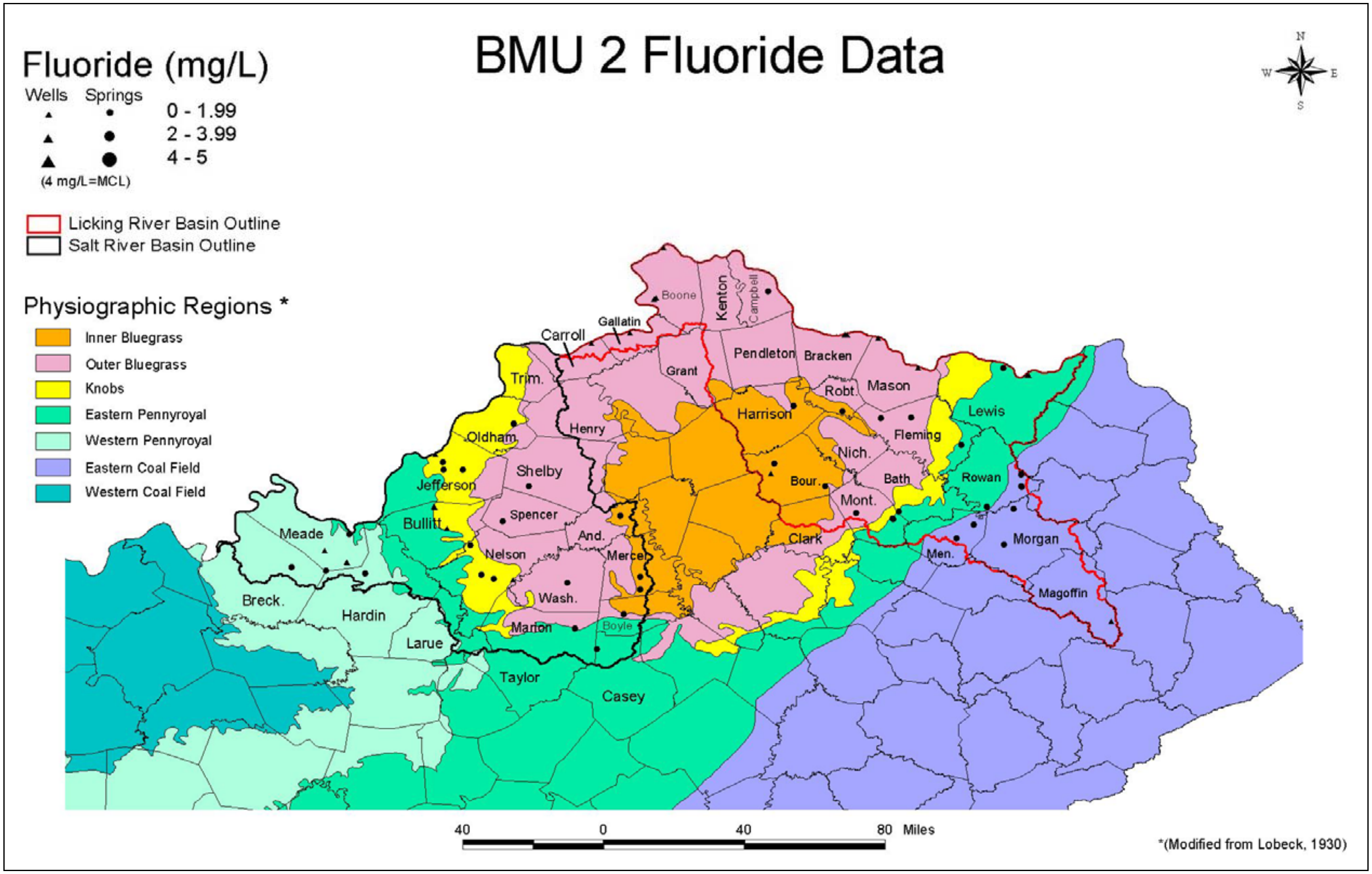
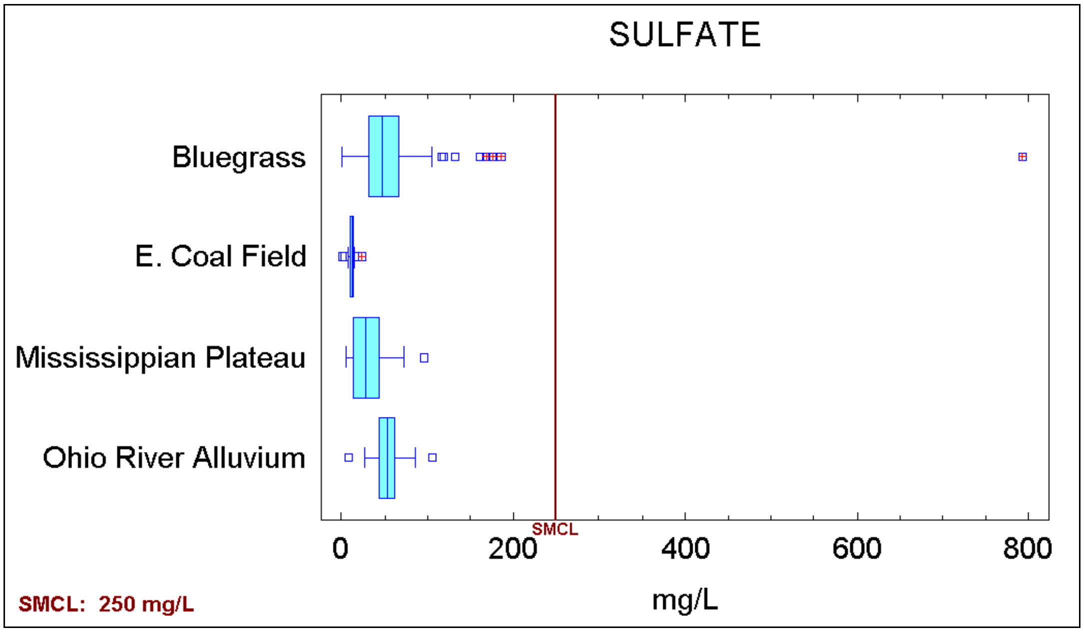


Figure 14. Map of Fluoride Date for BMU 2

Figure 15. Boxplot for Sulfate measurement distributions in BMU #2



in the Eastern Coal Field. The far outlier of approximately 800 mg/L in the Bluegrass is the Arrasmith well in Boone County, shown in Figure 16. This well is located in the thinly-bedded shale and limestone terrane of the Outer Bluegrass where water quality is often naturally high in dissolved solids, especially sulfate. The existence of highly-mineralized groundwater in this area is also supported by the occurrence of several nearby natural mineral springs. These springs are commonly known as "licks" because of the wild animals that lick the mineral rich water and soils. One such spring occurs at Big Bone Lick State Park, in Boone County, about two miles south of the Arrasmith well.

Because there is no direct evidence of nonpoint sources of sulfate affecting the groundwater sites in this study, and because sulfate is commonly naturally occurring in groundwater throughout the study area, this parameter was not a useful indicator of nonpoint source pollution. Although coal mining is known to affect groundwater in some areas of BMU 2, this study does not confirm that. However, data in the Eastern Coal Field are limited, and if other sites had been sampled immediately adjacent to current or historical coal-mining areas, the results might have supported different conclusions.

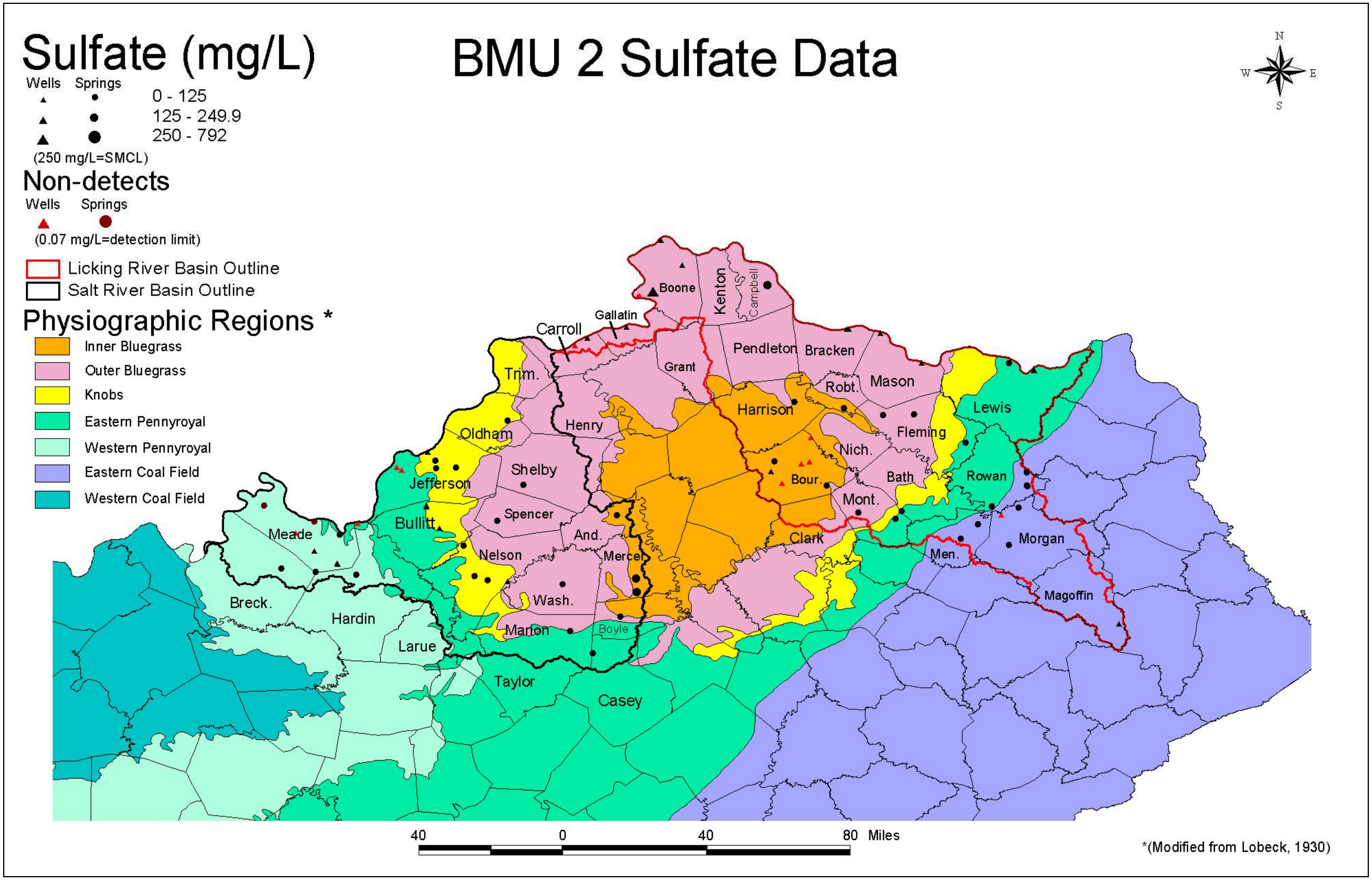


Figure 16. Map of Sulfate Data for BMU 2

Metals

Groundwater samples were analyzed for arsenic, barium, iron, manganese, and mercury, because they are common constituents of sedimentary rocks, especially coal and black shales (USGS, 2002b; Tuttle, and others, 2001), and in soils (Logan, and Miller 2002). In water, lower pH values, as well as higher dissolved oxygen content, increase the dissolution of metals. Common anthropogenic nonpoint sources of problem metals include mining, urban run-off, industrial operations, land farming of sewage and other waste, and emissions from coal-fired power plants. High concentrations of metals in groundwater are sometimes difficult to interpret and may indicate point or nonpoint sources of contamination, or may even be naturally occurring. Comparison with reference reach springs (Table 2), as well as reviewing relevant literature, can prove useful.

A complete suite of total and dissolved metals was analyzed for each sample collected. Because MCL's are based upon total metal analysis, the results presented below are based upon total, rather than dissolved, concentrations. Although other metals, such as silver, vanadium, and gold were analyzed, detections of these were exceedingly rare, and invariably at very low levels. Consequently, these results are not presented here.

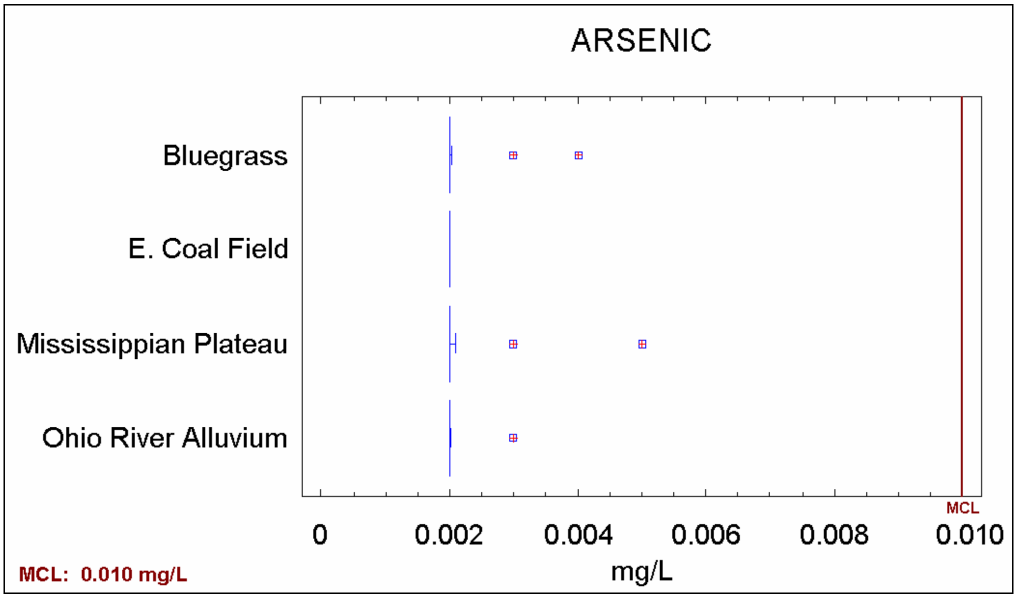
Arsenic is often found as a trace element associated with coal and shale (USGS, 2002b). In addition, the USGS (2002a) notes that the majority of arsenic in groundwater is the ". . . result of minerals dissolving from weathered rocks and soils." Blanset and Goodmann (2002) note that the ". . . most prominent source of arsenic in Kentucky's aquifers results from the oxidation of arsenopyrite, incorporated in iron hydroxides."

Other sources of arsenic include deposition from coal-fired power plants and metal-smelting/manufacturing processes, historical use in pesticides (USEPA, 2002a), and from embalming fluid, especially from about 1860 until its use was banned in 1910 (Fetter, 1992). Arsenic occurs in organic and non-organic forms, and generally, the latter are more harmful to human health. Arsenic exposure in humans has been linked to bladder and other cancers (USGS, 2000). Arsenic has an MCL of

0.010 mg/L. The USEPA lowered this MCL from 0.05 mg/L in 2001, and will require public water systems to meet the new standard by January 2006.

Arsenic was detected in 10 (approximately 4%) of the 225 samples. The detection limit for arsenic is 0.002 mg/L; figures 17 and 18 indicate that most samples were non-detectable at this limit.

Figure 17. Boxplot for total arsenic measurement distributions in BMU #2



There were only 5 outliers and the other 5 detections are within 1.5 times the IQR for arsenic, indicating that there is not a wide range in these result values. The largest concentration of arsenic was 0.005 mg/L, from a spring in the Mississippian Plateau region, but this value is still well below the MCL of 0.010 mg/L. Subsequent samples taken at this site show concentrations less than the MDL of 0.002 mg/L.

Fisher (2002) reviewed statewide arsenic data and found that for ambient groundwater about 95% of 4,402 analyses from 930 sites were less than the MCL of 0.010 mg/L. Blanset and Goodmann (2002) reviewed total arsenic data from 1,249 ambient groundwater samples from 240 sites and found 10 sites with total arsenic exceeding the MCL of 0.010 mg/L. In their study, Blanset and Goodmann concluded that alluvial aquifers were most at-risk through the reduction of arsenic containing iron hydroxides. Our

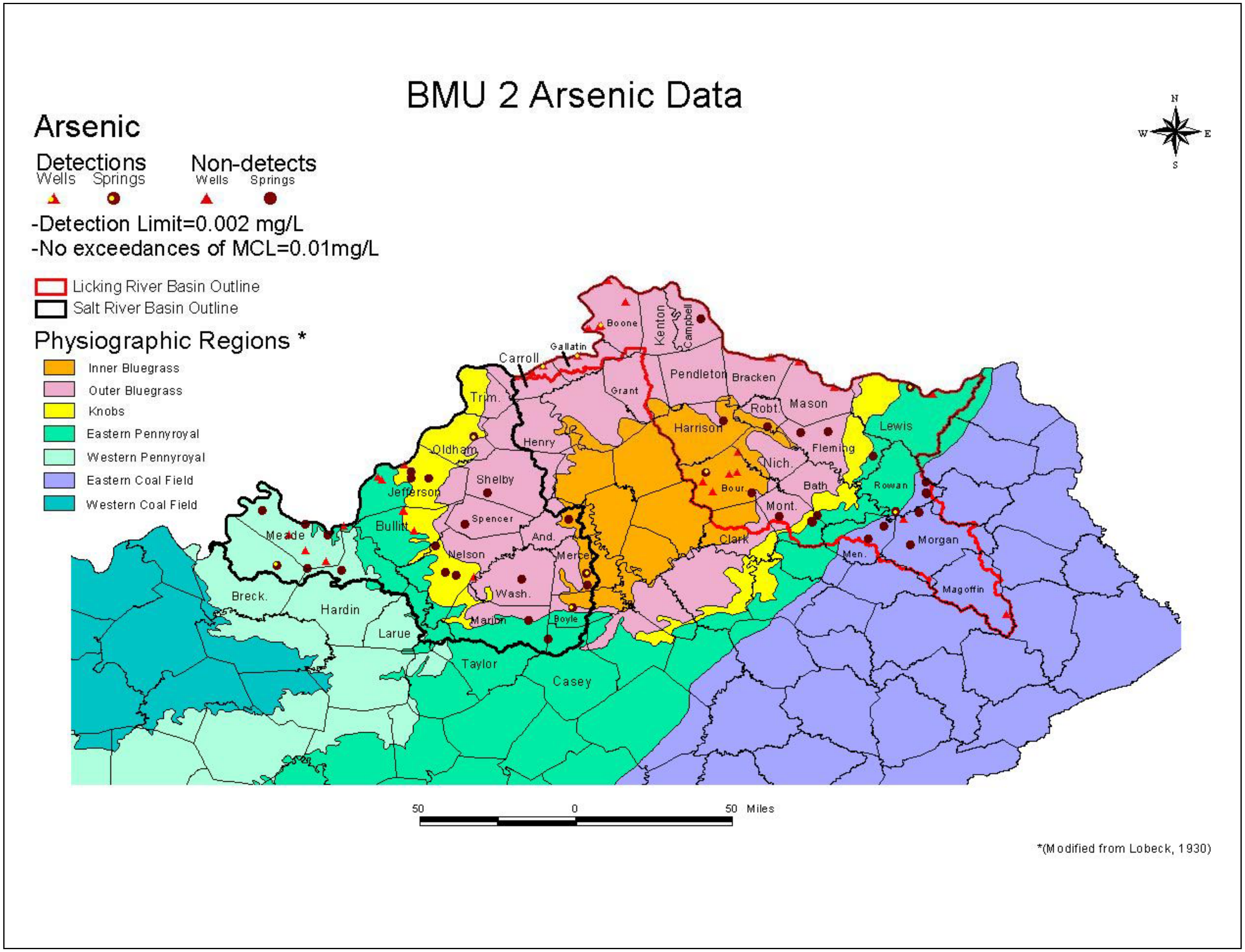


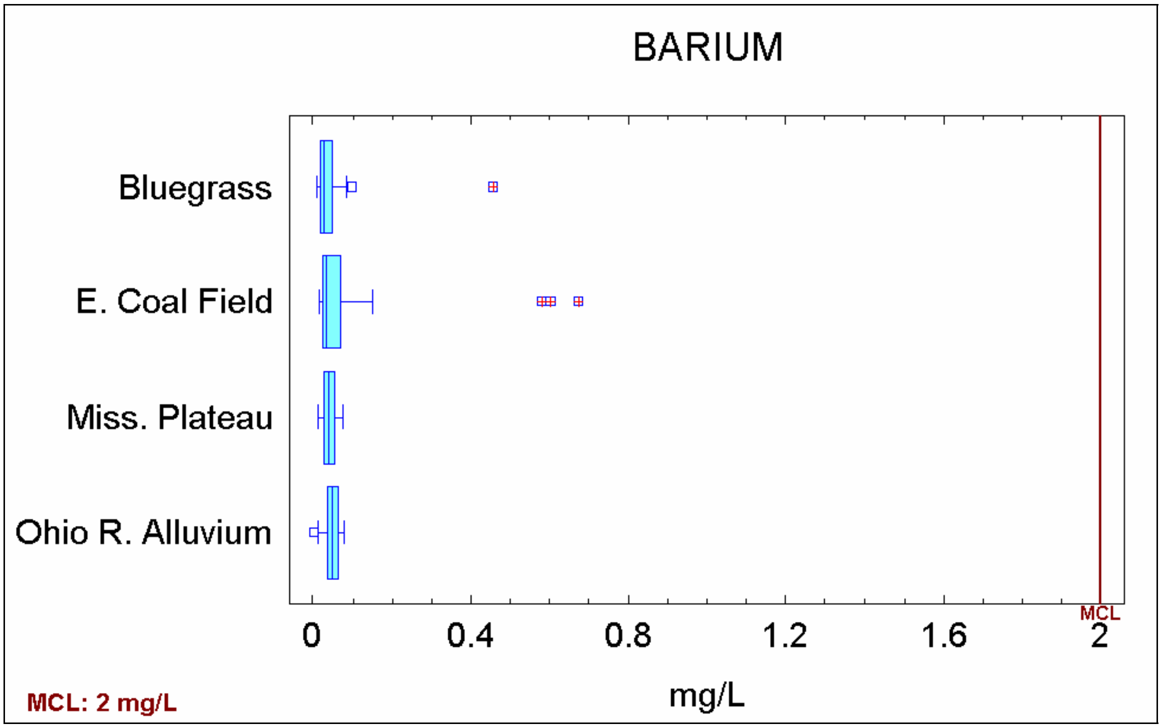
Figure 18. Map of Arsenic Data for BMU 2

study, however, found no differences in the occurrence of arsenic between alluvial aquifers and other physiographic provinces, as shown in Figure 17. The low levels of arsenic found in our study, as well as the absence of any apparent sources, indicate no negative impacts through nonpoint source pollution in BMU 2.

Barium occurs most commonly as the mineral barite ($BaSO_4$). This naturally occurring mineral occurs in nodules in sedimentary rocks and as a trace element in coal. Barite is particularly common in the Inner Bluegrass of central Kentucky. The drilling industry uses barium, and this mineral also occurs in a variety of products such as glass and paint. The MCL for barium is 2 mg/L, and exposure to high levels of barium has been associated with cardiovascular problems such as high blood pressure.

Barium was found in almost all of the samples collected. However, most detections occurred within a narrow range in all physiographic provinces (Figures 19 and 20). Outliers reflect the natural

Figure 19. Boxplot for barium measurement distributions in BMU #2



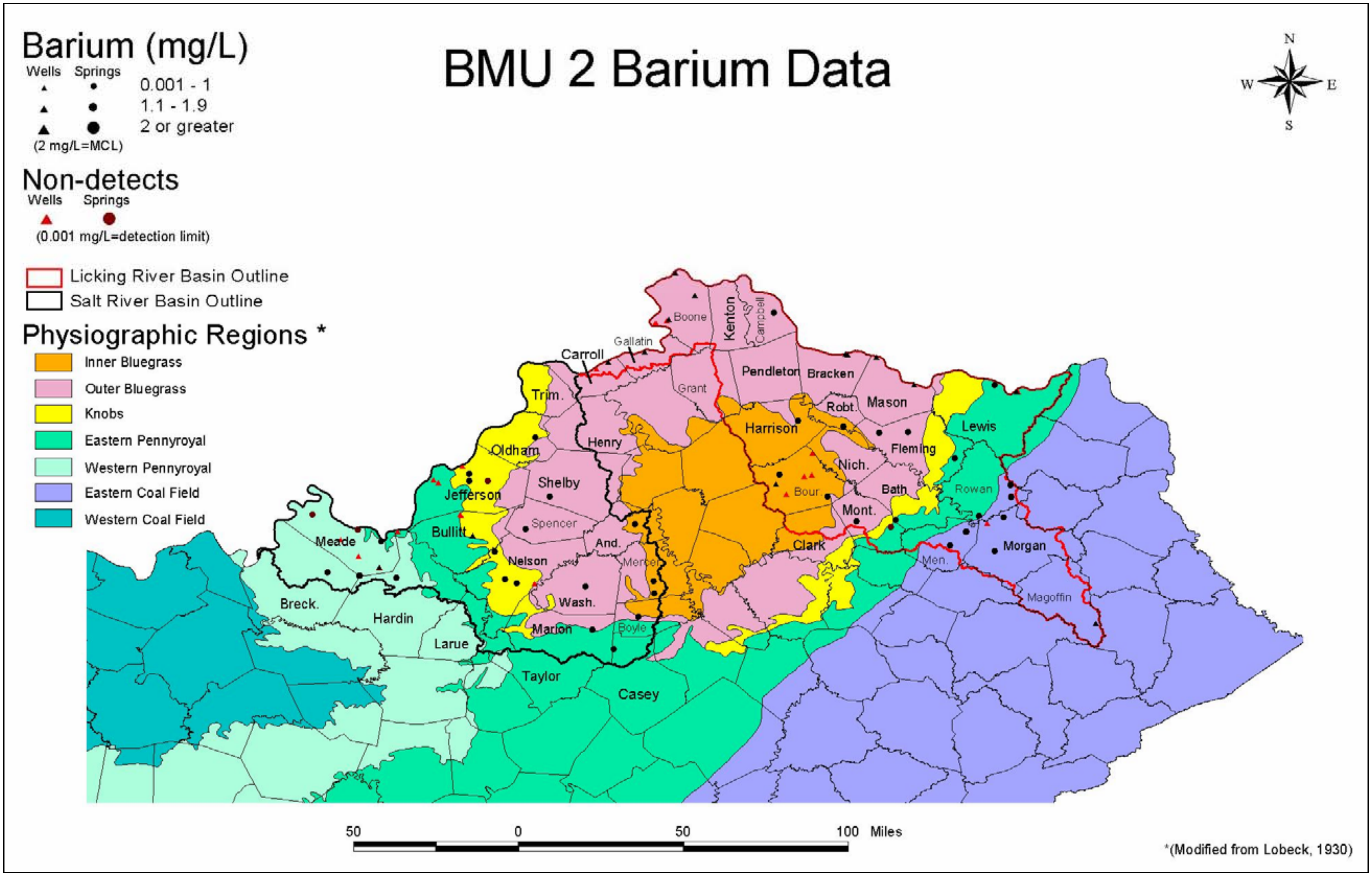


Figure 20. Map of Barium Data for BMU 2

variability in the karst Bluegrass. Barium is known to occur naturally and at relatively high levels, often above the MCL, in the Eastern Coal Field (Wunsch, 1991). However, this study did not detect barium at such levels. Barium is not typically indicative of nonpoint source pollution, and in the absence of any known nonpoint sources in the study area, barium occurrence in Kentucky represents natural groundwater quality.

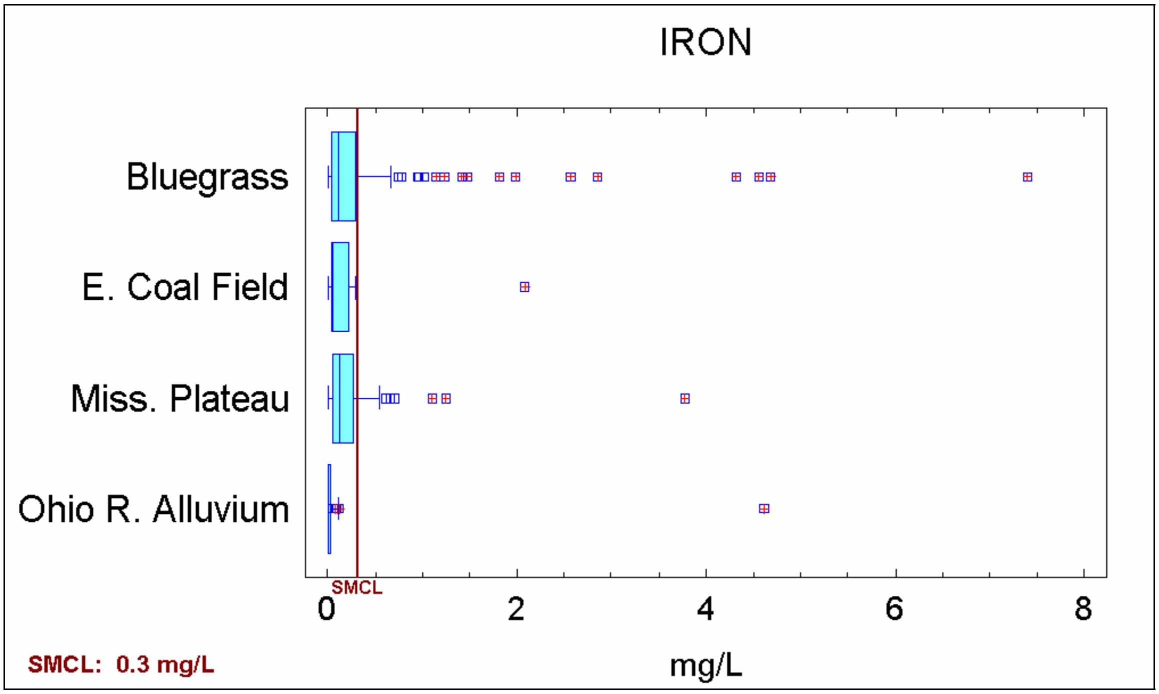
Iron (Fe) is commonly found in at least trace amounts in practically all sediments and sedimentary rocks (Driscoll, 1986). Iron is also one of the most prevalent groundwater quality problems in wells in Kentucky. However, in almost all cases, elevated iron is naturally occurring and therefore not generally diagnostic of nonpoint source pollution. One notable exception is that high levels of iron may be associated with run-off from coal mining. Typically, this high iron discharge affects surface water rather than groundwater, but wells in old mine works and adjacent areas can also be affected.

Iron is a basic water quality parameter regarding the suitability of water for drinking and industrial use. Iron helps transport oxygen in the blood and is essential for good health. Excessive iron in water used for human consumption is an aesthetic, rather than a health-based concern. Iron has an SMCL of 0.3 mg/L.

Iron causes problems when it changes from the dissolved, or *ferrous* state, to the precipitated state, or as *ferric* iron. Precipitated iron can coat or encrust well screens and casing, pipes, pumping equipment, and plumbing fixtures. Additionally, various metal-reducing bacteria that feed on iron can coat fixtures. Sometimes iron bacteria can grow to such an extent that a gelatinous mass is formed that can completely plug a well and associated equipment. Although iron bacteria are not usually a health problem, they do render the water unpalatable and are indicators of unsanitary conditions that may harbor other, more harmful, bacteria.

In this study, more than 87% of the samples had detections of iron (Figure 21), but most detections were less than the SMCL. Numerous outliers show the natural variability of this element. Given the absence of specific nonpoint sources of iron, Figure 21 indicates naturally occurring variations

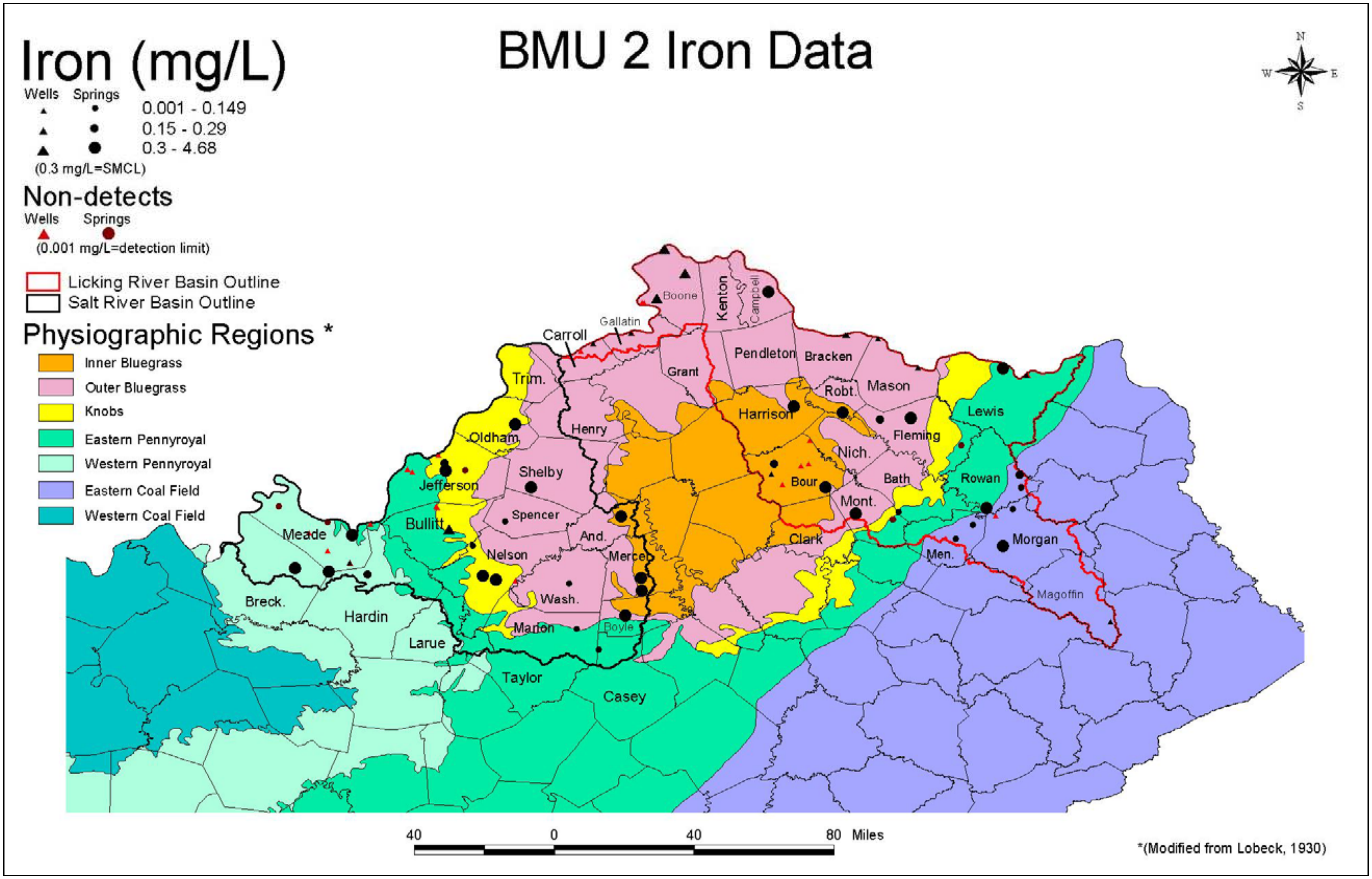
Figure 21. Boxplot for Iron measurement distributions in BMU #2



in groundwater quality, rather than nonpoint source pollution. Figure 22 illustrates the wide-spread occurrence of iron throughout all physiographic provinces.

Manganese (Mn) is a relatively common element, but occurs less abundantly in groundwater than iron. Manganese is associated with discharges from coal mining and metal manufacturing. Manganese in water supplies can cause staining and encrustation of plumbing fixtures, piping, and well screens, as well as discoloring laundry. The MCL for manganese is 0.05 mg/L.

Manganese is a common, naturally occurring water quality problem in Kentucky, and occurred in more than 87% of the samples. As shown in Figure 23, values clustered in a narrow range just below the SMCL of 0.05 mg/L, but levels above this are common. Manganese is generally not a direct indicator of nonpoint source pollution. Mayes Spring in Boyle County (Bluegrass) had the highest level of manganese found in this study, and is the outlier shown in Figure 23 at about 12 mg/L. The reason for this unusually high value, unconfirmed by other samples at this site, is unknown.



*(Modified from Lobeck, 1930)

Figure 22. Map of Iron data for BMU 2

Figure 23. Boxplot for manganese measurement distributions in BMU #2

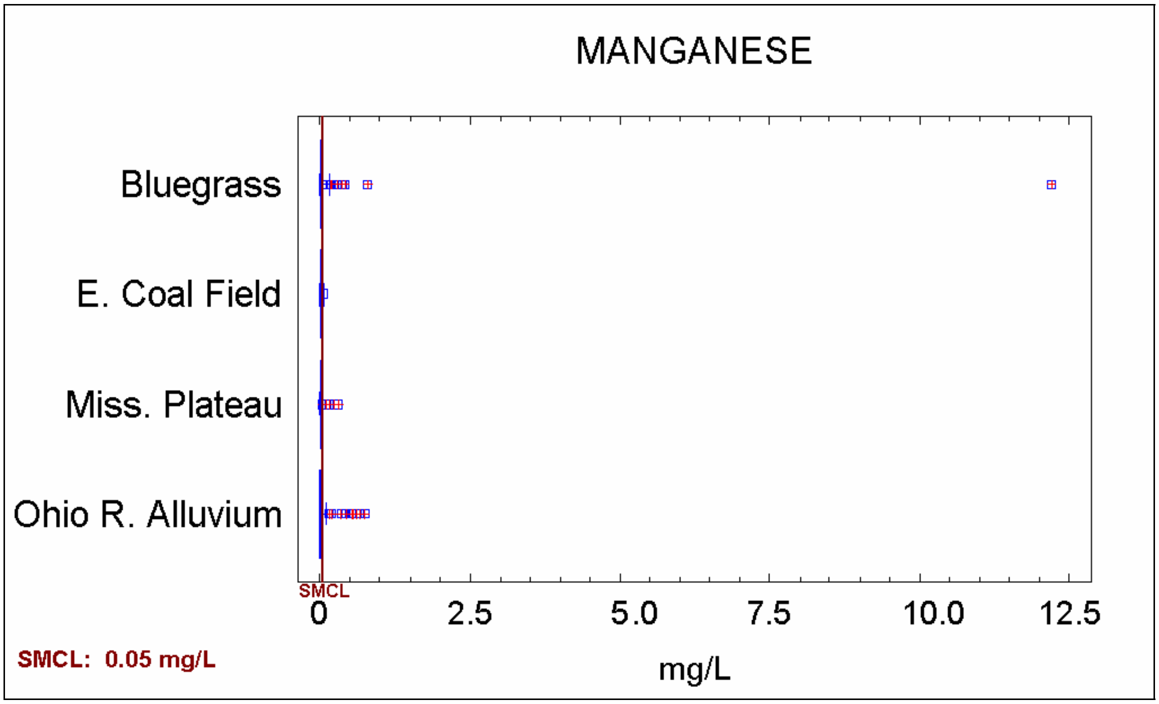


Figure 24 shows the occurrence of manganese throughout the study area, with no apparent pattern of distribution among the various physiographic provinces.

Mercury (Hg) occurs naturally in the Eastern Coal Field as a trace element in coal (USGS, 2002b). Primary nonpoint sources of mercury pollution are via atmospheric deposition from coal-burning power plants and boilers, waste incineration, and manufacturing. The MCL for mercury is 0.002 mg/L.

Mercury occurred in 1 of 225 samples. This single detection, at McKenzie Spring in Rowan County, was 0.000056 mg/L, which is slightly above the DES method detection limit (MDL) of 0.00005 mg/L. No other samples at this site duplicated or exceeded this value, and no source for mercury in this area was found. Because there was only this single detection of mercury, no map is presented. Mercury data indicate that this metal does not occur naturally in groundwater in the study area, nor does it occur in groundwater through air-borne deposition from coal-fired power plants or other sources.

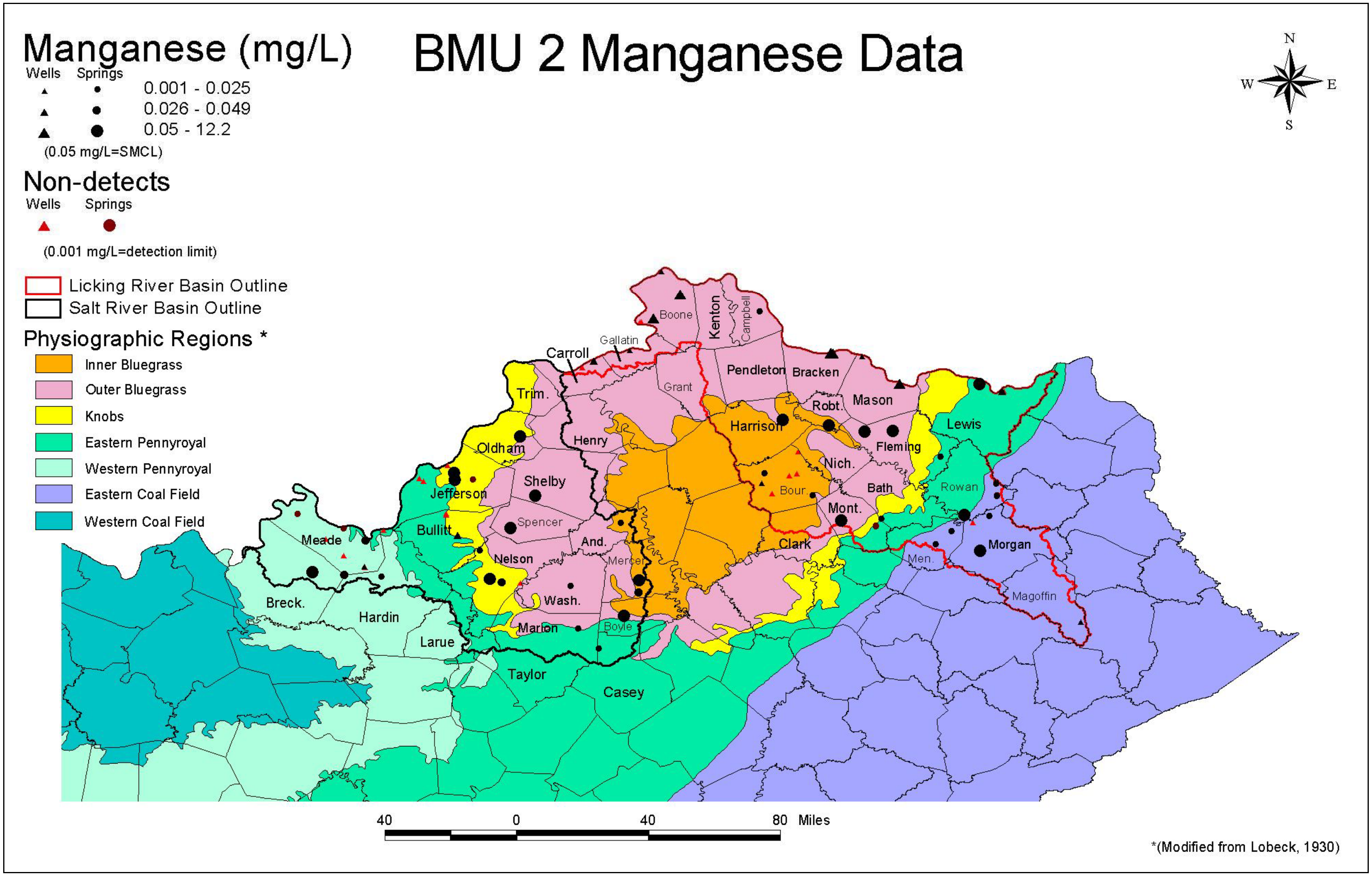
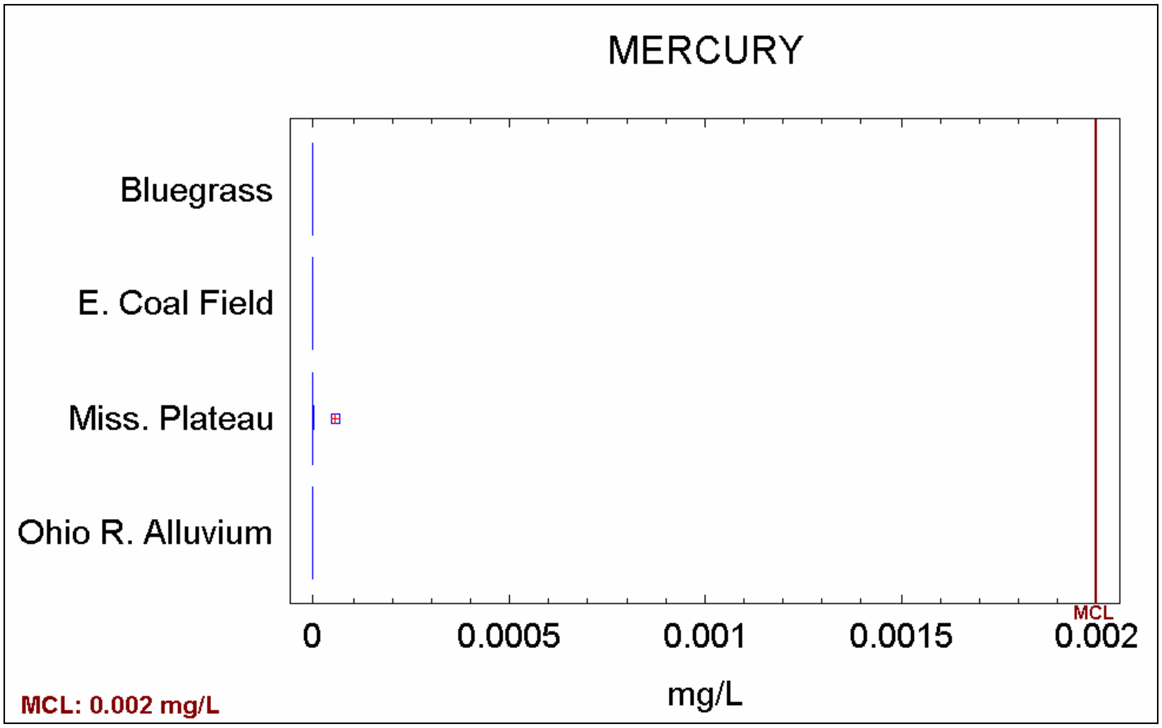


Figure 24. Map of Manganese data for BMU 2

Figure 25. Boxplot for mercury measurement distributions in BMU #2



Although the Division of Water has issued statewide fish consumption advisories for mercury, groundwater in BMU 2 does not appear to contribute to this surface water problem. However, only a limited data set of 15 mercury samples were analyzed for the Eastern Coal Field. Because mercury occurs as a trace element in coal, and because air-borne deposition from coal-fired power plants is on-going, additional sampling should include mercury to fully determine the potential long-term impacts of this metal on groundwater.

Pesticides

Five commonly used pesticides are included in this report: atrazine, metolachlor, cyanazine, simazine, and alachlor. Because these pesticides do not occur naturally, and because their introduction into the environment from point sources such as leaking tanks is relatively limited geographically, the detection of pesticides in groundwater indicates nonpoint source pollution.

Atrazine was the most frequently detected pesticide, found in 15.5% of 342 samples analyzed. Metolachlor was the next most frequently detected pesticide, detected in about 10% of the samples. Alachlor and simazine were each detected in about 3% of the samples. Cyanazine was not detected in 314 samples. This information is summarized in tabular form in Appendix D.

Detection limits for the pesticides discussed in this report vary widely, depending on the laboratory method used, as shown in Table 4.

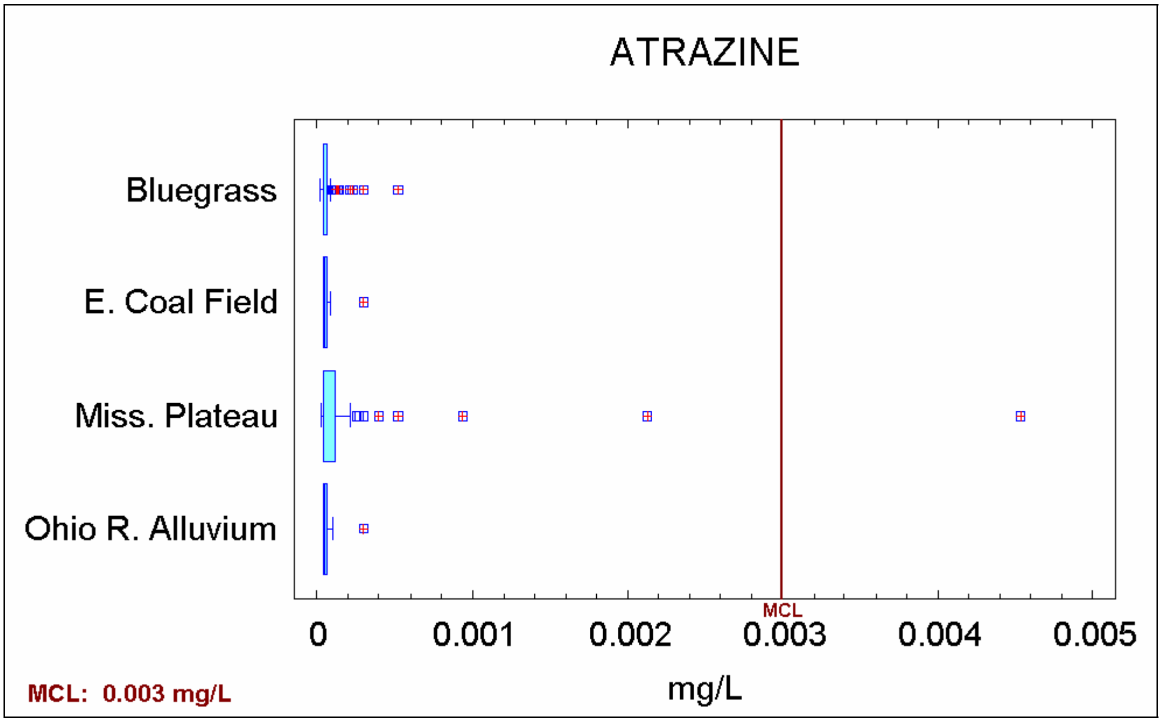
Table 6. Pesticide Method Detection Limits

Pesticide	Method Detection Limit Used for Samples, mg/L
Atrazine	0.0003, 0.00004, 0.00005
Metolachlor	0.00002, 0.00004, 0.00005, 0.00006, 0.00008
Cyanazine	No detects at any MDL; 0.00004 most frequent MDL
Simazine	0.0003, 0.00004, 0.00005
Alachlor	0.00002, 0.00004, 0.00005, 0.00006

Atrazine (trade names include Lariat and Bullet) is used primarily for weed control for corn and soybean production, and is one of the most commonly-used herbicides in Kentucky. In 1999, when this study began, approximately 900,000 pounds of atrazine were sold in Kentucky (KYEQC, 2001). Atrazine has an MCL of 0.003 mg/L. Atrazine is a carcinogen and exposure to excess amounts is associated with weight loss, cardiovascular damage, and degeneration of muscle tissue and the retina. Atrazine has also recently been demonstrated to cause hermaphroditism in frogs (Hayes and others, 2002).

Not surprisingly, atrazine was most often detected in agricultural areas characterized by row crop production, primarily in the Bluegrass and Mississippian Plateau (Figure 26). Karst springs, in particular, are vulnerable to pesticide contamination via surface water runoff to sinkholes, sinking streams, and macroporic flow through soils. The variability of pesticide levels in karst areas, such as the Mississippian Plateau, reflects the variability of flow in quick recharge/quick discharge karst systems. The occurrence

Figure 26. Boxplot for atrazine measurement distributions in BMU #2



of atrazine is rare in the Eastern Coal Field where row cropping is limited. However, some herbicides are applied along roads and utility rights of way.

Figure 27 illustrates the occurence of atrazine in BMU 2. The highest occurrence, and the only detection of any pesticide above MCL, was 0.004535 mg/L at Big Spring in Breckinridge County, which is a karst window in an area of row crops (Figures 26 and 27). Atrazine was also detected at 1 other site besides Big Spring in the Mississippian Plateau as well as at 13 sites in the Bluegrass, and at 3 sites in the Ohio River Alluvium. All sites with atrazine detections were in agricultural areas including row crops, except for two urban springs in the Bluegrass: Cat Spring in Oldham County and Jesse's Spring in Jefferson County. Cat Spring is adjacent to a farm supply store and this may explain the detection of atrazine; Jesse's Spring is in a residential area where atrazine application is less likely to occur.

Metolachlor (trade names include Cycle and Dual) is used as a pre-emergent and pre-plant weed control for the production of corn and soybeans. In 1999, approximately 900,000 pounds of metolachlor

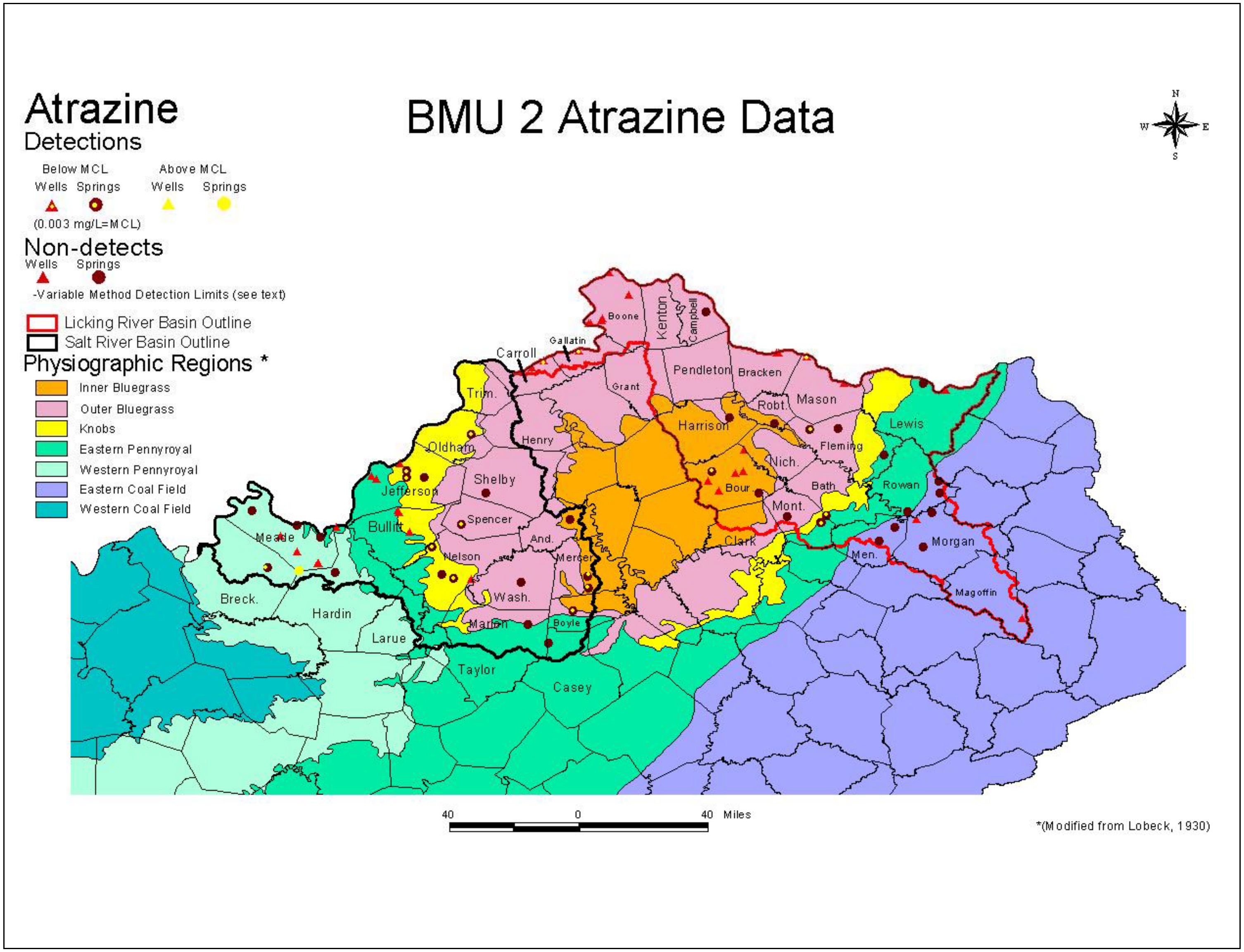
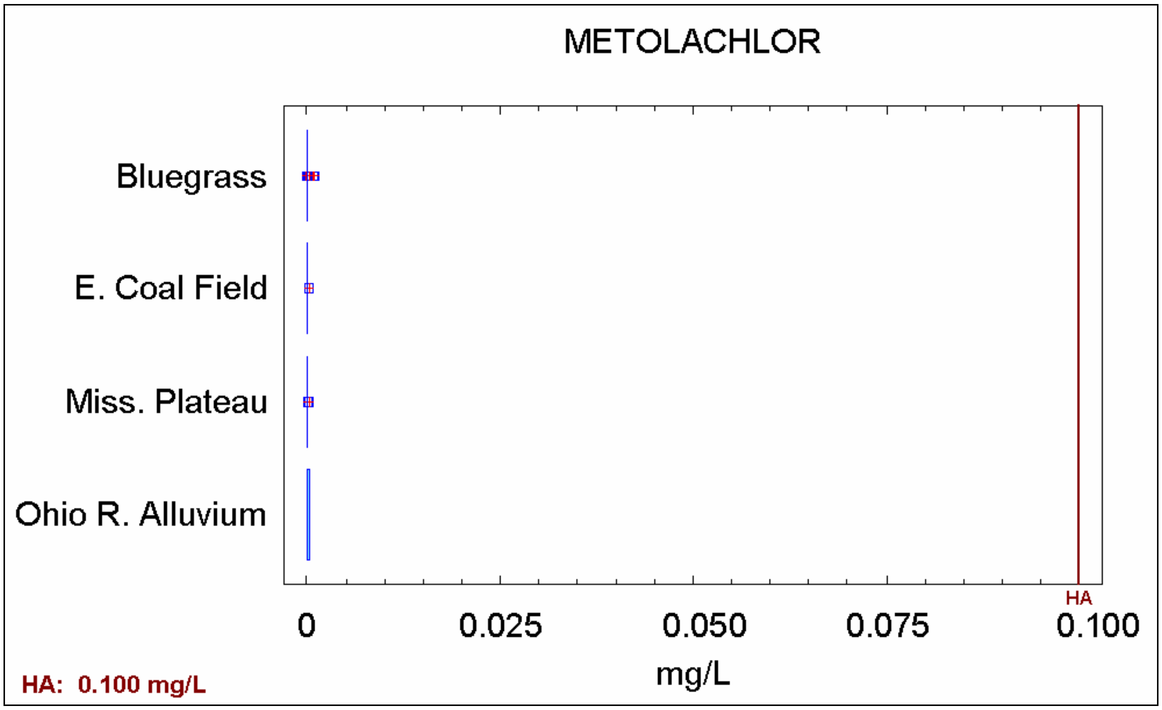


Figure 27. Map of Atrazine data for BMU 2

were sold in Kentucky (KYEQC, 2001). Metolachlor is a possible human carcinogen and has an HAL of 0.1 mg/L.

Metolachlor occurred at very low levels in approximately 10% of the samples analyzed (Figure 28). There was virtually no variation between the physiographic regions (Figure 29) and the range of values was narrow. Metolachlor was not detected above its HAL. Although the number of detections of this herbicide does indicate nonpoint source pollution, the low levels showed minimal impacts to groundwater quality.

Figure 28. Boxplot for metolachlor measurement distributions in BMU #2



Simazine (trade names include Aquazine and Princep) is used to control annual nuisance grasses and broadleaf weeds, especially for corn and alfalfa production. In humans, simazine is carcinogenic and exposure to simazine is associated with tremors, damage to liver, testes, kidneys and thyroid, and gene mutation. Simazine has an MCL of 0.004 mg/L.

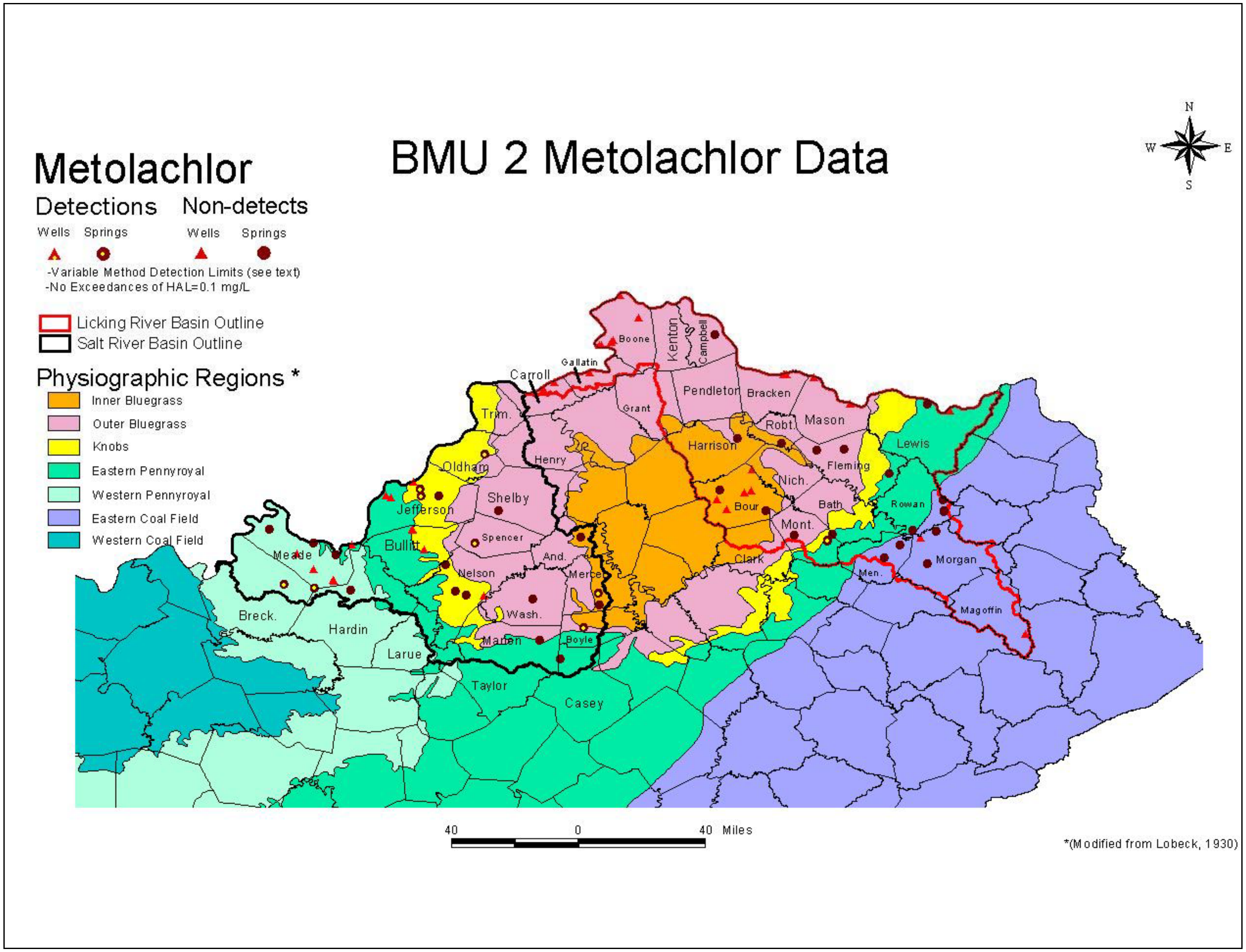
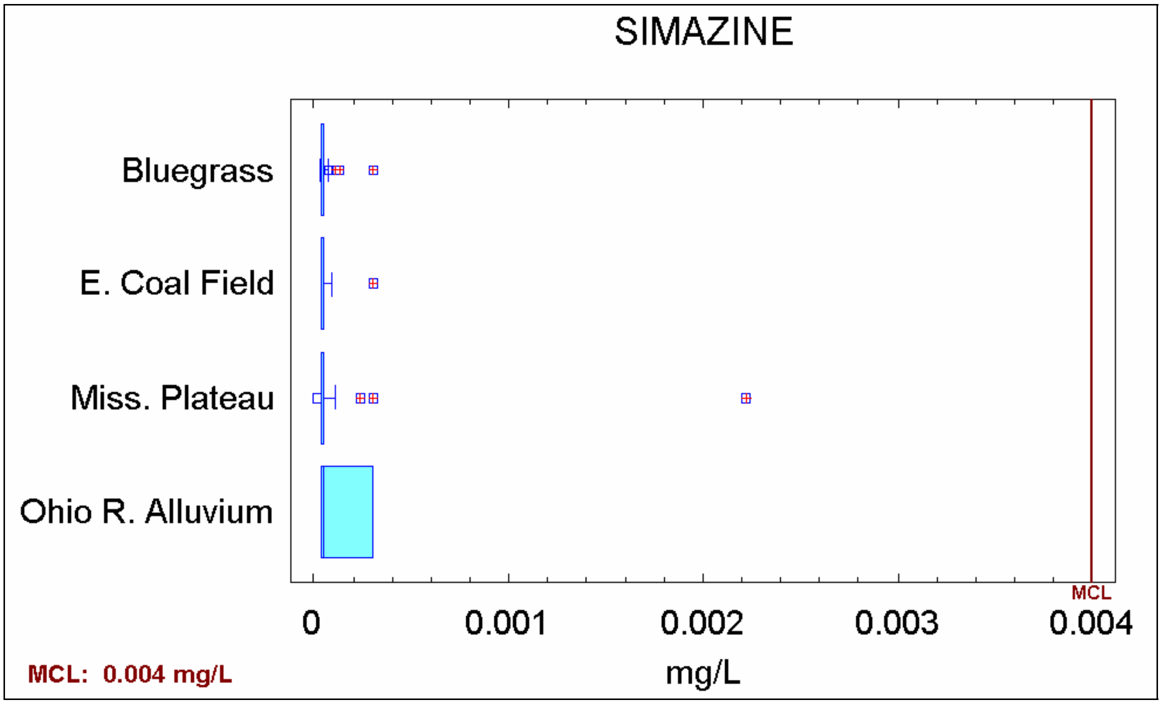


Figure 29. Map of Metolachlor data for BMU 2

Simazine occurred in approximately 3% of the samples, but never above the MCL. The highest occurrence was in the Mississippian Plateau (Big Spring, Breckinridge County) at about half the MCL. Simazine was detected sporadically in the Bluegrass, Eastern Coal Field, and Mississippian Plateau (Figures 30 and 31).

Figure 30. Boxplot for Simazine measurement distributions in BMU #2



Alachlor (trade names include Lasso and Lariat) is used for corn and soybean production for pre-emergent weed control. Alachlor has an MCL of 0.002 mg/L. Alachlor has been associated with cancer in humans, and has also been linked with noncancerous effects in the liver, spleen, and kidneys.

Alachlor occurred at eight sites in this study, but never above the MCL (Figure 32). As shown in Figure 33, alachlor was found at 3 sites each in the Bluegrass and Mississippian Plateau and at 2 sites in

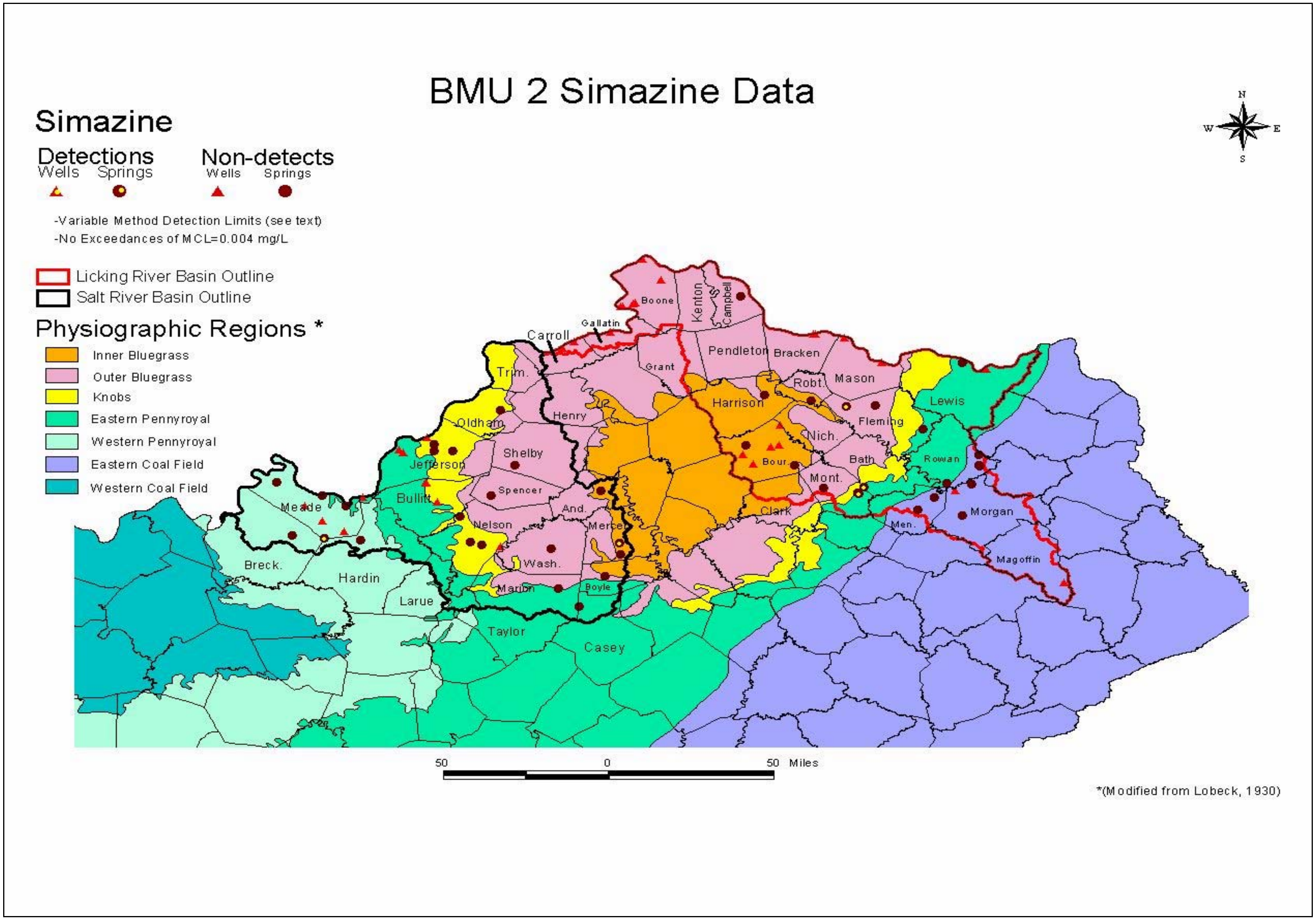
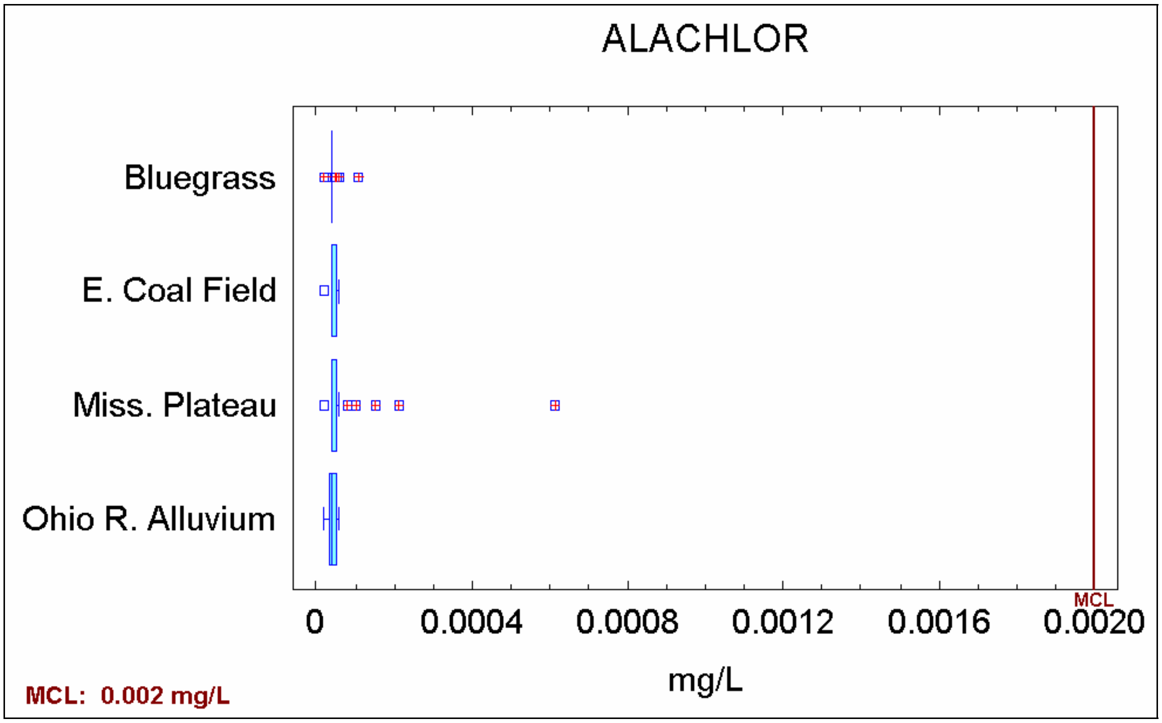


Figure 31. Map of Simazine data for BMU 2

the Ohio River Alluvium. The maximum detected value was at Big Spring in Breckinridge County at less than one-third of the MCL. Based upon its limited occurrence, alachlor has apparently had minor impacts on groundwater in this area.

Figure 32. Boxplot for Alachlor measurement distributions in BMU #2



Cyanazine production ceased in December 1999, and the sale and use of this herbicide was prohibited effective September 2002. Cyanazine was not detected in this study. The number of samples analyzed is presented in Appendix D.

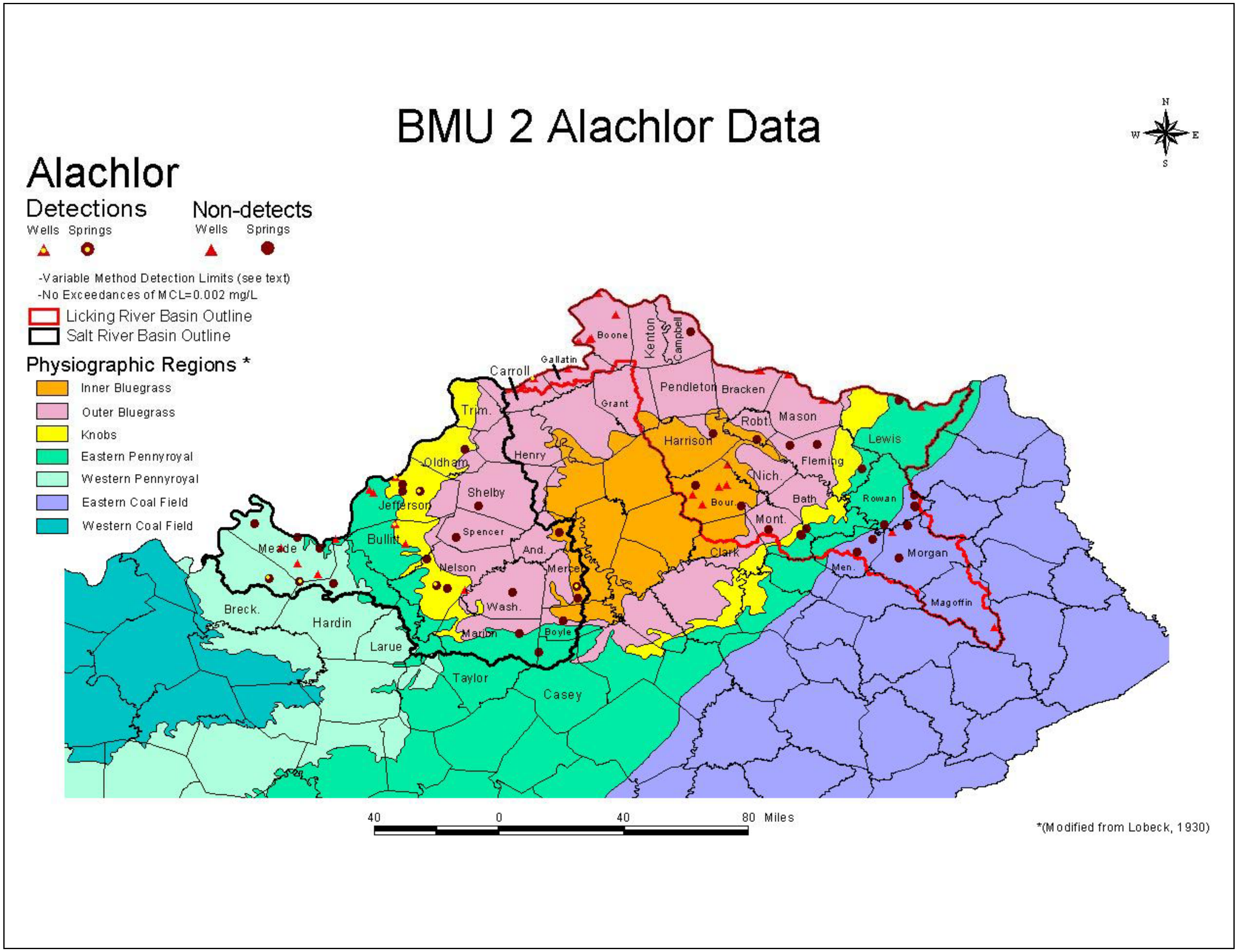


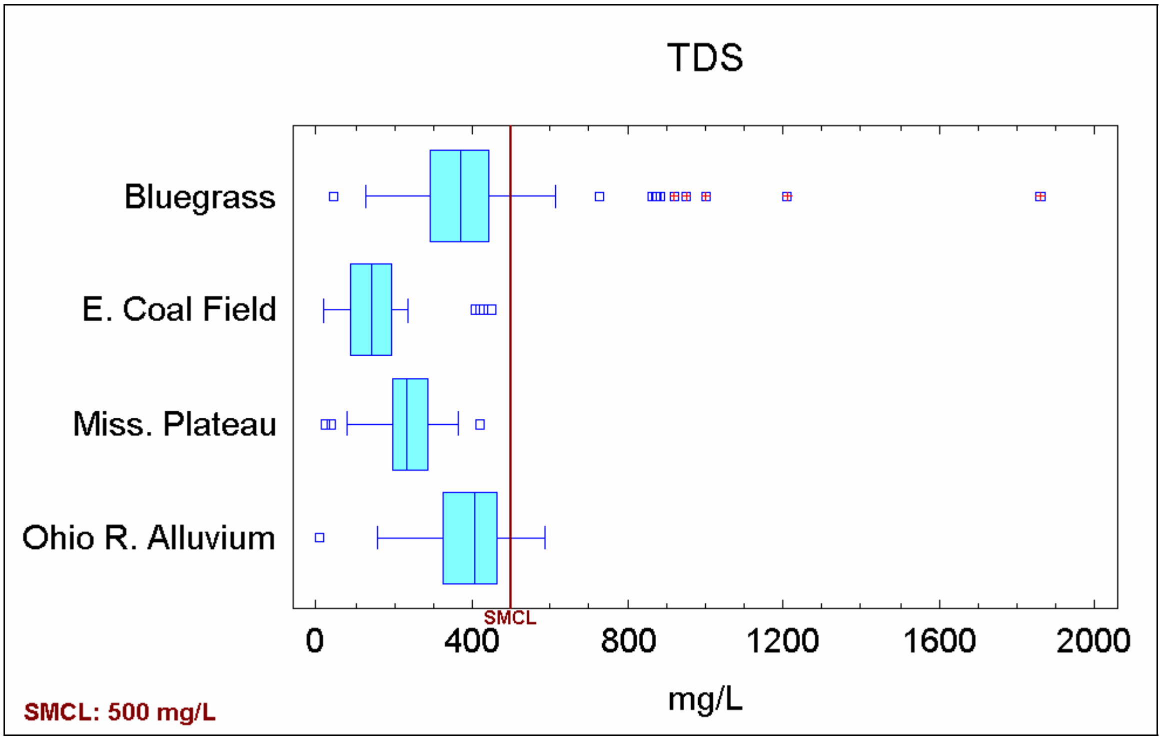
Figure 33. Map of Alachlor data for BMU 2

Residues (Total Dissolved Solids (TDS) and Total Suspended Solids (TSS))

Total Dissolved Solids (TDS) measures the solids remaining in a water sample filtered through a 1.2 µm filter. According to the World Health Organization (WHO, 1996), the compounds and elements remaining after filtration are commonly calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulfate, silica, and nitrate-n. High TDS affects the taste and odor of water, and in general, levels above 300 mg/L become noticeable to consumers. As TDS increases, the water becomes increasingly unacceptable. Although the SMCL for TDS is 500 mg/L, levels above 1200 mg/L are unacceptable to most consumers. Because TDS measurements may include a variety of parameters which can be naturally occurring or anthropogenic, its value as an indicator of nonpoint source pollution is limited.

Median values of TDS were found below the SMCL of 500 mg/L, but outliers were common, especially in the Bluegrass (Figure 34). TDS was surprisingly low in the Mississippian Plateau,

Figure 34. Boxplot for TDS measurement distributions in BMU #2



especially considering that this is soluble carbonate terrane. One possible explanation is that the quick flow characteristics of this region reduces the contact time between water and rock, thereby retarding dissolution. In general, TDS is not usually an important *primary* indicator of nonpoint source pollution of groundwater, although this parameter can serve as a surrogate indicative of general water quality. Because no probable sources for elevated TDS were noted adjacent to sampling sites, no nonpoint source impacts could be confirmed. Figure 35 shows higher values in the Bluegrass and Ohio River Alluvium. These higher values are probably natural, resulting from longer residence times, which allow for more dissolution in these areas.

Total Suspended Solids (TSS), also known as non-filterable residue, are those solids (minerals and organic material) that remain trapped on a 1.2 μm filter (USEPA, 1998). Suspended solids can enter groundwater through run-off from industrial, urban, or agricultural areas. Elevated TSS (MMSD, 2002) can ". . . reduce water clarity, degrade habitats, clog fish gills, decrease photosynthetic activity and cause an increase in water temperatures." TSS has no drinking water standard. Therefore, data in this report are compared to the KPDES surface water discharge permit requirement for sewage treatment plants of 35 mg/L.

Approximately 57% of the samples analyzed detected TSS, with about 6% of the detections above 35 mg/L. Most values occurred within a narrow range, but outliers were common (Figure 36). In general, TSS is not usually considered a good indicator for nonpoint source pollution in groundwater. However, in some karst systems, turbidity and TSS vary with change in flow. Poor management practices associated with activities such as construction and agricultural tillage can strip vegetation and allow the quick influx of sediment into groundwater via overland flow. Therefore, outliers in the karst of the Bluegrass and Mississippian Plateau may represent nonpoint source impacts. Typically, given the nature of the activities that introduce sediments into karst groundwater, these impacts are transient. In the Eastern Coal Field, however, high TSS values are more difficult to interpret. Outliers here may represent sloughing of unstable beds within the well bore or possibly failure of the well's annular seal.

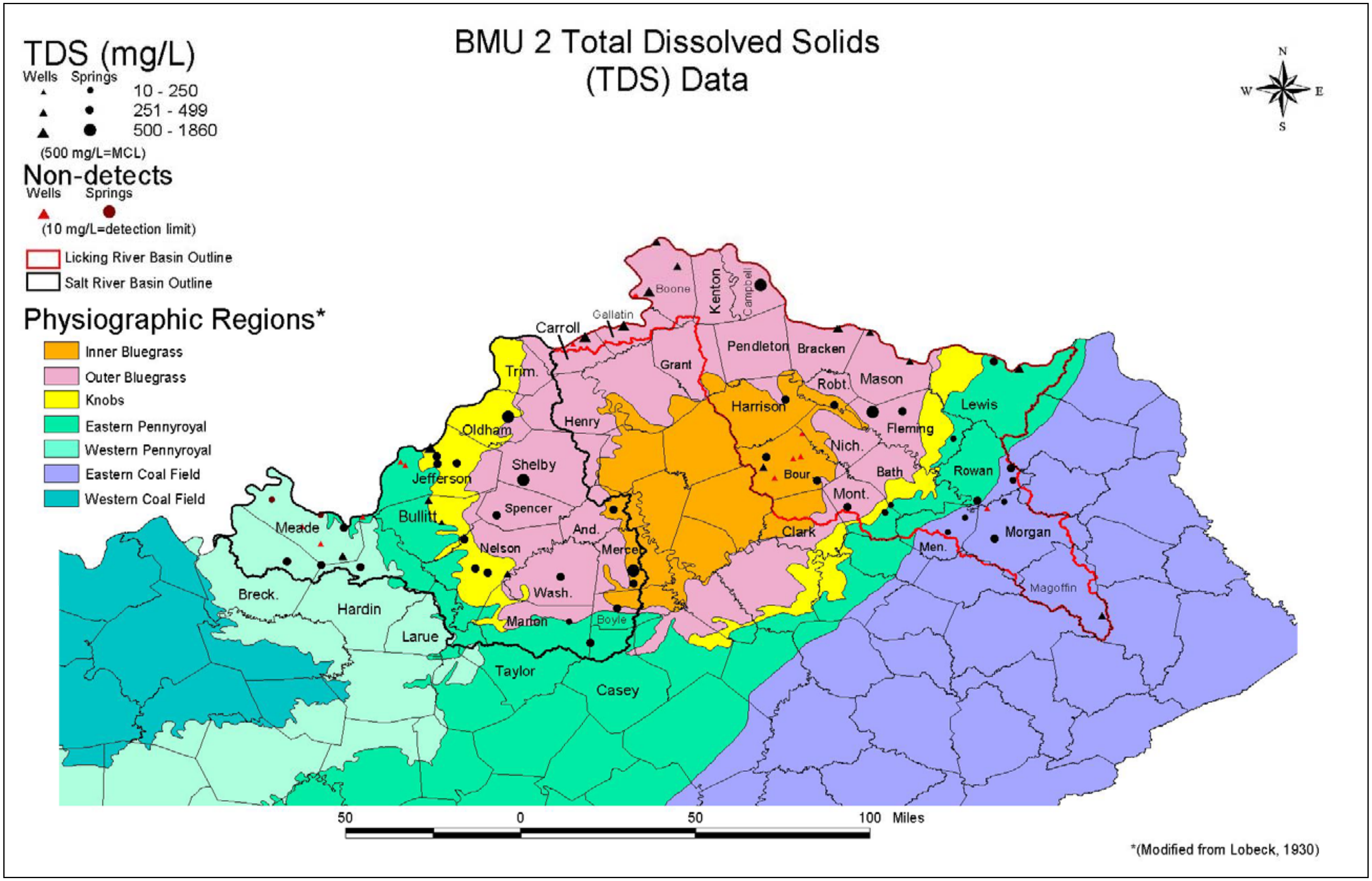


Figure 35. Map of Total Dissolved Solids data for BMU 2

Figure 36. Boxplot for TSS measurement distributions in BMU #2

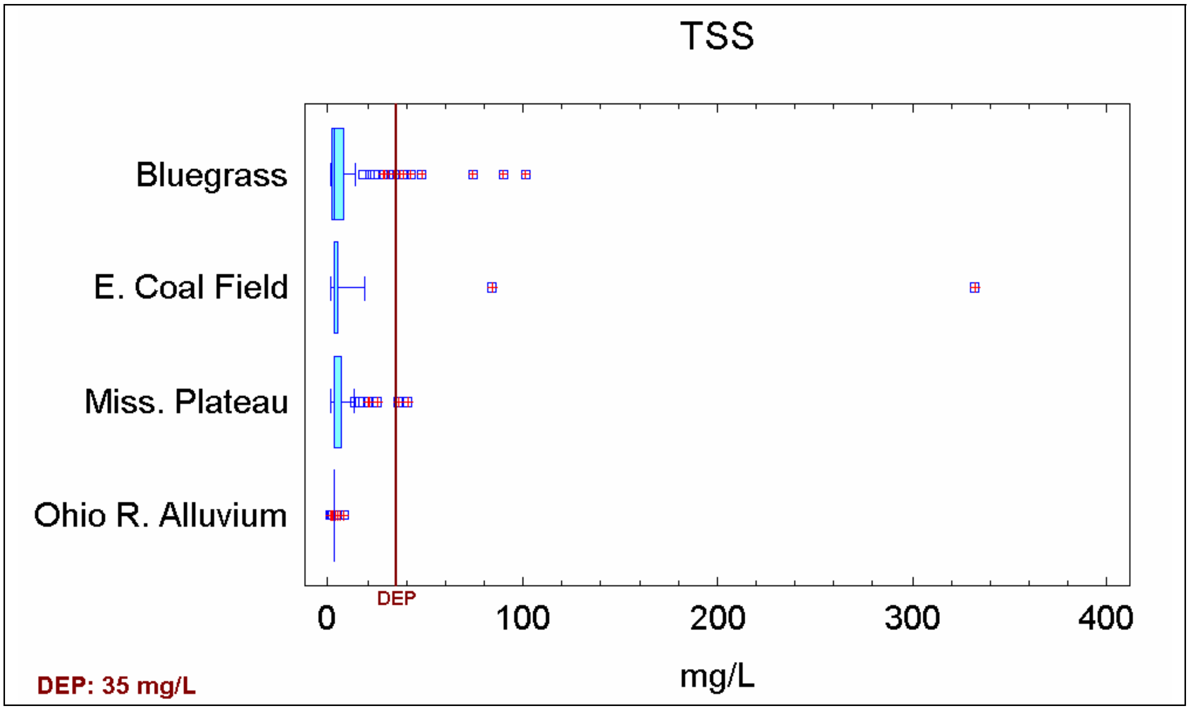


Figure 37 illustrates that high levels of TSS generally occur in karst areas where aquifers can be under the direct influence of surface water runoff.

Nutrients

Nutrients included in this report are nitrate-nitrogen, nitrite-nitrogen, ammonia, orthophosphate, and total phosphorous. Nutrients are particularly important in surface water, where they are the main contributors to eutrophication, which is excessive nutrient enrichment of water. This enrichment can cause an overabundance of some plant life, such as algal blooms, and may also have adverse effects on animal life, because excessive oxygen consumption by plants leaves little available for animal use. In addition to comparisons with various water quality standards, nutrient data from sites in this study were compared to the two reference springs.

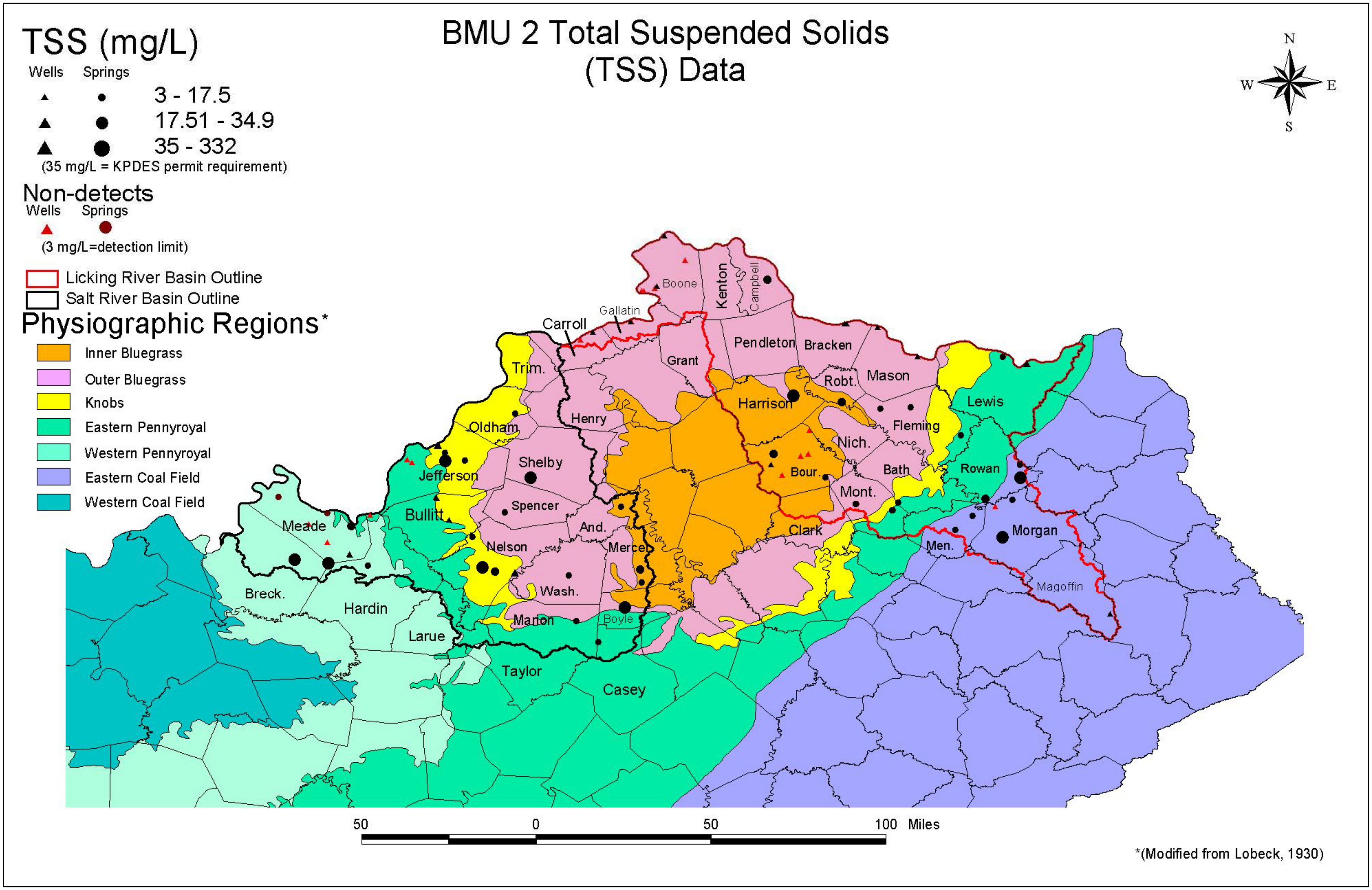


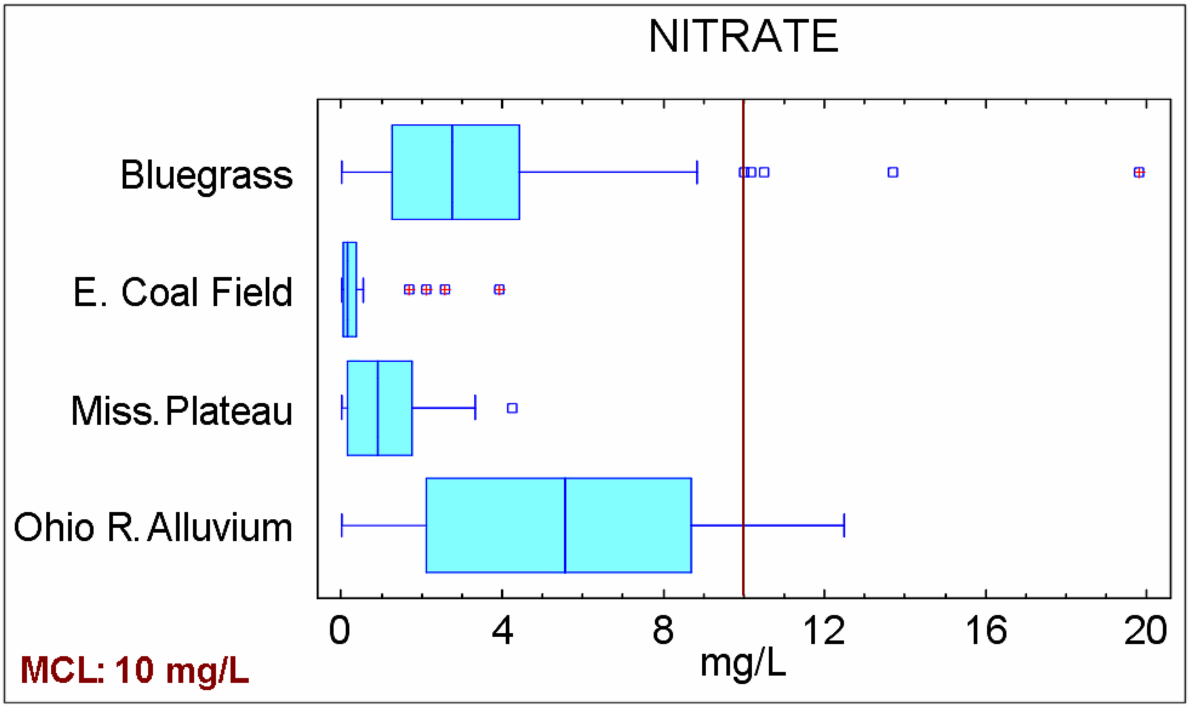
Figure 37. Map of Total Suspended Solids data for BMU 2

Nitrate (NO_3) occurs in the environment from a variety of anthropogenic and natural sources: nitrogen-fixing plants such as alfalfa and other legumes, nitrogen fertilizers, decomposing organic debris, atmospheric deposition from combustion, and from human and animal waste. Nitrate is reported either as the complex ion NO_3, or as the equivalent molecular nitrogen-n. Since 1 mg/L of nitrogen equals 4.5 mg/L nitrate; therefore, the drinking water MCL of 10 mg/L nitrate-n equals 45 mg/L nitrate. In this report, results are reported as "nitrate-n."

In infants, excess nitrate consumption can cause methemoglobinemia, or "blue-baby" syndrome. In adults, possible adverse health effects of nitrate ingestion are under study and much debated. Because nitrate is difficult to remove through ordinary water treatment, its occurrence at levels above the MCL in public water systems is a problem.

As shown in Figure 38, and in the Nutrients Summary Statistics table in Appendix F, median

Figure 38. Boxplot for Nitrate-Nitrogen measurement distributions in BMU #2

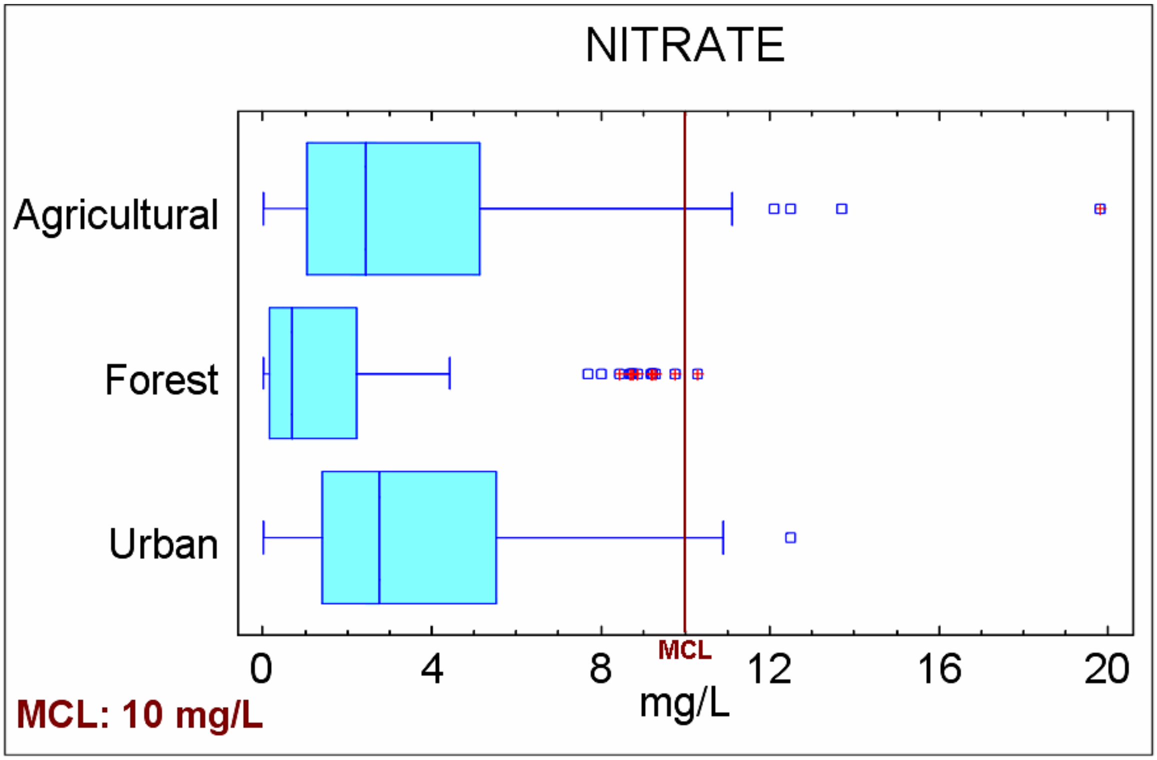


values of nitrate-n varied from a low of 0.1785 mg/L in the Eastern Coal Field to a high of 5.58 mg/L in the Ohio River Alluvium. Median values for the Bluegrass and the Mississippian Plateau were 2.76 mg/L and 0.9025 mg/L respectively. Approximately 4.48% of nitrate-n detections were found above the MCL of 10.0 mg/L, and these exceedances occurred in the Bluegrass and Ohio River Alluvium. No MCL exceedances occurred in the Eastern Coal Field or the Mississippian Plateau.

Nitrate-n values found in this study were compared to the values found in other studies, as well as those from reference springs (Table 2). Based upon nitrate-n data from throughout the United States (USGS, 1984), most researchers believe that nitrate-n levels of 3.0 mg/L or lower represent background levels. However, in Kentucky some nitrate-n data support significantly lower levels for ambient conditions. For example, a review of nitrate-n analyses from three reference springs (Table 2) show a median value of 0.1805 mg/L for these sites. In addition, Carey and others (1993) found a median of 0.71 mg/L for nitrate-n in 4,859 groundwater samples collected from predominantly domestic water wells throughout the state. In their statewide study of nitrate-n, Conrad and others (1999) found that depth was a determining factor regarding the occurrence of nitrate-n in groundwater. MCL exceedances occurred most frequently in shallow dug wells and declined with depth. Nearly 10% of dug wells exceeded the MCL; whereas only about 1% of wells greater than 151 feet were in exceedance, and median values were only 0.6 mg/L. In conclusion, the median value of 2.38 mg/L for nitrate-n found in this study is well above background levels, and indicates probable nonpoint source impact on groundwater in all physiographic provinces except the Eastern Coal Field.

Figure 39 indicates that urban areas have comparable or higher levels than agricultural areas, which was an unexpected result. This higher than expected occurrence of nitrate-n in urban areas may be the result of leakage from sanitary sewers combined with infiltration from the application of nitrogen-based lawn fertilizers. Forested areas showed the lowest median values of nitrate-n but unexpected outliers occurred, several of which approach the MCL, with one exceeding that value. These higher values are may be the result of nearby failing septic systems, which could allow untreated waste to

Figure 39. Boxplot for Nitrate-Nitrogen Distributions by Land-Use in BMU #2.



infiltrate into the groundwater. High nitrate-n values in agricultural areas are expected, and are the result of the application of nitrogen fertilizers combined with livestock grazing and feeding operations.

Figure 40 shows the geographical distribution of nitrate-n values in BMU 2. High values in wells in the Ohio River Alluvium and in springs, especially in the Bluegrass, were observed. The highest value found in this study (19.8 mg/L) occurred at a spring in western Fleming County, and is probably the result of intense livestock grazing in the area immediately up-gradient of the spring.

Nitrite (NO_2) also occurs naturally from most of the same sources as nitrate. However, nitrite is an unstable ion and is usually quickly converted to nitrate in the presence of free oxygen. The MCL for nitrite-n is 1 mg/L.

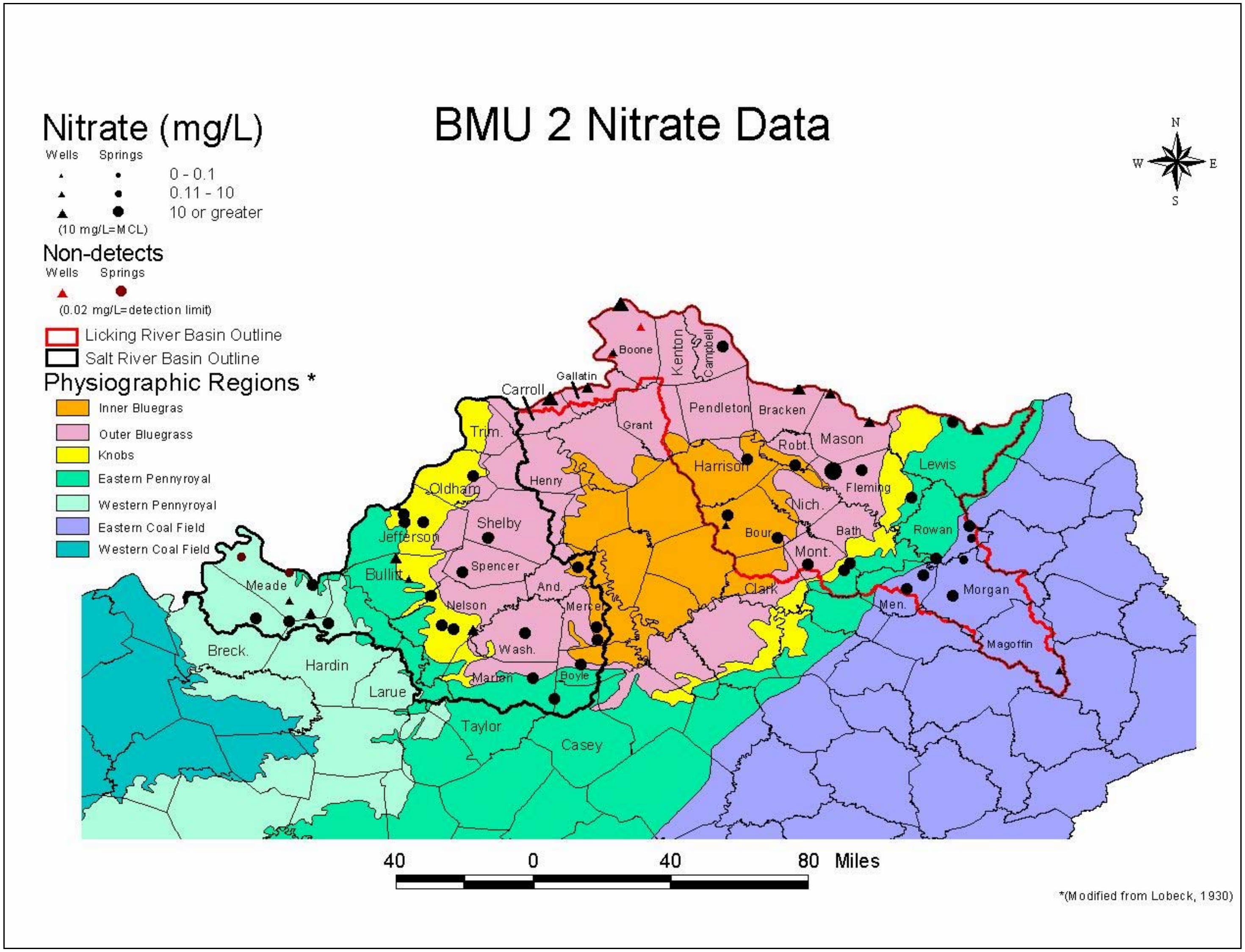


Figure 40. Map of Nitrate data for BMU

Nitrite-n was found to occur at very low levels and with several outliers, as shown in Figure 41 and 42. Nitrite-n was not detected above the MCL, and the highest values were less than half the MCL of

Figure 41. Boxplot for Nitrite-Nitrogen measurement distributions in BMU #2

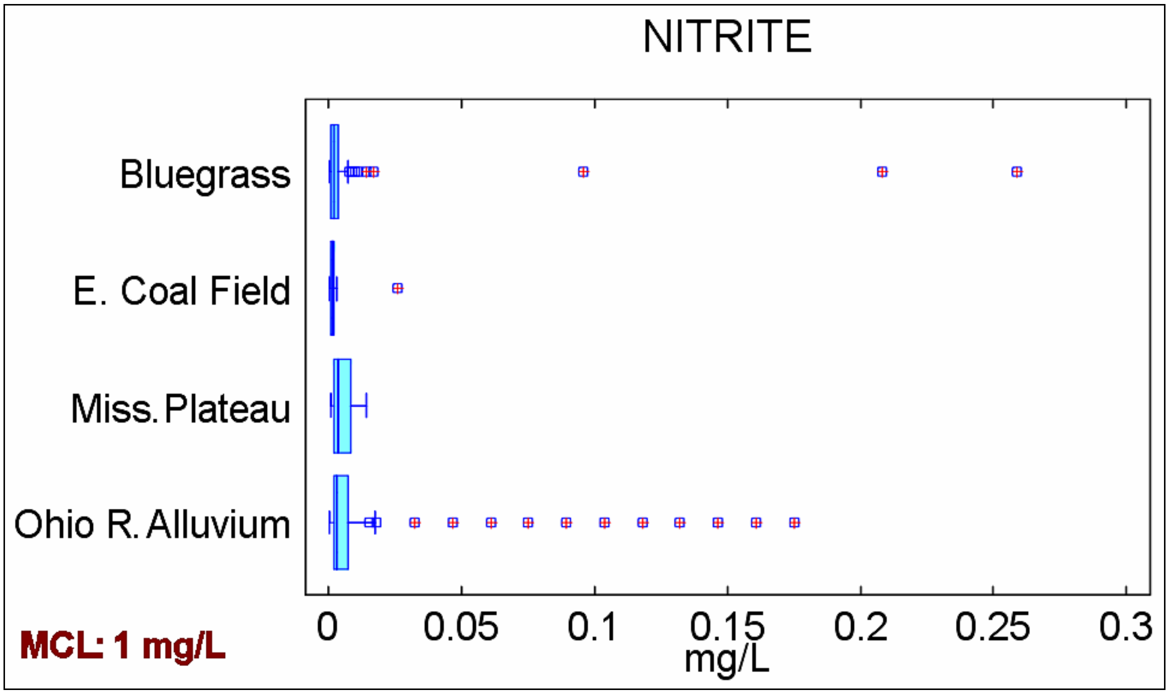
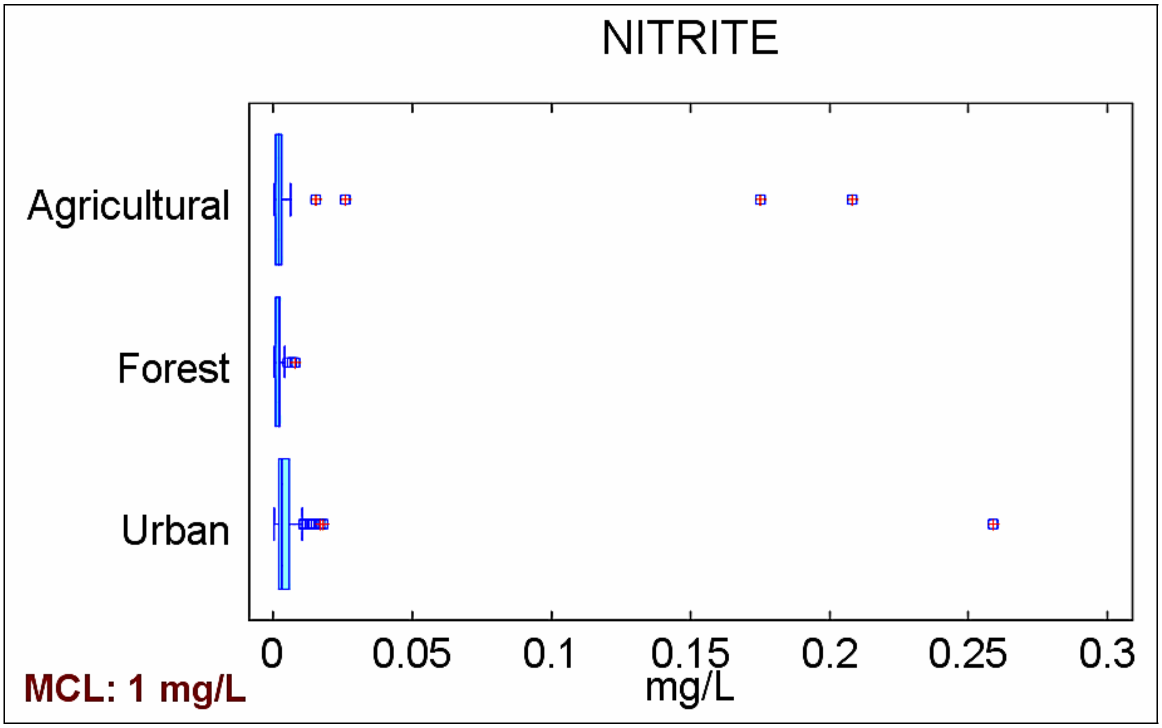


Figure 42. Boxplot for Nitrite-Nitrogen Distribution by Land-Use in BMU #2



1 mg/L. The lowest median value found in this study was 0.001165 mg/L in the Eastern Coal Field (Appendix F, Nutrients Summary Statistics Table). Values almost as low occurred in the Ohio River Alluvium and the Bluegrass: 0.002 mg/L. The highest median value of 0.00375 mg/L occurred in the Mississippian Plateau.

In the environment, nitrite-n generally converts rapidly to nitrate through oxidation, which this study reflects. Nitrite is not a significant nonpoint source pollutant, although it may contribute to high levels of nitrate. In this study, the occurrence of nitrite-n was not dependent on land use, as shown in Figure 42. In addition, Figure 43 further supports the conclusion that no significant problem with nonpoint source pollution from nitrite-n was found in this study. However, when viewed together nitrate-n and nitrite-n do have broad nonpoint source impacts.

Ammonia (NH_3) occurs naturally in the environment, primarily from the decay of plants and animal waste. The principle source of man-made ammonia in groundwater is from ammonia-based fertilizers. No drinking water standards exist for ammonia; however, the proposed DEP limit for groundwater is 0.110 mg/L.

Reference spring data (Table 2) shows that ammonia values are typically very low, often below the method detection limit of 0.02 mg/L. Low values, but above this level, may indicate natural variations. However, increasing values, as shown in the outliers in Figures 44 and 45 seem to indicate impacts from nonpoint source pollution. In this study, ammonia occurred in almost 30% of the samples, with the narrowest range of values in the Mississippian Plateau and Eastern Coal Field (Figure 46). High levels of ammonia were found in southern Mercer County at Humane Spring, which is adjacent to the Humane Society’s facility and may explain elevated ammonia.

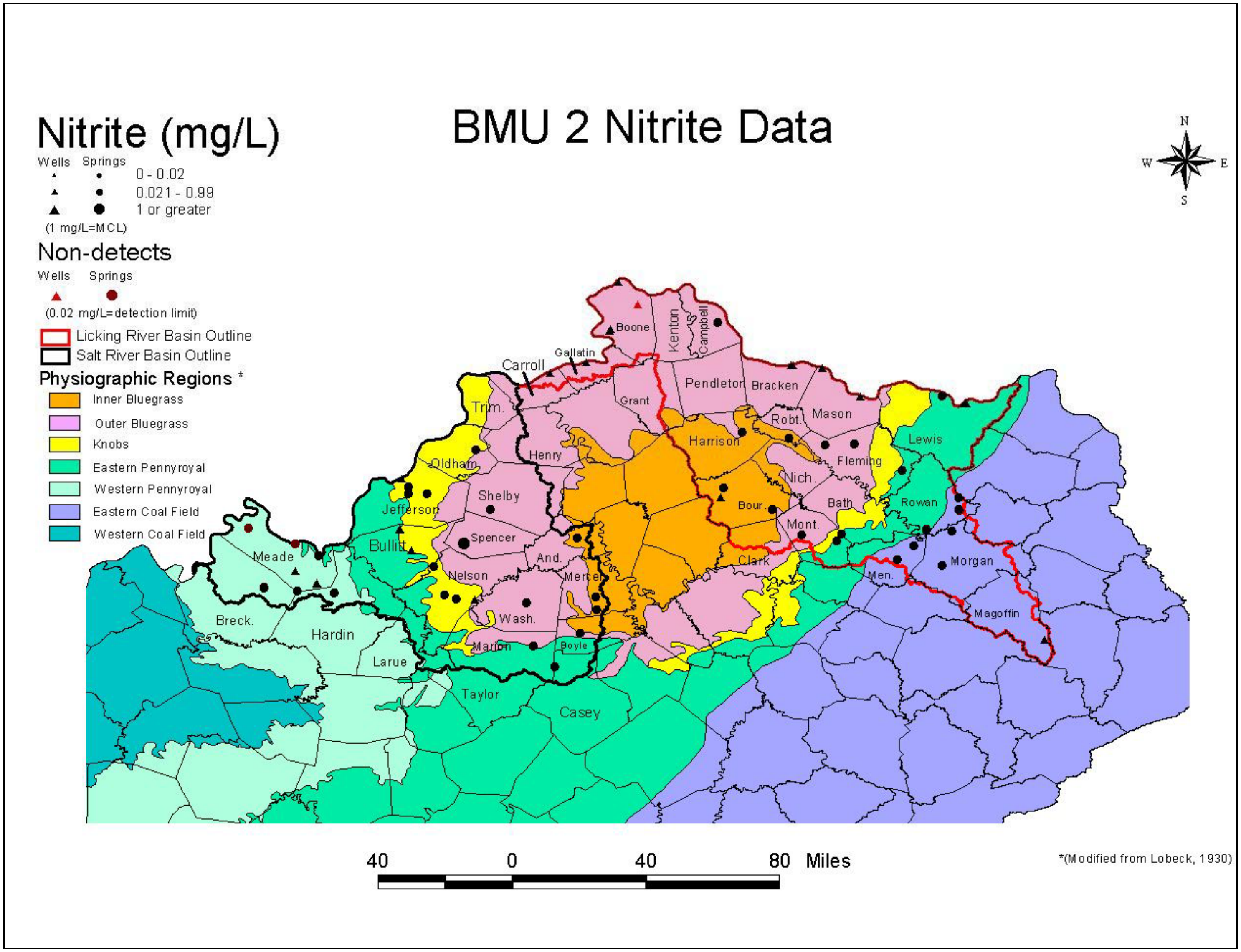


Figure 43. Map of Nitrite-n data for BMU 2

Figure 44. Boxplot for Ammonia measurement distributions in BMU #2

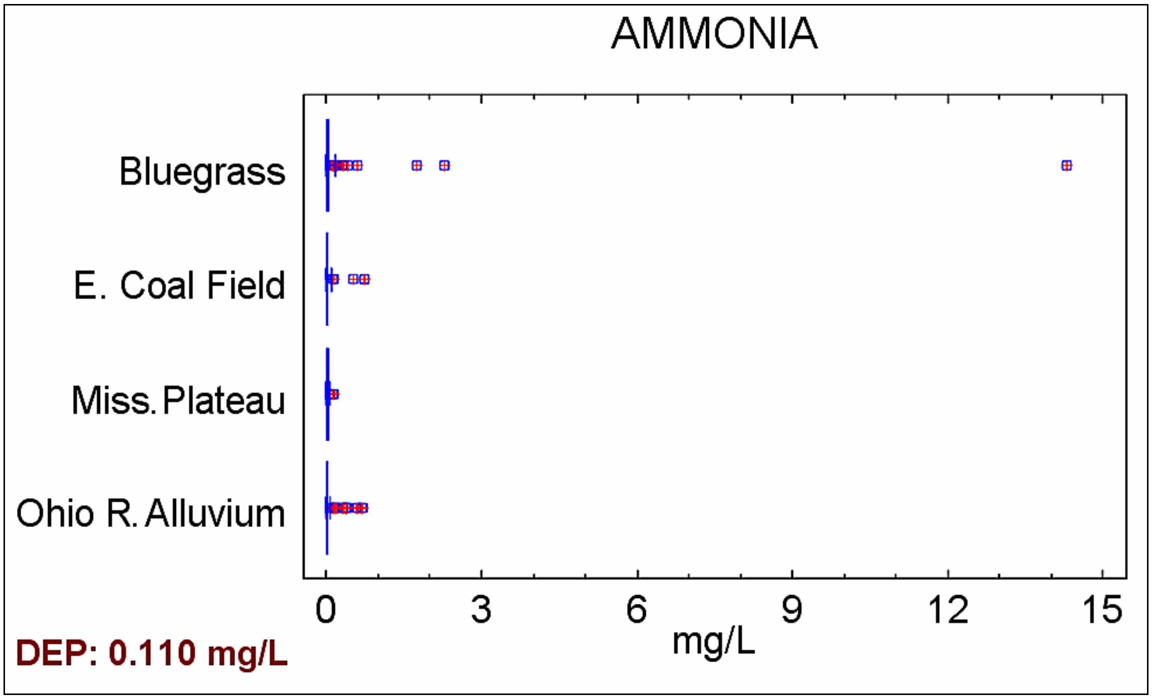
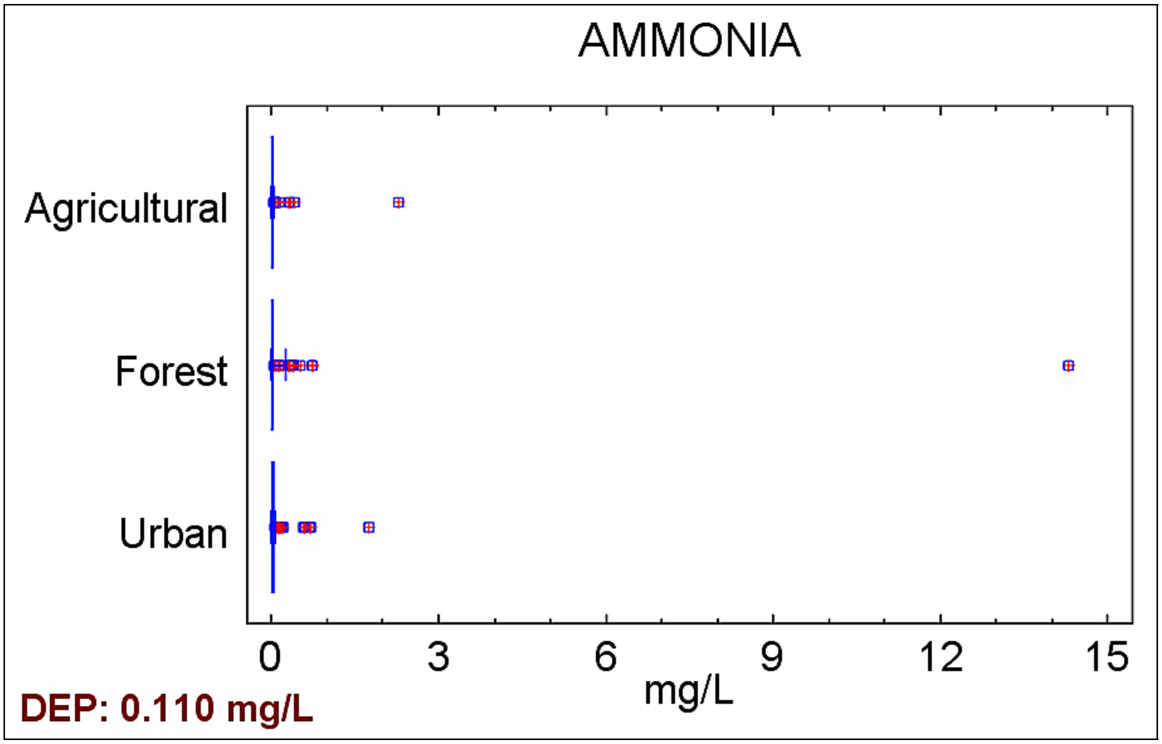


Figure 45. Boxplot for Ammonia Distribution by Land-Use in BMU #2.



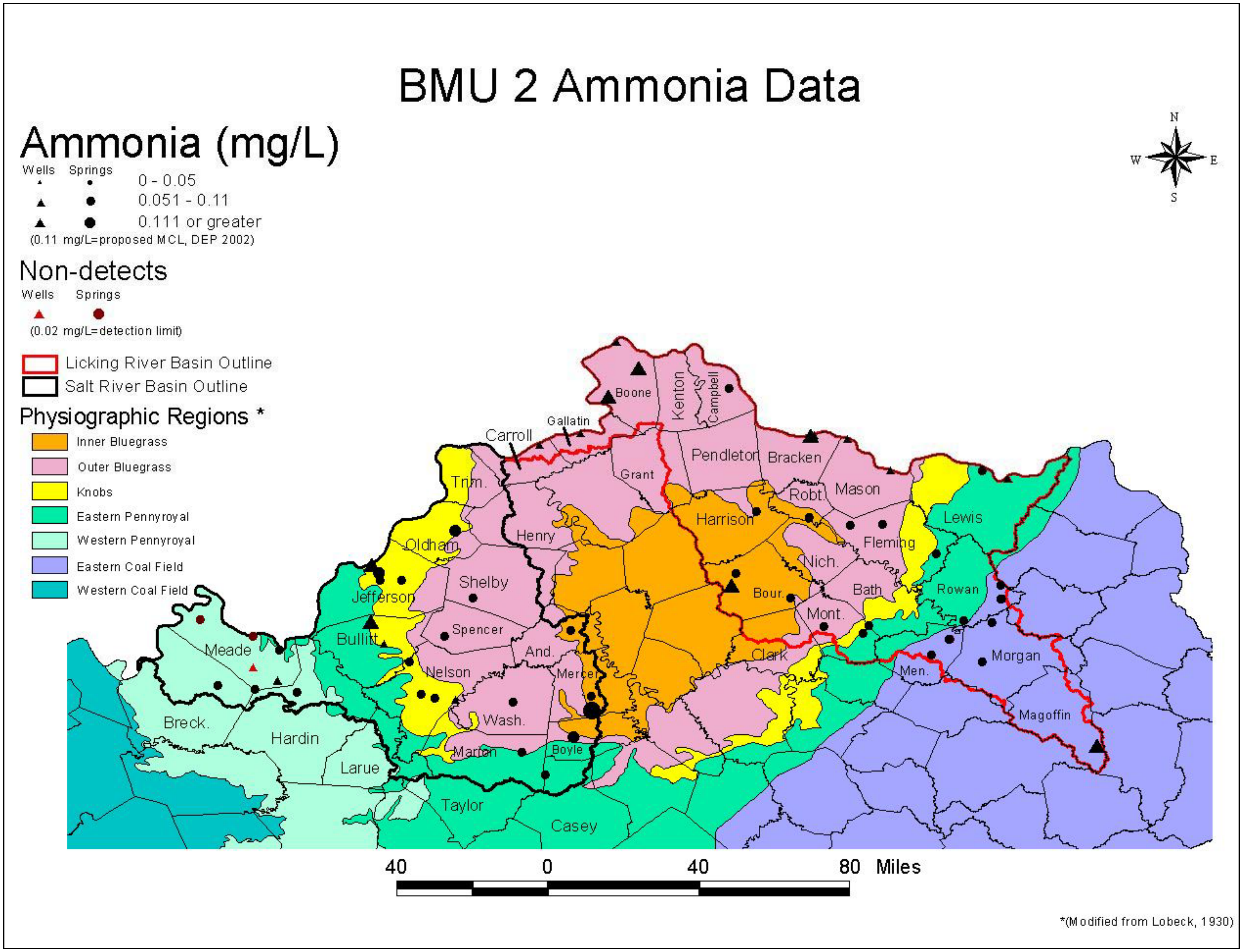


Figure 46. Map of Ammonia data for BMU 2

Two forms of phosphorus are discussed in this report: orthophosphate-p and total phosphorus. Orthophosphate-P (PO_4 -P), or simply "orthophosphate", or "ortho-p", is the final product of the dissociation of phosphoric acid, H_3PO_4. It occurs naturally in the environment most often as the result of the oxidation of organic forms of phosphorus and is found in animal waste and in detergents. Orthophosphate is the most abundant form of phosphorus, usually accounting for about 90% of the available phosphorus. Phosphorus contributes to the eutrophication of surface water, particularly lakes, commonly known as "algal blooms".

The most common phosphorus mineral is apatite [$Ca_5(PO_4)_3(OH,F,Cl)$], which is found in the phosphatic limestones in the Bluegrass. Neither orthophosphate nor total phosphorus has a drinking water standard. Orthophosphate data are compared to the Texas surface water quality standard of 0.04 mg/L and total phosphorus data to the surface water limit of 0.1 mg/L recommended by the USGS.

In natural systems relatively unimpacted from anthropogenic sources, orthophosphate occurs at very low levels. For example, reference reach springs typically were either non-detect for ortho-p, or had values in the range of 0.002 – 0.004 mg/L. Although some more sensitive laboratory methods were used in this study, the most common MDL was 0.059 mg/L, which is above the surface water quality standard of 0.04 mg/L used for comparison in this study. Because approximately 70% of the samples were non-detect using that relatively high detection limit, the narrow range of values shown in Figure 47 may not reflect the true occurrence of orthophosphate in this area. In the Bluegrass, numerous high outliers of orthophosphate may be the result of naturally occurring phosphatic limestones and from agricultural practices, including livestock production and grazing or the application of phosphate-rich fertilizers. Therefore, this may indicate possible nonpoint source pollution. Higher median values of orthophosphate in urban areas, as shown in Figure 48, probably reflect impacts from leaking sanitary sewers. A map illustrating the distribution of orthophosphate data is presented in Figure 49, which shows that most of the higher values occur within the Bluegrass.

Figure 47. Boxplot for Orthophosphate measurement distributions in BMU #2

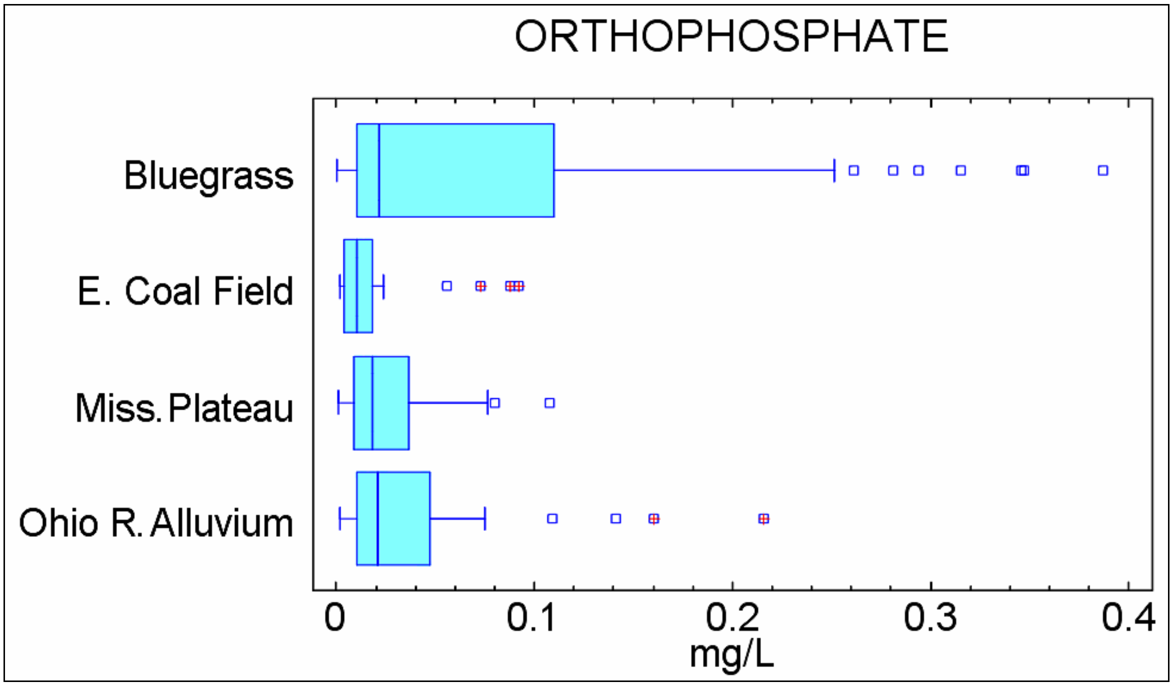
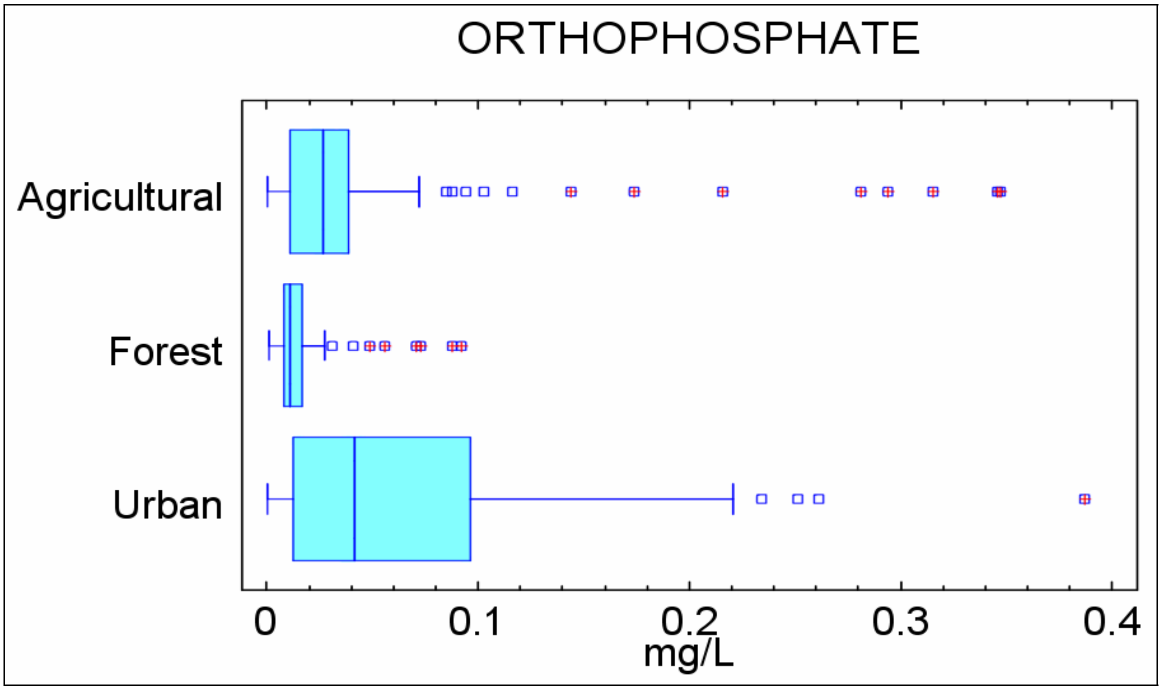


Figure 48. Boxplot for Orthophosphate Distribution by Land-Use in BMU #2



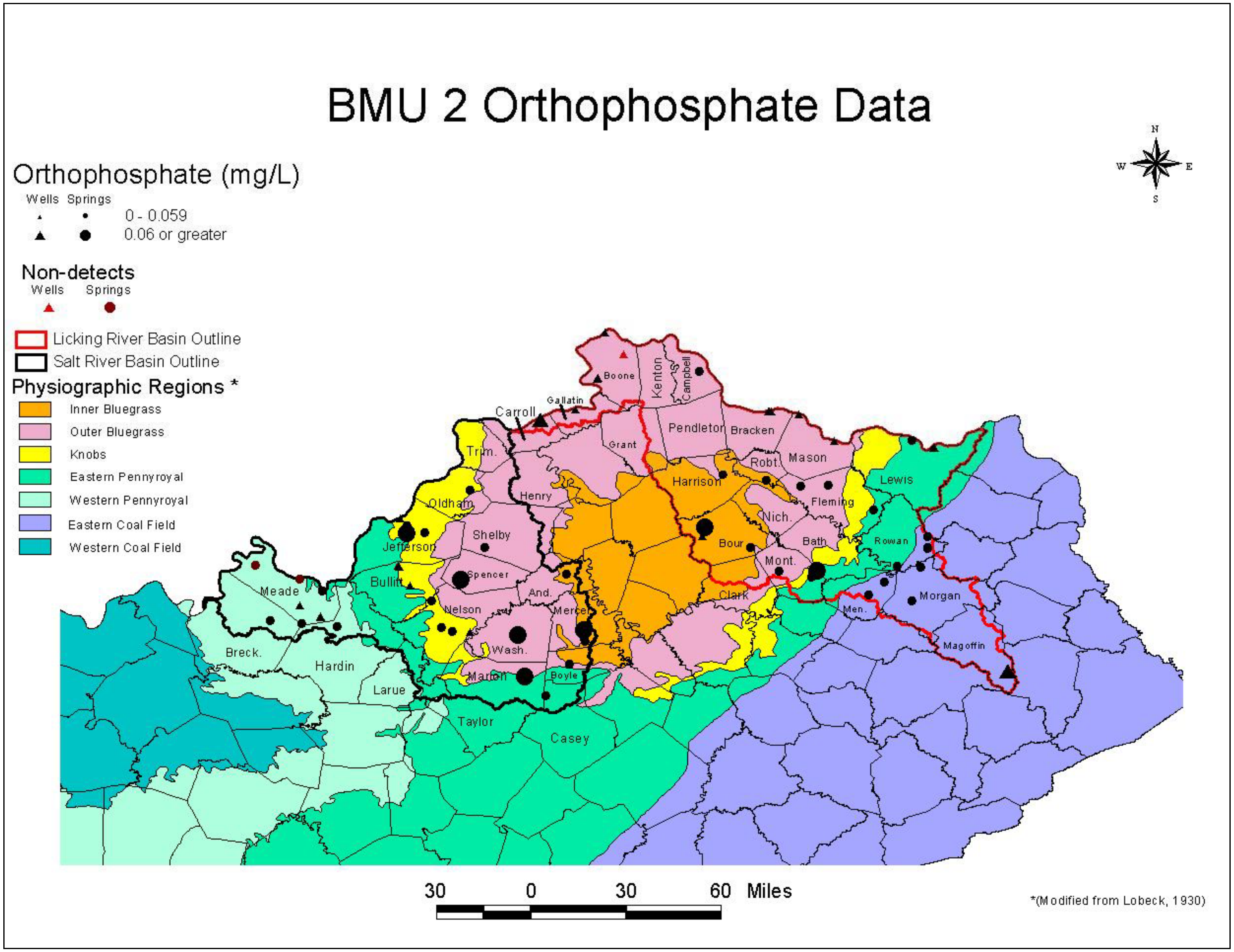


Figure 49. Map of Orthophosphate data for BMU 2

Total phosphorus is the sum of organic and inorganic forms of phosphorus. Total phosphorus in reference reach springs was usually non-detect, using an MCL of 0.05 mg/L. Low amounts of phosphorus within a narrow range occur in BMU 2, except for the Bluegrass (Figure 50). Phosphatic limestones are well known in the Bluegrass (McDowell, 2001). Therefore, in the Bluegrass the most of the variability of this parameter is probably the result of natural variability in the system, with some possible introduction from anthropogenic sources. As expected, forested areas show the lowest levels of total phosphorus, as shown in Figure 51. Agricultural and urban areas showed only slightly greater levels, indicating possible nonpoint source impacts from animal waste in agricultural areas and human waste and phosphatic detergents from sanitary sewer leaks, as well as the application of lawn fertilizer, in urban areas. Figure 52 shows the distribution of total phosphorus in BMU 2.

Figure 50. Boxplot for Total Phosphorus measurement distributions in BMU 2

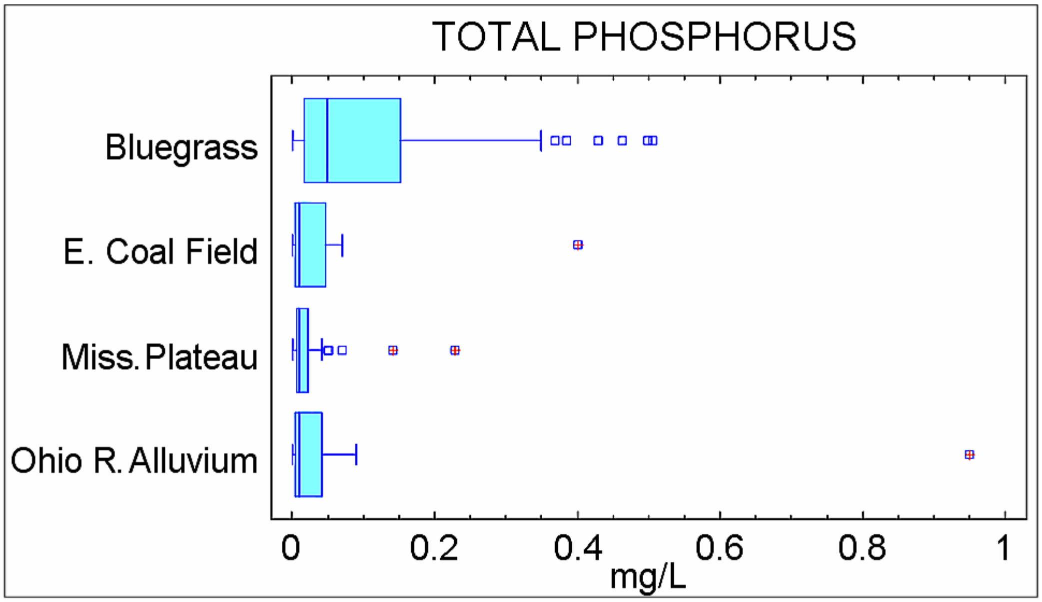
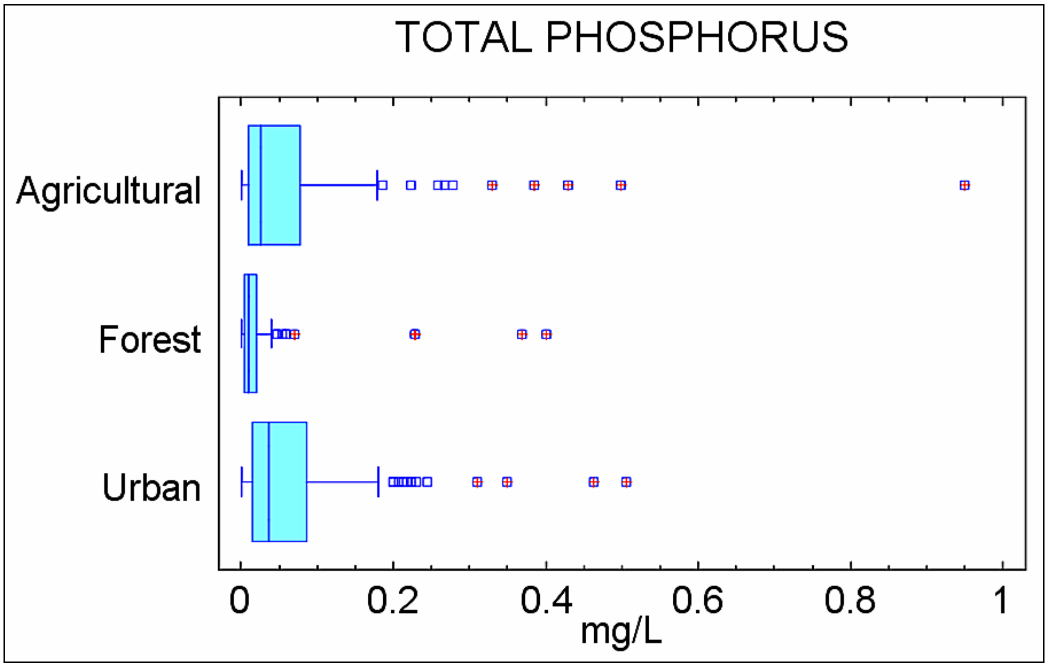


Figure 51. Boxplot of Total Phosphorus Distribution by Land-Use in BMU #2.



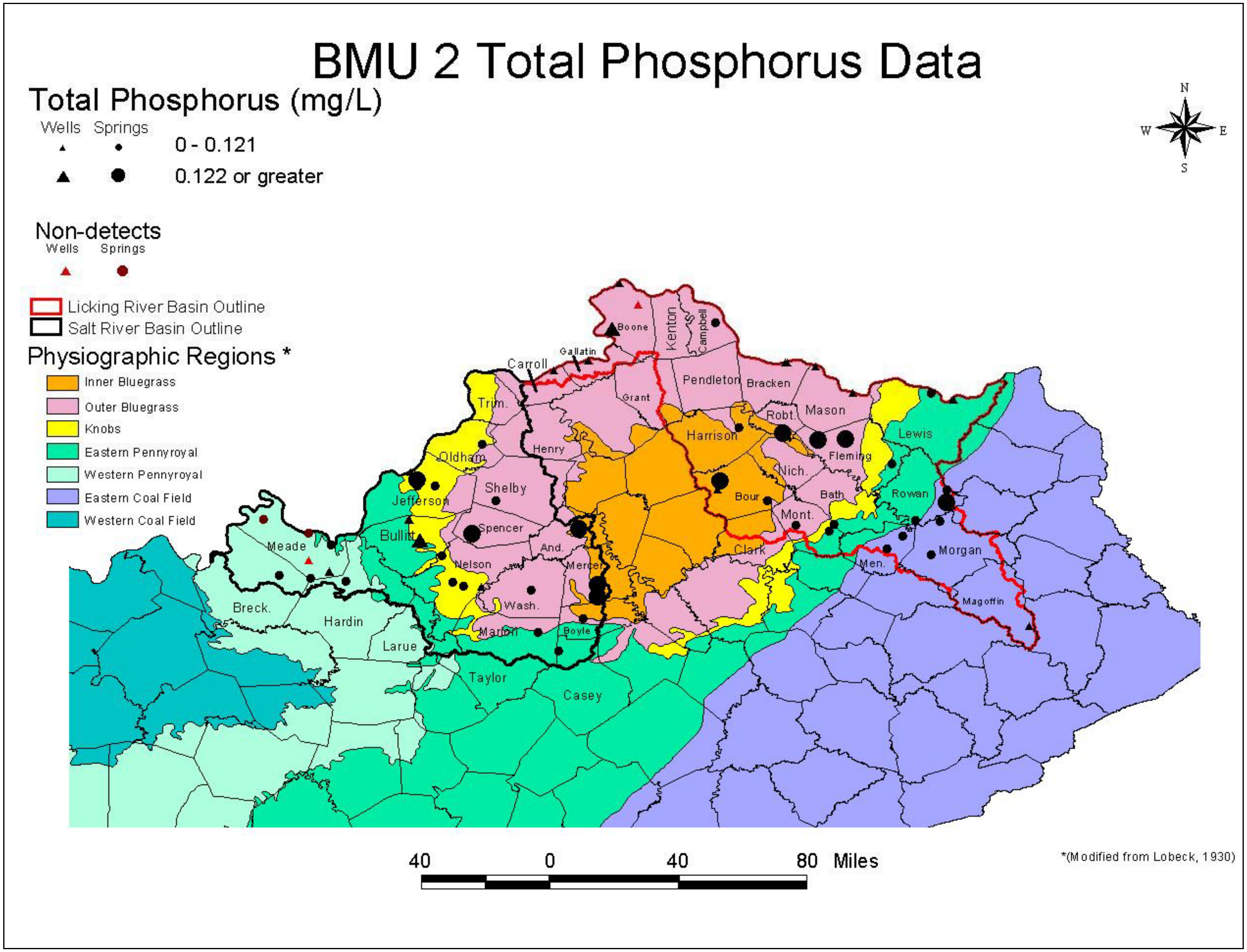


Figure 52. Map of Total Phosphorus data for BMU 2

Volatile Organic Compounds

The volatile organic compounds most often detected in groundwater are the BTEX compounds: benzene, toluene, ethylbenzene, and xylenes. Also of concern is methyl-tertiary-butyl-ether, or MTBE. Because these compounds are among the most commonly-found hazardous components of gasoline (Irwin, and others, 1997), and because of potential acute and long-term impacts to aquatic life and human health, they are included in this report. Although BTEX compounds also occur naturally, their occurrence in groundwater is usually indicative of point source contamination, most often leaking underground storage tanks.

In urban areas, nonpoint sources of BTEX and MTBE include leaks from automobile gas tanks. Some researchers are concerned with possible air-borne deposition of BTEX and MTBE from the incomplete combustion of fossil fuels. An additional potential source is from pesticides that may contain volatile organic compounds, including BTEX, used as carriers for the active ingredient. These volatile organic compounds are important to evaluate because of various detrimental effects to human health and the environment.

BTEX and MTBE are persistent in the environment, particularly groundwater, for two primary reasons. First, water solubility of BTEX is moderate to high, ranging from a low of 161 mg/L for ethylbenzene to 1730 mg/L for benzene. In comparison, MTBE is very soluble, with values from 43,000 to 54,300 mg/L. Because of this solubility, MTBE in contaminant plumes moves at virtually the same rate as the water itself, whereas BTEX plumes move at somewhat slower rates. Second, because these compounds (except for benzene) have relatively low vapor pressure and Henry’s law constants, they tend to remain in solution, rather than being volatilized.

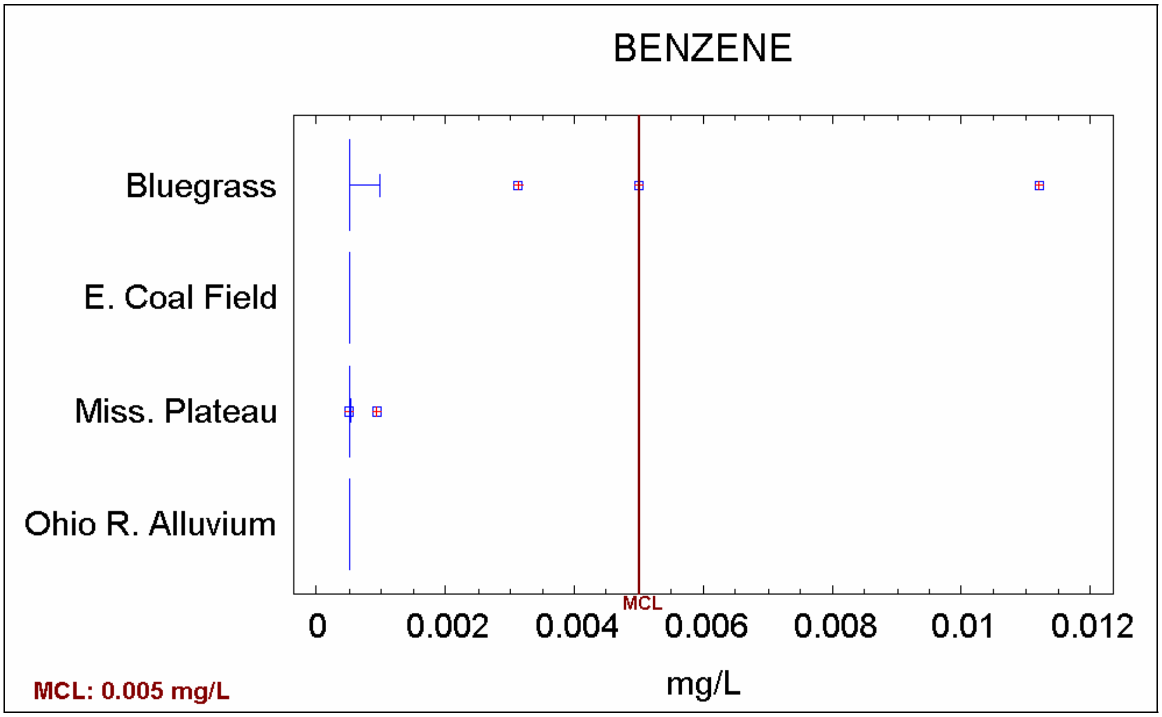
Because of these, and other, physical and chemical characteristics, cleanup of contaminanted groundwater is difficult. “Pump and treat” and various bioremediation techniques have proven the most useful techniques.

Benzene

Benzene is found naturally in the environment in organic matter, including coal and petroleum, and is released into the environment during combustion. Benzene is also found in products manufactured from crude oil, including gasoline, diesel and other fuels, plastics, detergents, and pesticides. Benzene is also produced during the combustion of wood and vegetation. Benzene is a known carcinogen in humans and has been associated with various nervous system disorders, anemia, and immune system depression (USEPA, 2000). The MCL for benzene is 0.005 mg/L.

Benzene was detected at only two locations (Figures 53 and 54) in this study: Humane Spring in Mercer County and at a public water supply well (since abandoned) in Meade County. Both occurrences are from known point sources. For benzene, this study found no nonpoint source impacts from urban run-off.

Figure 53. Boxplot for Benzene measurement distributions in BMU #2



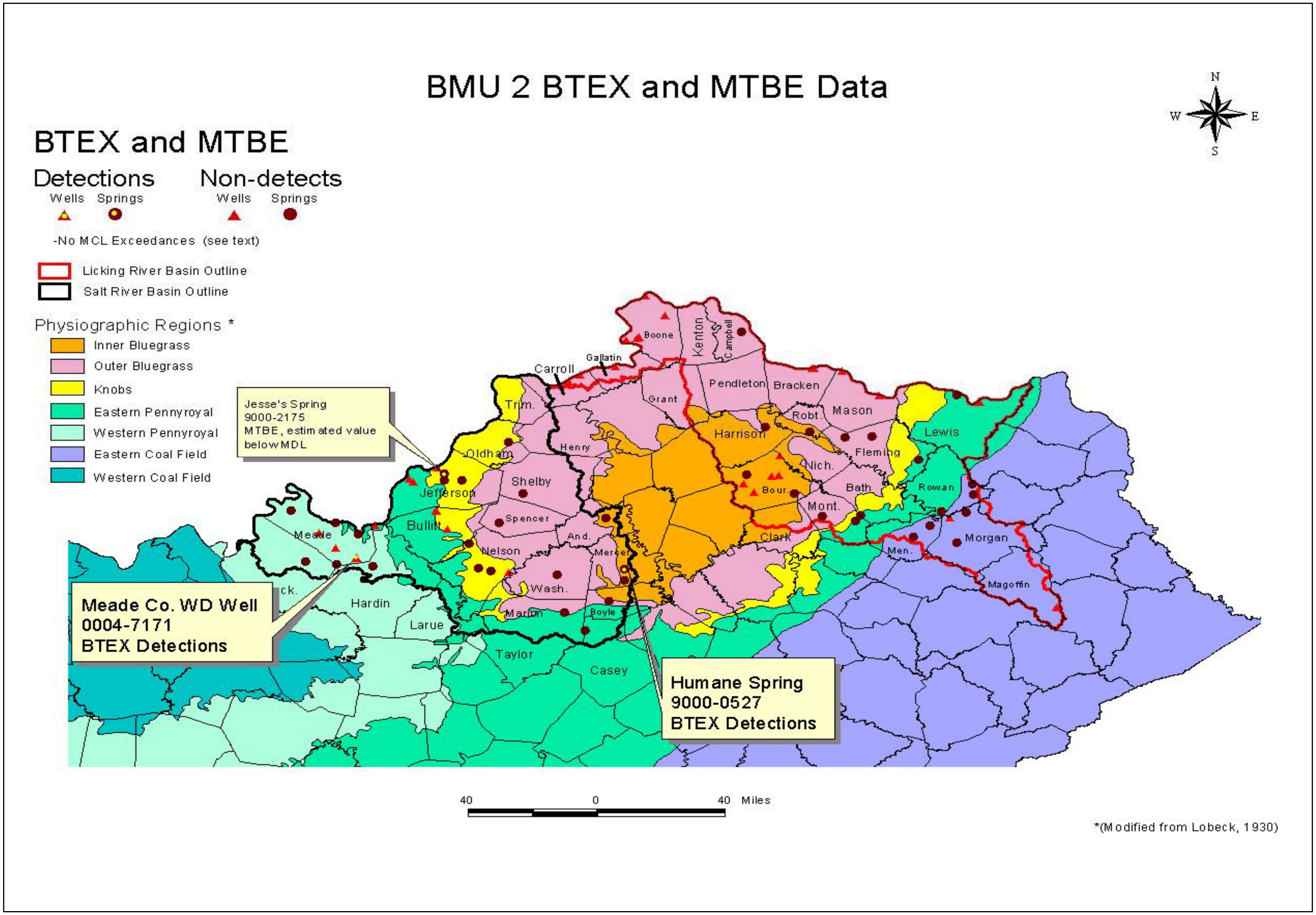
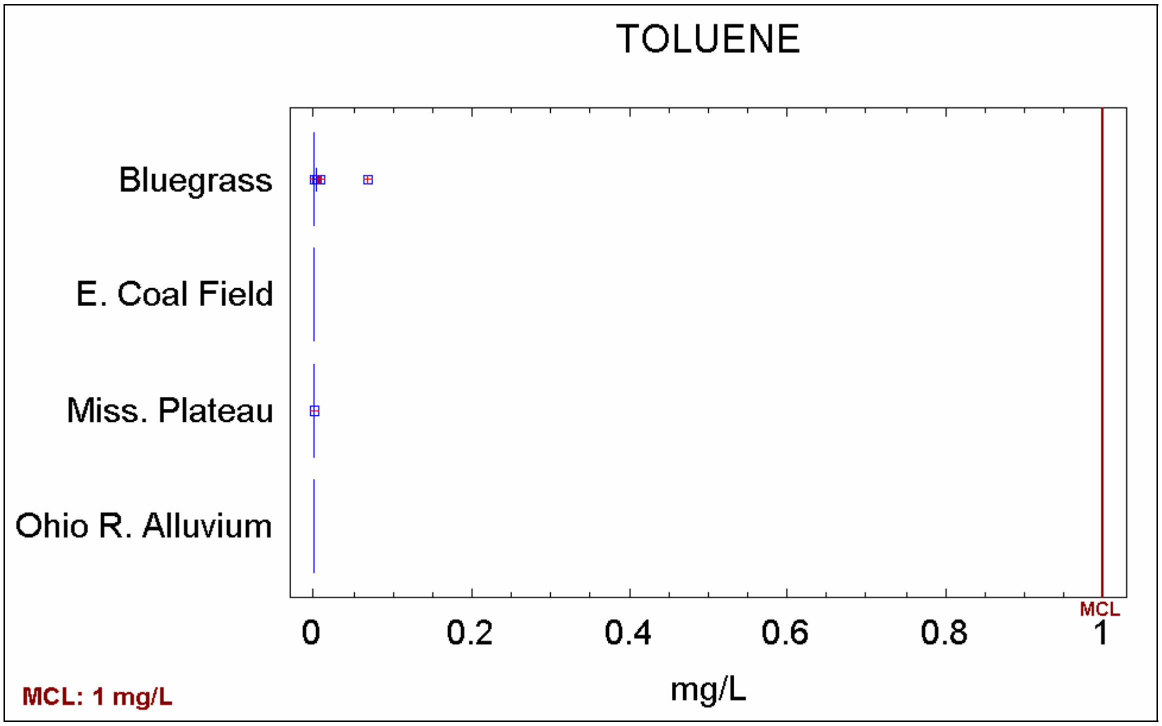


Figure 54. Map of BTEX and MTBE data for BMU 2

Toluene is a clear liquid that occurs naturally in crude oil, as well as in refined oil products, such as gasoline. Toluene also occurs naturally in coal and is common in paints, paint thinner, fingernail polish, and other products. Although toluene is not considered carcinogenic in humans (USEPA, 2000), it has been linked with several detrimental physical and neurological effects, including diminished coordination and the loss of sleep ability. Toluene has an MCL of 1.0 mg/L.

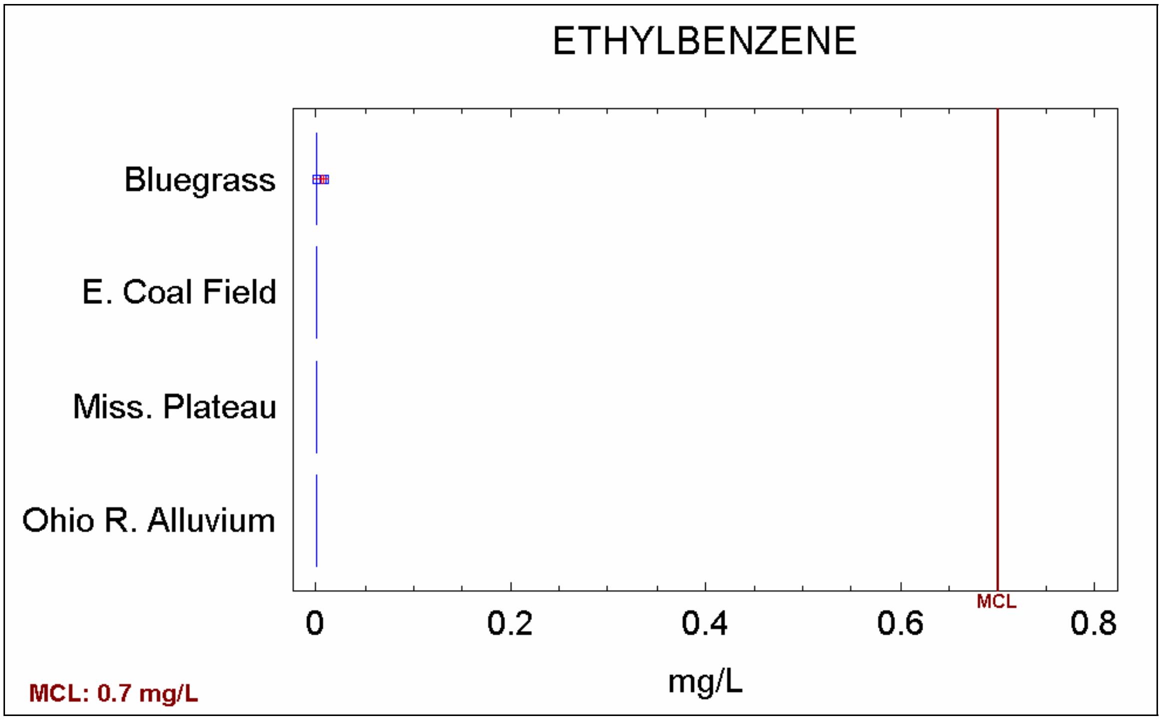
In this study, toluene was detected at the same two sites as benzene (Figure 55). Because these sites are known point sources, no nonpoint source impacts to groundwater from this parameter were found in this study.

Figure 55. Boxplot for Toluene measurement distributions in BMU #2



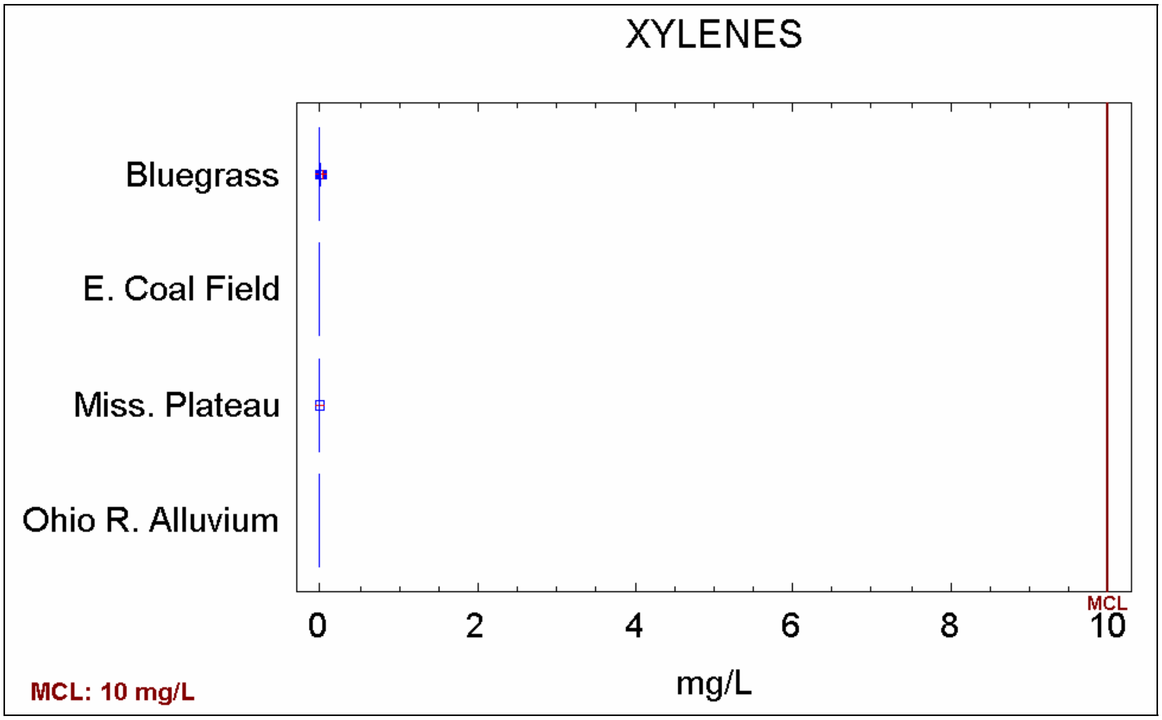
Ethylbenzene is a component of crude oil, and is a constituent of refined petroleum products, including gasoline. In addition, this colorless liquid is used to manufacture styrene. According to the USEPA (2000), limited studies of ethylbenzene have shown no carcinogenic effects in humans; however, animal studies have shown detrimental health effects to the central nervous system. The MCL for ethylbenzene is 0.7 mg/L. Ethylbenzene was only detected at Humane Spring (see Figure 54 for reference) as shown in Figure 56. As with the other volatile organic compounds included in this report, this occurrence is from a known point source, and therefore no nonpoint source impacts to groundwater were found in this BMU.

Figure 56. Boxplot for Ethylbenzene measurement distributions in BMU #2



Xylenes are any one of a group of organic compounds typically found in crude oil, as well as in refined petroleum products such as gasoline. Xylenes are clear, sweet-smelling, and are used as solvents and in the manufacture of plastics, polyester, and film. Xylenes have an MCL of 10 mg/L. Xylenes are not carcinogenic in humans, although data are limited. In humans, exposure to excessive amounts are associated with disorders of the central nervous system, kidneys, and liver (USEPA, 2000). Xylenes were only detected at Humane Spring and the Meade County well (see Figures 54 and 57). Again, these occurrences are from known point sources, and therefore no nonpoint source impacts from this volatile organic compound were found.

Figure 57. Boxplot for Xylenes measurement distributions in BMU #2



Methyl-tertiary-butyl-ether, or MTBE, is a man-made compound and is used as an oxygenate added to gasoline in order to promote more complete combustion, increase octane, and to reduce emissions of carbon monoxide and ozone. MTBE is very mobile in groundwater and has contaminated numerous aquifers throughout the United States. This compound has no MCL; however, the proposed DEP standard is 0.05 mg/L. According to the USEPA (1997), no studies have documented human health effects from the consumption of MTBE contaminated water. However, animal studies have shown some carcinogenic and non-carcinogenic effects.

One sample in 81 analyses detected a trace of MTBE. In this sample, the volume remaining after other volatile organic analyses were performed was too low for a precise value to be determined: therefore, an *estimated* value of 0.00042 mg/L was assigned. This concentration, however, is lower than the detection limits used for the 80 other samples analyzed. These detection limits were 0.001 mg/L, 0.02 mg/L, and 0.2 mg/L. No MTBE occurred in any other sample in this study, using these various detection limits. Because MTBE was detected in only one sample, at Jesse's Spring in Louisville, no boxplot is presented. However, the map presented in Figure 54 shows this occurrence. This occurrence may be due to urban run-off, or possibly atmospheric deposition, but because no other volatile organic compounds were detected, any conclusions for this single estimated detection are tentative at best.

CONCLUSIONS

Although limited in scope, this study adds valuable data to the existing body of knowledge regarding groundwater in the state in general, and this BMU in particular. This additional information will assist efforts to understand and manage this resource.

As previously above, differentiating between naturally-occurring and groundwater impacted by nonpoint source pollution is sometimes difficult. For parameters that are man-made, such as pesticides and MTBE, the determination of nonpoint source pollution can be readily made; however, for parameters that also occur naturally, such as metals and nutrients, such a determination is problematic. For these parameters, data from this study of BMU 2 can be compared with data from reference reach springs and the state-wide ambient network, as well as with data published by other researchers. Through these comparisons tentative conclusions can be made.

Table 7 summarizes the conclusions reached in this study. This table categorizes impacts to groundwater from various nonpoint sources as "Definite”, "Possible”, or as not existing or simply as "No”.

A "**Definite**" impact is defined as an occurrence or detection of an unnatural parameter, such as a pesticide, or the detection of a compound that is both naturally occurring and anthropogenic, such as nitrate-n, that far exceeds background concentrations, as determined by comparison with reference site data, or data from other groundwater studies. Whether such impacts are detrimental would require receptor studies outside the scope of this particular inquiry. **Definite** nonpoint source impacts to groundwater were documented for the following parameters: nitrate-n, and several herbicides, including atrazine, metolachlor, alachlor, and simazine.

Table 7. Nonpoint Source Impacts to Groundwater, BMU 2

	PARAMETER	NO NPS INFLUENCE ON GROUNDWATER QUALITY	POSSIBLE NPS INFLUENCE ON GROUNDWATER QUALITY	DEFINITE NPS INFLUENCE ON GROUNDWATER QUALITY
Bulk Water Quality Parameters	Conductivity	•		
	Hardness (Ca/Mg)	•		
	PH		•	
Inorganic Ions	Chloride	•		
	Fluoride	•		
	Sulfate	•		
Metals	Arsenic	•		
	Barium	•		
	Iron	•		
	Manganese	•		
	Mercury	•		
Nutrients	Ammonia		•	
	Nitrate-n			•
	Nitrite-n	•		
	Orthophosphate		•	
	Total phosphorous		•	
Pesticides	Alachlor			•
	Atrazine			•
	Cyanazine	•		
	Metolachlor			•
	Simazine			•
Residues	Total Dissolved Solids		•	
	Total Suspended Solids		•	
Volatile Organic Compounds	Benzene	•		
	Ethylbenzene	•		
	Toluene	•		
	Xylenes	•		
	MTBE	•		

A "**Possible**" impact is a tentative category for those parameters that occur both naturally as well as from anthropogenic sources. These impacts are difficult to assess and at this time only tentative conclusions can made. **Possible** nonpoint source impacts to groundwater were found for several nutrients, including ammonia, total phosphorus, and orthophosphate; and for total suspended solids and total dissolved solids. The latter two parameters in particular are difficult to assess because they each measure numerous elements and compounds, rather than discrete ones.

Parameters with "**No**" significant impacts to groundwater were: 1) either not detected; 2) were detected in a limited number of samples or at very low values, such as mercury; or 3) are thought to occur at natural levels. This study concluded that **No** impacts to groundwater were apparent for the following parameters: conductivity, hardness, chloride, fluoride, sulfate, arsenic, barium, iron, manganese, mercury, nitrite-n, cyanazine, BTEX, and MTBE. (Note that although BTEX compounds occurred at two sites, these are the result of known point sources and therefore not indicators of nonpoint source pollution. The source of the single occurrence of MTBE at one site in Louisville is unexplained, as previously noted.)

Several biases inherent in any sampling program are a concern in the design, implementation, and analysis of results. Most importantly, personnel and funding limit both the geographical distribution of sites, as well as the sampling schedule itself. Therefore, only one site per approximately 100 square miles could be sampled. Temporal variations, which are important in all groundwater systems, but especially in quick flow karst systems, may not be adequately addressed through a quarterly sampling schedule over one year's time. Another bias of the study was that there were no wells sampled in the Mississippian Plateau. Although these problems may preclude definitive conclusions regarding short-term changes in groundwater quality, this project, and others like it, contribute vital data that add to our continued incremental understanding of this resource.

The authors recommend that additional groundwater studies continue, including expansion of the statewide ambient program and more focused nonpoint source projects, in order to continue the characterization, protection, and management of this resource. In particular, continued studies should focus on increasing the density of sampling sites as well as addressing temporal water quality variations, especially in karst terrane.

Based upon a review of groundwater data from this study in conjunction with surface water data, several areas in BMU 2 will receive additional monitoring in the next cycle of the watershed management system: Sinking Creek, Beargrass Creek, and selected portions of the Licking River. In the Sinking Creek area, additional dye-tracing will further define groundwater basins and water quality studies will focus on pesticides, nutrients, and pathogens. Beargrass Creek, in urban Jefferson County, has been impaired through urban run-off and possibly leaking sewers; therefore, further groundwater studies in this area will focus on these impacts. In the Licking River basin, the GWB will sample areas lacking groundwater quality data.

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Appendix A. Financial & Administrative Closeout

Workplan Outputs

The Groundwater Branch has committed to the following outputs:

- identification of suitable groundwater monitoring sites in the Salt and Licking River basins
- collection of samples from 30 sites quarterly for one year and delivering these samples to the laboratory for analysis for several parameters, including major inorganic ions, nutrients, pesticides, metals, volatile organic compounds, and residues
- data analysis, including data collected within these basins for other projects
- production of a report summarizing all relevant groundwater data for this BMU
- delivering hard-copies of the basin report to the River Basin Teams, local conservation districts, Natural Resource Conservation Service, Agricultural Water Quality Authority, Agricultural Extension offices, and interested stakeholders
- posting the report on the Division of Water's internet site

Budget Summary

- total project budget is $88,000
- budget has been expended in personnel costs approximately equivalent to 1.25 person years
- Groundwater Branch has managed the project, including:
    - ✓ researching background data
    - ✓ conducting on-site inspections to identify sampling sites
    - ✓ collecting groundwater samples
    - ✓ transporting samples to the laboratory
    - ✓ interpreting sample results
    - ✓ preparing maps and reports
    - ✓ providing reports to interested parties

- time codes used for this project were:
  - ✓ Division for Environmental Services: A-38
  - ✓ DOW original time code: NACA131
  - ✓ DOW new time code:

ORG	2DOW
PBU	BA00
FUND	1200
ACT	MOAM
FUNCTION	B007
PROJECT	NPS9602Z

Budget Summary Table

Category	BMP Implementation	Management	Public Education	Monitoring	Technical Assistance	Other	Total
Personnel				$88,000			$88,000
Supplies							
Equip.							
Travel							
Contract							
Op. Costs							
Other							
Total				$88,000			$88,000

Detailed Budget Table

Budget Categories	Section 319(h)	Non-Federal Match	Total
Personnel	$55,000	$33,000	$88,000
Supplies	$	$	$
Equipment	$	$	$
Travel	$	$	$
Contractual	$	$	$
Operating Costs	$	$	$
Other	$	$	$
TOTAL	$55,000	$33,000	$88,000

Funds Expended

All funds for this project were expended using personnel dollars.

Equipment Summary

No equipment was purchased for this project.

Special Grant Conditions

No special grant conditions were placed on this project by the EPA.

Appendix B. Quality Assurance / Quality Control for Water Monitoring

1. Title Section

A. Project Name

Expanded Groundwater Monitoring for Non-point Source Pollution Assessment in the Salt and Licking River Basins

B. QA/QC Plan Preparers

James S. Webb, Geologist - Registered
David P. Leo, Geologist Supervisor - Registered

Kentucky Division of Water, Groundwater Branch
14 Reilly Road
Frankfort, Kentucky 40601

(502) 564-3410

C. Date

January 14, 1999

D. Project Description

The Kentucky Division of Water currently conducts quarterly nonpoint source groundwater monitoring at approximately 70 sites across the state. This project means to expand that monitoring effort in the Salt and Licking River Basins (Kentucky Basin Management Unit Two) by increasing the number of monitoring sites and focusing additional efforts of the existing monitoring network in these watersheds. This project is intended to work in coordination with other members of the River Basin Team who are conducting surface water and biological sampling.

The goal of this project is to identify the impacts of nonpoint source pollution on the groundwater in the Salt and Licking River Basins. The objective of this study is to identify aquifers that have been impacted by nonpoint source pollution. Problems in these areas will be identified in order that future nonpoint source resources may be properly focused regarding nonpoint source pollution prevention and pollution abatement.

2. Project Organization and Responsibility

A. Key Personnel

James Webb, Geologist-Registered, Technical Services Section of the Kentucky Division of Water Groundwater Branch will coordinate this project. David P. Leo, Geologist Supervisor - Registered, Technical Services Section, and Peter T. Goodmann, Manager, Groundwater Branch, will provide additional project oversight.

Gary O'Dell, Environmental Technologist Chief with the Data Management & Support Section of the Groundwater Branch will scout suitable sampling locations. O'Dell and other members of the Groundwater Branch, and Kevin Francis, Hazard Regional Office, will assist in sampling and sample delivery. The Kentucky Department for Environmental Protection's Division of Environmental Services laboratory will be responsible for sample analysis. All data generated will be delivered to the Kentucky DEP Consolidated Groundwater Database and will be forwarded to the Kentucky Geological Survey's Groundwater Data Repository.

B. Laboratory

Division of Environmental Services
100 Sower Boulevard
Frankfort, Kentucky 40601

(502) 564-6120

C. Participating Agencies

This project will coordinate/cooperate with the Division of Water's Watershed Initiative, the Salt and Licking River Basin Teams, and the Division of Water's Water Quality Branch.

3. Watershed Information

A. Stream Names

The Salt and Licking Rivers, and their tributaries. For purposes of this study, some Minor Ohio River Tributaries (MORT) adjacent to these basins have been included.

Numerous groundwater monitoring sites in these areas have been identified.

B. Major River Basin

Salt and Licking River Basins.

Water Body Number

Salt River Basin:	21024402
Licking River Basin:	21015583

USGS Hydrologic Unit Number

Salt River Basin:	05140102 05140103
Licking River Basin:	05100101 05100102
Minor Ohio River Tribs:	05140101 05140104

C. Stream Order

This project encompasses the entire Salt and Licking River Basins.

D. Counties in Which Study Area is Located

Salt River Basin: Anderson, Boyle, Breckinridge, Bullitt, Carroll, Casey, Hardin, Jefferson, Larue, Marion, Meade, Mercer, Nelson, Oldham, Shelby, Spencer, Trimble.

Licking River Basin: Bath, Boone, Bourbon, Bracken, Campbell, Carroll, Fleming, Gallatin, Grant, Harrison, Kenton, Lewis, Mason, Menifee, Montgomery, Morgan, Nicholas, Pendleton, Robertson, Rowan.

4. Monitoring Objectives

Determine impacts of nonpoint source pollution on groundwater resources in selected areas of the Licking and Salt River Basins.

Provide guidance for the nonpoint source program to focus future resources relating to nonpoint source pollution of groundwater.

Support other programs, such as the Wellhead Protection program, the Groundwater Protection Plan program, the Agriculture Water Quality Authority, etc.

Provide additional data useful for the long-term management of the resource.

5. Study Area Description

The Salt River Basin occurs mainly within the Outer Bluegrass Physiographic Region, which is underlain by thin-bedded Ordovician shale and limestone. The Salt River Basin extends into the Mississippian Plateau/Eastern Pennyroyal Physiographic Region, which is characterized by thick sequences of Mississippian limestone with well developed karst hydrology.

The Licking River rises in the Eastern Kentucky Coal Field Region, underlain by Pennsylvanian shale, sandstone, coal, and siltstone. The middle reaches of the Licking River pass through the Outer Bluegrass Region and into the Inner Bluegrass Region, characterized by rolling topography and underlain by Ordovician limestone with some interbedded shale and moderately developed karst hydrology. The Licking River also passes through a narrow strip of the Mississippian Plateau Physiographic Province.

The minor Ohio River tributaries included in the Salt/Licking River Basin management unit primarily drain the Outer Bluegrass and thick alluvium along this major river.

6. Monitoring Program/Technical Design

A. Monitoring Approaches

Monitoring will begin in April 1999. Duplicate samples will be collected for at least 10% of all samples in order to check reproducibility and provide QA/QC.

Field reconnaissance will be conducted prior to groundwater sampling to assess the suitability and accessibility of each site. The appropriate Well Inspection or Spring Inventory records will be completed. Site locations will be plotted on 7.5-minute topographic maps, and identified by a site name and unique identification number (AKGWA number) for incorporation into the Department for Environmental Protection's Consolidated Groundwater Data Base and the Kentucky Geological Survey's Groundwater Data Repository.

B. Monitoring Station Location Strategy

All monitoring station locations will be in addition to other stations currently sampled in the basin. All monitoring sites will be karst groundwater basin springs or karst windows, fracture springs, contact springs or water wells.

C. Sample Frequency and Duration

Monitoring will begin in April 1999 and samples will be collected quarterly through March 2000.

D. Sample Parameters, Containerization, Preservation, and Handling

Consistent with other monitoring efforts, samples will be collected at each spring or well and samples analyzed for some or all of the following: major inorganic ions; nutrients; total organic carbon; pesticides, including the most commonly used herbicides, insecticides, and fungicides; and dissolved and total metals. The list of parameters can be found on the attached Chain-of-Custody Form. The analytical methods, containers, volumes collected, preservation, and sample transport will be consistent with the Division of Water's Standard Operating Procedures for Nonpoint Source Surface Water Quality Monitoring Projects, prepared by the Water Quality Branch (August, 2002).

Major inorganic ions are used to establish background groundwater chemistry and also used to measure impacts from nonpoint source pollutants such as abandoned mine lands and abandoned oil and gas production operations by measuring pH, alkalinity, chloride, sulfate, and fluoride. Nutrients and total organic carbon are used to measure impacts from agricultural operations (Ammonia, Nitrate, Nitrite, TKN, and orthophosphate) and/or improper sewage disposal (nitrates, ammonia). Where sewage is suspected as a nonpoint source pollutant, unbleached cotton "bugs" may be used to detect optical brighteners (whitening agents used in laundry products and commonly found in sewage). Pesticides are measured to determine both rural agriculture and urban domestic- and commercial-use impacts on ground water. Metals are used to establish the rock-groundwater chemistry, establish local and regional backgrounds for metals, and determine nonpoint source impacts from abandoned coal mine operations.

Bacteria is **not** a proposed sampling parameter because of logistic considerations. Sampling at numerous sites occurs over a one or two-day period, commonly in remote regions. Because of the short holding time for bacteria (6 hours for fecal coliform, 24 hours for total coliform) we are unable to sample efficiently and regularly collect bacteria samples and comply with the required holding times. Where bacteria is suspected to be a nonpoint source pollutant, bacteria samples may be collected or other sampling events may be scheduled. In addition, unbleached cotton "bugs" may be used to detect optical brighteners, common in domestic sewage, originating from laundry products.

All samples will be analyzed by the Division of Environmental Services laboratory according to the appropriate EPA water method.

7. Chain-of-Custody Procedures

Sample containers will be labeled with the site name and well or spring identification number, sample collection date and time, analysis requested, preservation method, and collector's initials. Sampling personnel will complete a Chain-of-Custody Record, developed in conjunction with the DES laboratory, for each sample. The DES laboratory will be responsible for following approved laboratory QA/QC procedures, conducting analyses within the designated holding times, following EPA-approved analytical techniques, and reporting analytical results to the Groundwater Branch.
A sample Chain-of-Custody Form is attached.

8. Quality Assurance/Quality Control Procedures

A. Decontamination Protocols

All sampling supplies that come in contact with the sample will be new, disposable equipment, or will be decontaminated prior to and after each use, using the following protocols.

Sample Collection and Filtration Equipment

Whenever possible, sample collection is conducted using the sample container, except for dissolved metals, which are filtered on site. Sample collection equipment, such as bailers and buckets, will consist of Teflon. Pesticide samples will be collected using the sample container or a stainless steel bailer or bucket, in order to avoid the problem of pesticide adsorption to the sampling device (as is considered to occur with Teflon instruments). Any reusable equipment will be decontaminated by rinsing with a 10% hydrochloric acid (HCL) solution, triple rinsed with deionized water, and triple rinsed with water from the source to be sampled prior to collecting a sample. After sampling is complete, excess sample will be disposed of, and the equipment will again be rinsed with the 10% HCL solution and triple rinsed with deionized water.

New 0.45 micron filters will be used at each sampling site. Any tubing that contacts the sample will also be new. Any reusable filter apparatus will be decontaminated in the same manner as sample collection equipment. Additionally, any intermediary collection vessel will be triple rinsed with filtrate prior to use.

Field Meters

Field meter probes will be rinsed with deionized water prior to and after each use.

B. Equipment Calibration

Field meters will be calibrated in accordance with the manufacturers instructions.

C. Sample Collection and Preservation/Contamination Prevention

Water samples will be fresh groundwater collected prior to any type of water treatment. Samples not requiring field filtration will be collected directly in the sampling container. Samples requiring field filtration will be collected in a Teflon bucket decontaminated in accordance with decontamination protocols for sample collection and filtration equipment, filtered, and transferred to the appropriate container. Pesticide samples will be collected using the sample container or a stainless steel bailer or bucket, wherever necessary.

Sample containers will be obtained from approved vendors, and will be new or laboratory-decontaminated in accordance with Division of Environmental Services accepted procedures. Sample containerization, preservation, and holding time requirements are outlined in the Division of Water's Standard Operating Procedures for Nonpoint Source Surface Water Quality Monitoring Projects, prepared by the Water Quality Branch (August, 2002). Necessary preservatives will be added in the field; preservatives for dissolved constituents will be added after field filtration. Samples will be stored in coolers packed with ice for transport to the Division of Environmental Services laboratory.

Sample containers will be labeled with the site name and identification number, sample collection date and time, analysis requested, preservation method, and collector's initials. Sampling personnel will complete a Chain-of-Custody Record) for each sample. The Division of Environmental Services laboratory will be responsible for following approved laboratory QA/QC procedures, conducting analyses within the designated holding times, following EPA-approved analytical techniques, and reporting analytical results to the Groundwater Branch. Wells will be purged properly prior to sampling.

Samples will be collected as close to the spring resurgence as possible. If inhospitable terrain prohibits spring access, a decontaminated Teflon bucket attached to a new polypropylene rope may be lowered to the spring to collect the sample. Samples for pesticide analysis will be collected using a stainless steel bucket.

Duplicates and Blanks

Duplicate samples will be collected for at least 10% of all samples in order to check reproducibility and provide QA/QC control. At least one duplicate sample will be submitted with each batch of samples, regardless of the number of samples in the batch. Blanks of deionized water will be submitted at least once per quarter. Blanks will be collected, filtered, and preserved in the same manner as a sample.

Field Measurements

Conductivity, temperature, and pH will be measured in the field at each site using portable automatic temperature compensating meters, and recorded in a field log book. Meters will be calibrated according to the manufacturer's specifications, using standard buffer solutions. Meter probes will be decontaminated according to decontamination protocols for field meters and stored according to the manufacturer's recommendations.

CHAIN OF CUSTODY RECORD
NATURAL RESOURCES AND ENVIRONMENTAL PROTECTION CABINET
DIVISION OF WATER - GROUNDWATER BRANCH - NPS Salt/Licking River Basin Project - Funding Source A-40

Site Identification	**Collection Date/Time**	**Field Measurements**
Location:	Date: _______________	Temp: _______________ °C
County:		pH: _______________
AKGWA #:	Time: _______________	Cond: _______________ umhos

Sampler ID: ___________________________________

Division for Environmental Services Samples

Analysis Requested	Container Size, Type	Preservation Method	Parameters	Analysis Requested	Container Size, Type	Preservation Method	Parameters
	1000 ml Plastic	Cool to 4°C	**Bulk Parameters** **IC Scan** (includes Chloride, Fluoride, Nitrate-N, Nitrite-N, Sulfate, Ortho-P), **Alkalinity, Conductivity, pH, TSS, TDS**		1000 ml Plastic	Filtered HNO_3 Cool to 4°C	**Dissolved Metals by ICP** plus Arsenic, Lead, Mercury, Selenium
	1000 ml Plastic	H_2SO_4 Cool to 4°C	**NH_3/TKN/TOC** **Total P**		1000 ml Plastic	HNO_3 Cool to 4°C	**Total Metals by ICP** plus Arsenic, Lead, Mercury, Selenium
					1000 ml Glass	Cool to 4°C	**N/P Pesticides** Method 507
					1000 ml Glass	Cool to 4°C	**Pesticides/PCBs** Method 508
					1000 ml Glass	Cool to 4°C	**Herbicides** Method 515.1

Signatures:

Relinquished by: ___________________ Date: ________ Time: ________

Received by: _______________________________________

Relinquished by: ___________________ Date: ________ Time: ________

Received by: _______________________________________

Sample #: _______________ Report #: _______________

Appendix C. Groundwater Sites Monitored in BMU 2

COUNTY	SITE NUMBER	SITE NAME	PHYSIOGRAPHIC REGION	7.5 QUADRANGLE	TYPE	LATITUDE	LONGITUDE
Anderson	90002176	Hanks Spring	Bluegrass	Lawrenceburg	Unused Spring	38.0264	-84.9416
Bath	90002118	Hawk Spring	Bluegrass	Preston	Unused Spring	38.0433	-83.7972
Boone	00021106	Ammons Well	Ohio River Alluvium	Hooven	Irrigation Well	39.1314	-84.7641
Boone	00021576	Brueggemann Well	Bluegrass	Burlington	Private Well	39.0313	-84.6791
Boone	00030318	Potters Ranch Well	Bluegrass	Rising Sun	PWS Well	38.9188	-84.8027
Boone	00049450	Arrasmith Well	Bluegrass	Rising Sun	Private Well	38.9256	-84.7956
Bourbon	00048654	Wasson Well	Bluegrass	Paris W	Private Well	38.2022	-84.3225
Bourbon	90001678	Silver Spring	Bluegrass	Paris W	Unused Spring	38.2422	-84.3088
Bourbon	90001921	Lehman Spring	Bluegrass	North Middletown	Unused Spring	38.1467	-84.0986
Boyle	90002169	Mayes Spring	Bluegrass	Parksville	Unused Spring	37.6186	-84.9269
Bracken	00039375	Augusta Well 1	Ohio River Alluvium	Felicity	PWS Well	38.7722	-84.0086
Bracken	00042674	Augusta Well	Ohio River Alluvium	Felicity	PWS Well	38.7728	-84.0183
Bracken	00051635	Augusta Well 2	Ohio River Alluvium	Felicity	PWS Well	38.7730	-84.0175
Breckinridge	90001027	Fiddle Spring	Miss. Plateau	Garfield	Unused Spring	37.8131	-86.2919
Breckinridge	90001031	Big Spring	Miss. Plateau	Big Spring	Unused Spring	37.7988	-86.1516
Bullitt	00005572	Dezarn Well	Miss. Plateau	Shepherdsville	Private Well	37.9755	-85.6550
Bullitt	00025235	Hileman Well	Miss. Plateau	Brooks	Private Well	38.0694	-85.7083
Bullitt	00029676	Flowers Well	Miss. Plateau	Brooks	Private Well	38.0633	-85.7061
Campbell	90002112	Strickmeyer Spring	Bluegrass	New Richmond	Private Spring	38.9511	-84.3327
Carroll	00007131	Carroll Co. Well 3	Ohio River Alluvium	Vevay S	PWS Well	38.7377	-85.0600
Carroll	00007132	Carroll Co. Well 4	Ohio River Alluvium	Vevay S	PWS Well	38.7377	-85.0600
Carroll	00007133	Carroll Co. Well 5	Ohio River Alluvium	Vevay S	PWS Well	38.7377	-85.0600
Carroll	00007134	Carroll Co. Well 6	Ohio River Alluvium	Vevay S	PWS Well	38.7377	-85.0600
Casey	90002091	Michael Spring	Bluegrass	Bradfordsville NE	Unused Spring	37.4747	-85.0369
Fleming	90002093	Crain Spring	Bluegrass	Flemingsburg	Unused Spring	38.4311	-83.7452
Fleming	90002096	Belle Grove Spring	Bluegrass	Plummers Landing	Unused Spring	38.3164	-83.5380
Fleming	90002183	Ewing Spring	Bluegrass	Elizaville	Unused Spring	38.4267	-83.8705
Gallatin	00037376	Warsaw Well	Ohio River Alluvium	Florence	PWS Well	38.7825	-84.9016
Gallatin	00037377	Warsaw Well	Ohio River Alluvium	Florence	PWS Well	38.7825	-84.9016
Harrison	90002135	Bills Spring	Bluegrass	Shady Nook	Unused Spring	38.4792	-84.2277
Jefferson	00039351	Louisville Well	Ohio River Alluvium	Jeffersonville	PWS Well	38.2808	-85.7008
Jefferson	90001131	Forrest Hills Spring	Bluegrass	Jeffersontown	Unused Spring	38.2161	-85.5891
Jefferson	90001138	Farmington Spring	Bluegrass	Louisville E	Unused Spring	38.2147	-85.0025
Jefferson	90002175	Jesse's Spring	Bluegrass	Louisville E	Unused Spring	38.2461	-85.6713
Lewis	00014277	Vanceburg Well 3	Ohio River Alluvium	Vanceburg	PWS Well	38.6063	-83.2613
Lewis	00014293	Vanceburg Well 4	Ohio River Alluvium	Vanceburg	PWS Well	38.6066	-83.2661
Lewis	90002137	Cameron Spring	Miss. Plateau	Buena Vista	Private Spring	38.6350	-83.3650
Magoffin	00051638	Wireman Well	E. Coal Field	David	Private Well	37.5914	-82.9211
Marion	90002089	Turpin Spring	Bluegrass	Lebanon E	Private Spring	37.5606	-85.1292
Mason	00039353	W. Mason Well	Ohio River Alluvium	Higginsport	PWS Well	38.7572	83.8819
Mason	00044596	W.L.-Rectorville Well	Ohio River Alluvium	Maysville E	PWS Well	38.6381	-83.7169
Meade	00015022	Flaherty Well	Miss. Plateau	Flaherty	PWS Well	37.8336	-86.0638
Meade	00032211	Begley Well	Miss. Plateau	Guston	Private Well	37.8850	-86.1572
Meade	00047171	Meade Co. WD Well 3	Miss. Plateau	Flaherty	PWS Well	37.8363	-86.0658
Meade	90001063	Head of Wolf Cr. Spring	Miss. Plateau	New Amsterdam	Unused Spring	38.0661	-86.3594
Meade	90001824	Buttermilk Falls	Miss. Plateau	Mauckport	Unused Spring	38.0022	-86.1580
Meade	90002151	Morgan Cave Spring	Miss. Plateau	Rock Haven	Unused Spring	37.9503	-86.0558
Meade	90002179	Mallard Cave Spring	Miss. Plateau	Vine Grove	Unused Spring	37.7894	-85.9897
Menifee	90001136	Ezel Spring	E. Coal Field	Ezel	Unreg. Public Spring	37.9905	-83.4888
Menifee	90002147	Prater Cave Spring	Miss. Plateau	Scranton	Unused Spring	37.9328	-83.5594
Mercer	90000527	Humane Spring	Bluegrass	Harrodsburg	Unused Spring	37.7750	-84.8602
Mercer	90000582	Baker Spring	Bluegrass	Danville	Private Spring	37.7203	-84.8580
Montgomery	90000895	Roy's Spring	Bluegrass	Preston	Unused Spring	38.0122	-83.8200
Montgomery	90001147	Cunningham Spring	Bluegrass	Preston	Unused Spring	38.0136	-83.8208
Montgomery	90002115	Burden Spring	Bluegrass	Mount Sterling	Unused Spring	38.0381	-83.9713
Morgan	90002159	Bathtub Spring	E. Coal Field	West Liberty	Private Spring	37.9064	-83.3638
Morgan	90002161	Okley Spring	E. Coal Field	Wrigley	Unused Spring	38.0558	-83.3247

COUNTY	SITE NUMBER	SITE NAME	PHYSIOGRAPHIC REGION	7.5 QUADRANGLE	TYPE	LATITUDE	LONGITUDE
Nelson	00040416	Smith Well	Bluegrass	Bardstown	Private Well	37.7641	-85.3822
Nelson	90001003	Jutz Spring	Bluegrass	Cravens	Private Spring	37.7822	-85.5133
Nelson	90001551	Samuels Spring	Bluegrass	Samuels	PWS Spring	37.9039	-85.5580
Nelson	90002106	Hicks Spring	Bluegrass	Bardstown	Private Spring	37.7667	-85.4611
Oldham	90002170	Cat Spring	Bluegrass	La Grange	Unused Spring	38.4061	-85.3800
Robertson	90002110	Brumagen Spring	Bluegrass	Piqua	Unused Spring	38.4547	-84.0277
Rowan	90001151	Sheltowee Spring	E. Coal Field	Haldeman	Unused Spring	38.1463	-83.2913
Rowan	90001158	Austin Spring	E. Coal Field	Haldeman	Unused Spring	38.1438	-83.2897
Rowan	90002122	McKenzie Spring	Miss. Plateau	Bangor	Private Spring	38.0617	-83.4333
Rowan	90002123	Andy White Spring	Miss. Plateau	Haldeman	Unreg. Public Spring	38.1967	-83.2938
Shelby	90002102	Test Spring	Bluegrass	Simpsonville	Unused Spring	38.1469	-85.3163
Spencer	90002166	Foreman Spring	Bluegrass	Waterford	Unused Spring	38.0036	-85.4236
Washington	90002127	Shewmaker Spring	Bluegrass	Springfield	Unused Spring	37.7494	-85.1600

Table C-1 Groundwater Sites Monitored in BMU2

Appendix D. Reference Sites and Summary Statistics

COUNTY	SITE NUMBER	SITE NAME	PHYSIOGRAPHIC REGION	7.5 QUADRANGLE	TYPE	LATITUDE	LONGITUDE
Lewis	90002137	Cameron Spring	Miss. Plateau	Buena Vista	Private Spring	38.6350	-83.3650
Rockcastle	90001020	Fred Mullin Spring	Miss. Plateau	Johnetta	Unreg. Public Access	37.4533	-84.2361
Powell	90001134	Nada Spring	Miss. Plateau	Slade	Unreg. Public Access	37.8164	-83.6878

Table D-1 Reference Sites for Kentucky

NPS REFERENCE SITES
SUMMARY STATISTICS

	START DATE	END DATE	NUMBER OF SAMPLES	MEDIAN	MIN	MAX	RANGE
Conductivity	04/27/95	10/04/00	48	111.25	46.0	448.0	402.0
Hardness	07/14/95	12/03/01	28	52.3015	14.039	140.29	126.251
pH	04/27/95	10/04/00	44	7.31	6.01	8.12	2.11
Chloride	04/27/95	03/07/00	19	1.9	0.6	16.7	16.1
Fluoride	04/27/95	03/07/00	33	0.05	< 0.023	0.253	*0.230*
Sulfate	04/27/95	03/07/00	36	7.425	< 5.0	69.4	*64.4*
Arsenic	06/03/98	12/03/01	34	0.002	< 0.002	0.0045	*0.0025*
Barium	06/03/98	12/03/01	34	0.0305	0.0040	0.073	0.069
Iron	07/14/95	12/03/01	34	0.056	< 0.001	0.337	*0.336*
Manganese	06/03/98	12/03/01	34	0.0035	< 0.001	0.208	*0.207*
Mercury	06/03/98	12/03/01	34	0.00005	< 0.00005	< 0.00005	-
Ammonia	04/27/95	10/04/00	42	0.02	< 0.02	0.11	*0.09*
Nitrate	04/27/95	03/07/00	36	0.1805	< 0.01	0.888	*0.878*
Nitrite	04/27/95	03/07/00	21	0.005	< 0.002	0.006	*0.004*
Orthophosphate	04/27/95	10/04/00	43	0.011	< 0.003	0.069	*0.066*
Total Phosphorus	04/27/95	03/07/00	19	0.019	< 0.005	0.019	*0.014*
Alachlor	04/27/95	12/03/01	55	0.00004	< 0.00002	< 0.00006	-
Atrazine	04/27/95	12/03/01	55	0.00004	< 0.00004	< 0.0003	-
Cyanazine	05/03/95	12/03/01	48	0.00004	< 0.00004	< 0.0001	-
Metolachlor	04/27/95	12/03/01	55	0.00004	< 0.00004	< 0.0002	-
Simazine	04/27/95	12/03/01	52	0.00004	< 0.00004	< 0.0003	-
Total Dissolved Solids	04/27/95	10/04/00	48	63.0	< 10.0	266.0	*256.0*
Total Suspended Solids	04/27/95	10/04/00	48	3.0	< 1.0	13.0	*12.0*
Benzene	04/12/00	12/03/01	20	< 0.0005	< 0.0005	< 0.0005	-
Ethylbenzene	04/12/00	12/03/01	20	< 0.0005	< 0.0005	< 0.0005	-
Toluene	04/12/00	12/03/01	20	< 0.0005	< 0.0005	< 0.0005	-
Xylenes	04/12/00	12/03/01	20	< 0.0005	< 0.0005	< 0.0005	-
MTBE	04/12/00	12/03/01	20	< 0.001	< 0.001	< 0.001	-

Table D-2 Reference Sites, Summary Statistics

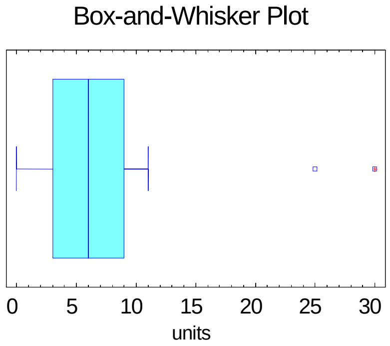
Appendix E. Constructing a Boxplot

Boxplots are useful to graphically depict the central location (point about which data points in a set will cluster) and the scatter or dispersion of the observations in a data set. This will better convey statistically significant information about a data set to a reader.

To construct a boxplot, first determine the quartiles Q_1, Q_2 (median), and Q_3.

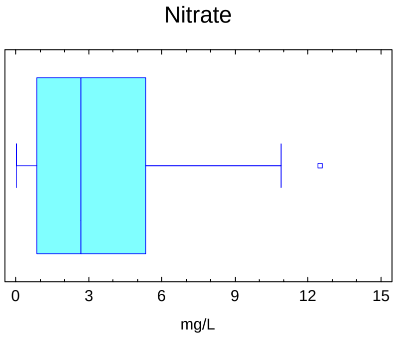
Q_1:	25th quartile	25% of the data lies below and 75% of the data lies above this point
Q_2:	(median)	50% of the data lies below and 50% of the data lies above this point
Q_3:	75th quartile	75% of the data lies below and 25% of the data lies above this point
IQR:	inter-quartile range	$Q_3 - Q_1$ (the center 50% of the data will lie within this range)

The box is then plotted as shown below:



In this example, $Q_3 = 9$ and $Q_1 = 3$, so the IQR = 6. You will note that the rectangular part of the boxplot extends for 6 units. The minimum sample point is 0 units and the maximum is 30 units, so the range of this data set is 30 units. The lines extending from the box are called "whiskers." The upper and lower boundaries for the whiskers are Q_3 + 1.5 IQR and Q_1 - 1.5 IQR, respectively. These boundary areas are called fences, but are not actually drawn in a boxplot. Vertical lines appear at the end of each whisker. These lines represent the smallest value within the lower fence area and the largest value within the upper fence area. Note the presence of two outliers: one at 25 units and one at 30 units. Outliers are observations more than 1.5 IQR from the quartiles, denoted by an open square. Extreme outliers, observations that lie greater than 3.0 IQR from the quartiles, are denoted by an open square overlain by a red cross.

Outliers are significant because they represent distinct deviations from the bulk of the data points in a set. In water quality data, values are generally skewed to the right, or positively skewed, due to the presence of a few high outliers. Most of the values in this type of data set cluster at or near 0, or some laboratory-defined detection limit. An example of this type of data is shown below:



The nitrate data range from 0.02 mg/L to 12.5 mg/L. The lower and upper quartiles are 0.859 mg/L and 5.330 mg/L, respectively, resulting in an IQR of 4.471 mg/L. Note the 12.5 mg/L is an outlier, as it is greater than 6.7065 mg/L above the upper quartile (1.5 * 4.471 = 6.7065).

Source: Brosius, 2001

Appendix F. Summarized and Graphical Representations of Study Data

BMU2: HYDROPARAMETERS SUMMARY STATISTICS

	pH					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**3.51**	**8.37**	**7.51**	**7.48**
BLUEGRASS (INNER & OUTER):	04/26/95	09/27/00	6.37	8.32	7.51	7.61
MISSISSIPPIAN PLATEAU:	04/26/95	10/11/00	6.60	8.37	7.66	7.66
EASTERN COAL FIELD:	05/08/95	05/30/00	3.51	8.18	7.66	7.44
OHIO RIVER ALLUVIUM:	04/26/95	10/04/00	3.51	8.11	7.43	7.48

	CONDUCTIVITY					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**54.20**	**2620.00**	**578.00**	**693.00**
BLUEGRASS (INNER & OUTER):	04/26/95	09/27/00	130.00	2620.00	612.50	578.00
MISSISSIPPIAN PLATEAU:	04/26/95	10/11/00	76.60	606.00	412.00	-
EASTERN COAL FIELD:	05/08/95	05/30/00	86.60	867.00	205.00	-
OHIO RIVER ALLUVIUM:	04/26/95	10/04/00	86.60	919.00	677.50	418.00

	HARDNESS					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**03/03/97**	**12/12/01**	**17.36**	**986.60**	**278.67**	**-**
BLUEGRASS (INNER & OUTER):	03/03/97	12/12/01	46.69	986.60	307.92	-
MISSISSIPPIAN PLATEAU:	05/20/98	11/07/01	17.36	549.08	195.30	-
EASTERN COAL FIELD:	03/10/98	05/30/00	23.98	173.64	83.46	-
OHIO RIVER ALLUVIUM:	02/10/98	10/03/01	23.98	476.46	355.26	-

Table F-1 Hydroparameters, Summary Statistics

BMU2: HYDROPARAMETERS SAMPLE SUMMARY

		pH[1 2]	Conductivity	Hardness[3 4]
NUMBER OF SAMPLES	**TOTAL:**	309	314	227
BY REGION:	**BLUEGRASS (INNER & OUTER):**	132	132	109
	MISSISSIPPIAN PLATEAU:	57	59	49
	EASTERN COAL FIELD:	26	27	15
	OHIO RIVER ALLUVIUM:	94	96	54
NUMBER OF SITES	**TOTAL:**	65	65	56
BY REGION:	**BLUEGRASS (INNER & OUTER):**	31	31	28
	MISSISSIPPIAN PLATEAU:	13	13	11
	EASTERN COAL FIELD:	6	6	5
	OHIO RIVER ALLUVIUM:	15	15	12
[1]Sites with at least one pH measurement in these categories:		**< 6.5**	**6.5 - 8.5**	**> 8.5**
pH sites	**TOTAL:**	3	64	0
	BLUEGRASS (INNER & OUTER):	1	31	0
	MISSISSIPPIAN PLATEAU:	0	13	0
	EASTERN COAL FIELD:	2	5	0
	OHIO RIVER ALLUVIUM:	0	15	0
[2]pH Samples in each of these categories:		**< 6.5**	**6.5 - 8.5**	**> 8.5**
pH samples	**TOTAL:**	4	305	0
	BLUEGRASS (INNER & OUTER):	1	138	0
	MISSISSIPPIAN PLATEAU:	0	57	0
	EASTERN COAL FIELD:	3	23	0
	OHIO RIVER ALLUVIUM:	0	87	0
[3]Sites with at least one hardness measurement in these categories:		**SOFT < 17**	**MODERATE 17 - 120**	**HARD > 120**
Hardness	**TOTAL:**		11	50
	BLUEGRASS (INNER & OUTER):		1	27
	MISSISSIPPIAN PLATEAU:		4	9
	EASTERN COAL FIELD:		5	2
	OHIO RIVER ALLUVIUM:		1	12
[3]Hardness was calculated (as equivalent CaCO3 in mg/L) as Hardness = 2.5(mg/L Ca) + 4.1(mg/L)Mg		**SOFT < 17**	**MODERATE 17 - 120**	**HARD > 120**
Hardness	**TOTAL:**	0	27	200
	BLUEGRASS (INNER & OUTER):	0	1	108
	MISSISSIPPIAN PLATEAU:	0	13	36
	EASTERN COAL FIELD:	0	12	3
	OHIO RIVER ALLUVIUM:	0	1	53

Table F-2 Hydroparameters, Samples Summary

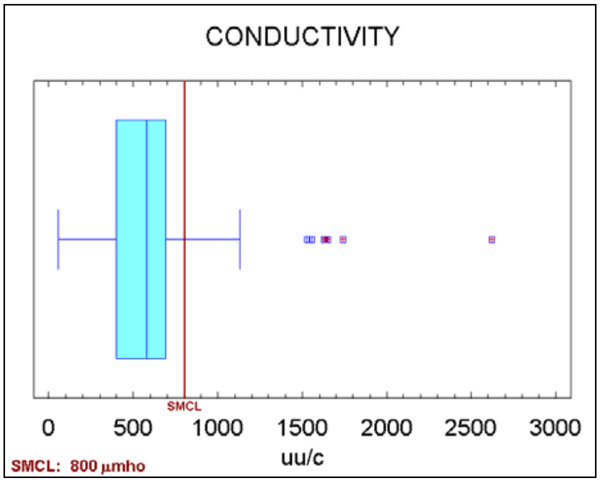


Figure F-3 Boxplot of conductivity measurements, BMU 2

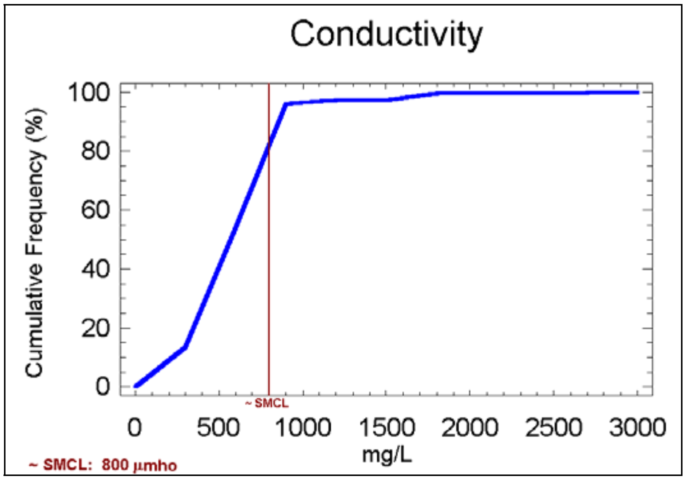


Figure F-4 Cumulative frequency curve for conductivity, BMU 2

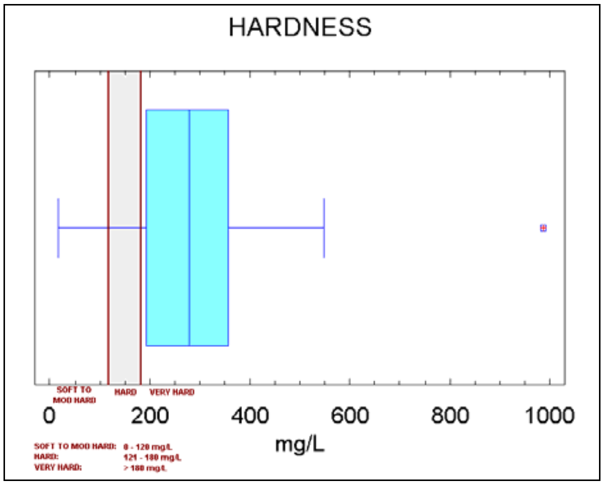


Figure F-5 Boxplot of hardness measurements, BMU 2

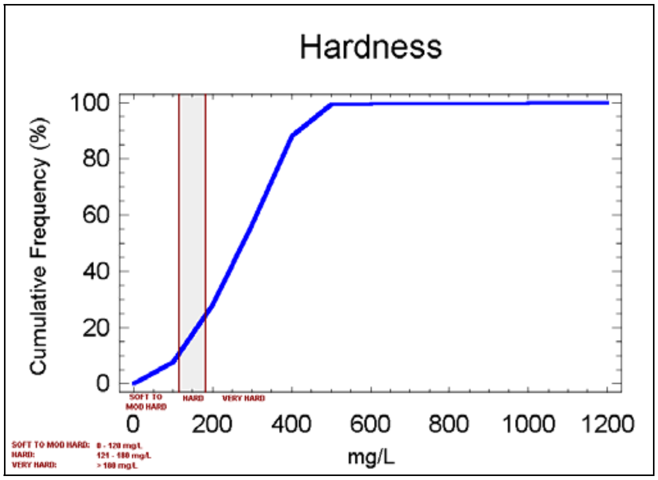


Figure F-6 Cumulative frequency curve for hardness, BMU 2

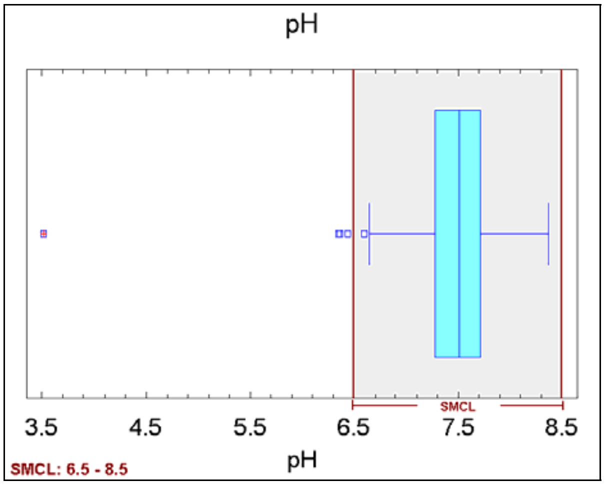


Figure F-7 Boxplot of pH measurements, BMU 2

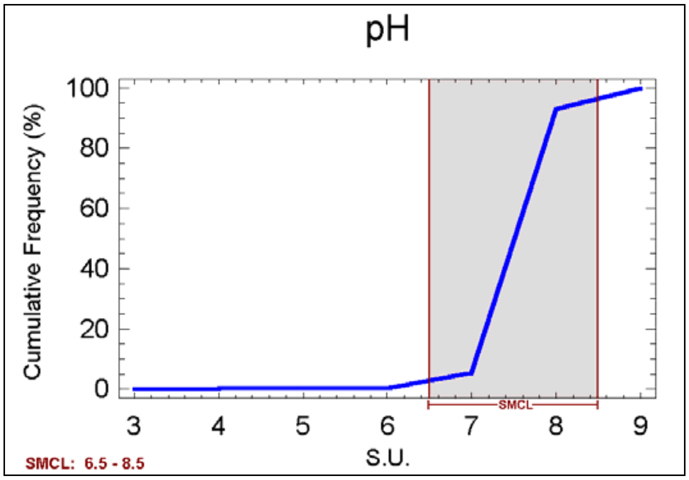


Figure F-8 Cumulative frequency curve for pH, BMU 2

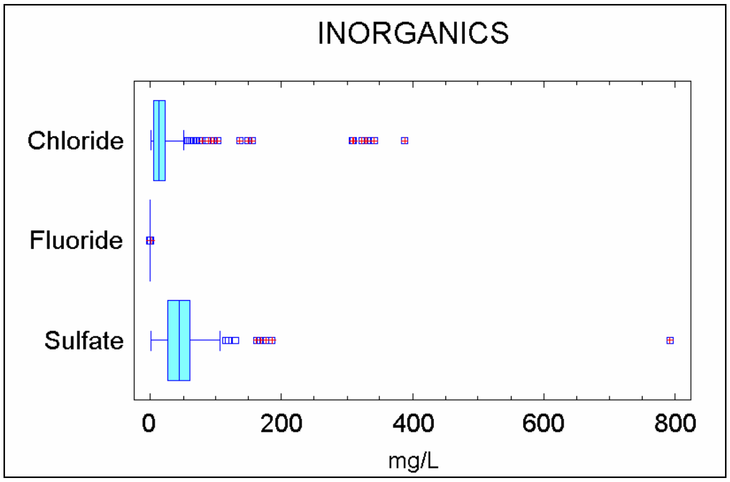


Figure F-9 Comparative boxplots of inorganics measurements

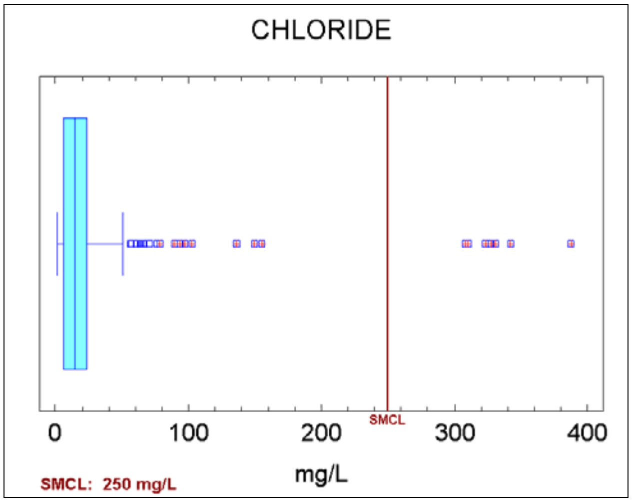
BMU2: INORGANICS SUMMARY STATISTICS						
	CHLORIDE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**0.9500**	**388.0000**	**14.5000**	**19.7000**
BLUEGRASS (INNER & OUTER):	04/26/95	09/21/00	0.9500	150.0000	18.8000	14.3000
MISSISSIPPIAN PLATEAU:	04/26/95	10/11/00	2.1000	155.0000	5.1300	3.6000
EASTERN COAL FIELD:	05/08/95	03/15/00	1.1300	40.3000	3.1700	1.4000
OHIO RIVER ALLUVIUM:	04/26/95	03/07/00	4.4000	388.0000	17.9000	19.7000
	FLUORIDE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**< 0.0230**	**1.9000**	**0.1400**	**0.1300**
BLUEGRASS (INNER & OUTER):	04/26/95	09/21/00	< 0.0230	0.6440	0.1420	0.1200
MISSISSIPPIAN PLATEAU:	04/26/95	10/11/00	< 0.0230	1.9000	0.1580	0.1100
EASTERN COAL FIELD:	05/08/95	03/15/00	< 0.0230	1.2100	0.0550	0.0500
OHIO RIVER ALLUVIUM:	04/26/95	03/07/00	0.0660	1.1600	0.1400	0.1300
	SULFATE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**0.6700**	**792.0000**	**44.6000**	**12.1000**
BLUEGRASS (INNER & OUTER):	04/26/95	09/21/00	0.6700	792.0000	47.6000	31.0000
MISSISSIPPIAN PLATEAU:	04/26/95	10/11/00	5.0400	95.8000	27.9000	12.1000
EASTERN COAL FIELD:	05/08/95	03/15/00	1.3400	23.3000	12.3500	12.7000
OHIO RIVER ALLUVIUM:	04/26/95	03/07/00	7.5000	106.0000	53.0000	28.9000

Table E-10 Inorganics, Summary Statistics

BMU2: INORGANICS SUMMARY TABLE				
		CHLORIDE	FLUORIDE	SULFATE
NUMBER OF SAMPLES	TOTAL:	283	281	283
BY REGION:	BLUEGRASS (INNER & OUTER):	123	122	123
	MISSISSIPPIAN PLATEAU:	53	53	53
	EASTERN COAL FIELD:	26	26	26
	OHIO RIVER ALLUVIUM:	81	80	81
NUMBER OF DETECTIONS	TOTAL:	283	276	282
	% DETECTS (vs SAMPLES):	100.00%	98.22%	99.65%
BY REGION:	BLUEGRASS (INNER & OUTER):	123	120	122
	MISSISSIPPIAN PLATEAU:	53	51	53
	EASTERN COAL FIELD:	26	25	26
	OHIO RIVER ALLUVIUM:	81	80	81
NUMBER OF SITES	TOTAL:	68	67	68
BY REGION:	BLUEGRASS (INNER & OUTER):	33	32	32
	MISSISSIPPIAN PLATEAU:	14	14	14
	EASTERN COAL FIELD:	6	6	6
	OHIO RIVER ALLUVIUM:	15	15	15
NUMBER OF SITES WITH DETECTIONS	TOTAL:	68	66	67
	% SITES W/DETECTIONS:	100.00%	98.51%	98.53%
BY REGION:	BLUEGRASS (INNER & OUTER):	33	31	33
	MISSISSIPPIAN PLATEAU:	14	14	14
	EASTERN COAL FIELD:	6	6	6
	OHIO RIVER ALLUVIUM:	15	15	14
NUMBER OF DETECTIONS ABOVE THE MCL	TOTAL:	7	0	1
	% DETECTIONS > MCL:	2.47%	0.00%	0.35%
	% SAMPLES > MCL:	2.47%	0.00%	0.35%
BY REGION:	BLUEGRASS (INNER & OUTER):	0	0	1
	MISSISSIPPIAN PLATEAU:	0	0	0
	EASTERN COAL FIELD:	0	0	0
	OHIO RIVER ALLUVIUM:	7	0	0

	MCL (mg/L)	Secondary (mg/L)	Other
CHLORIDE	-	250.000	-
FLUORIDE	4.000	-	-
SULFATE	-	250.000	-

Table E-11 Inorganics, Samples Summary



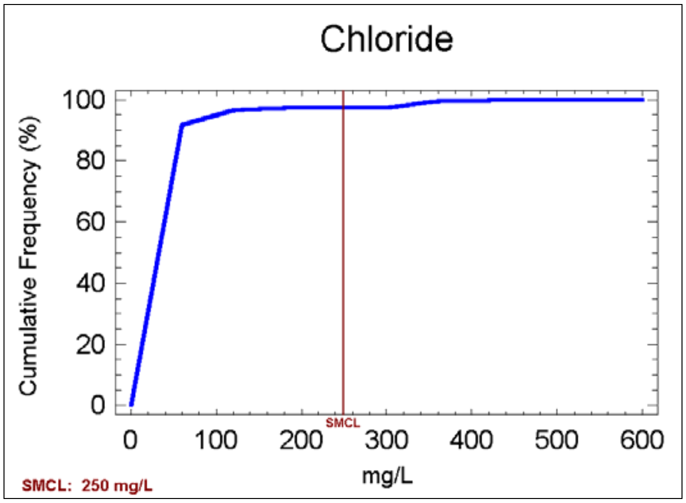
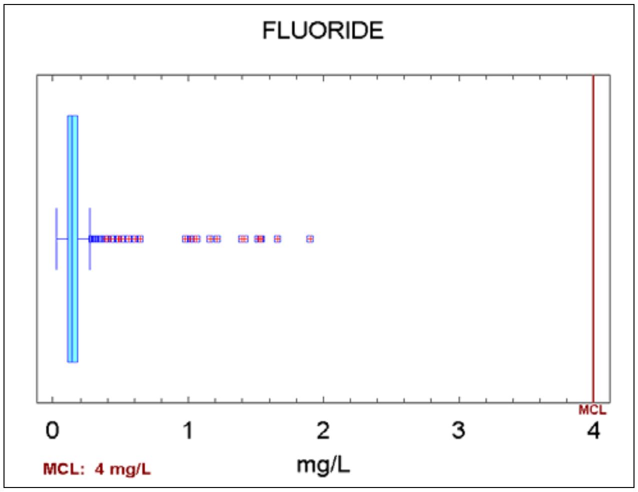


Figure F-12 Boxplot of chloride measurements, BMU 2

Figure F-12 Cumulative frequency curve for chloride, BMU 2



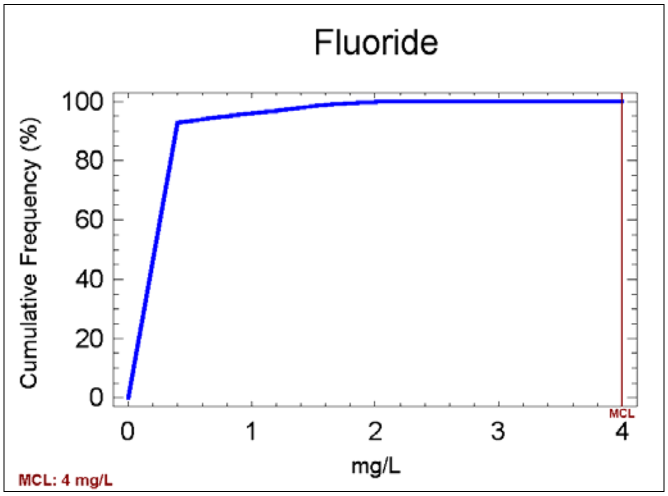
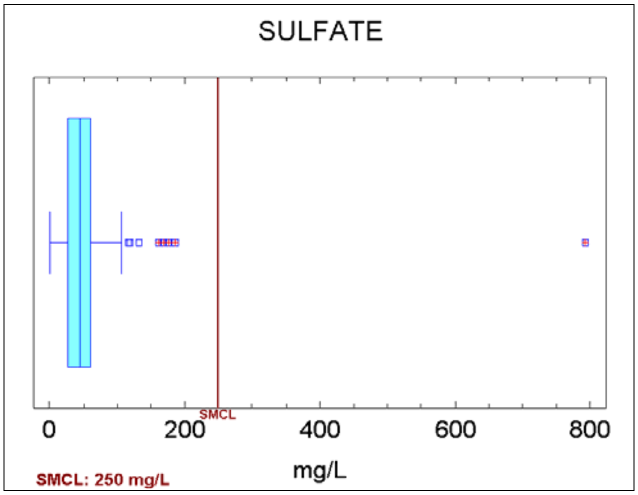


Figure F-14 Boxplot of fluoride measurements, BMU 2

Figure F-15 Cumulative frequency curve for fluoride, BMU 2



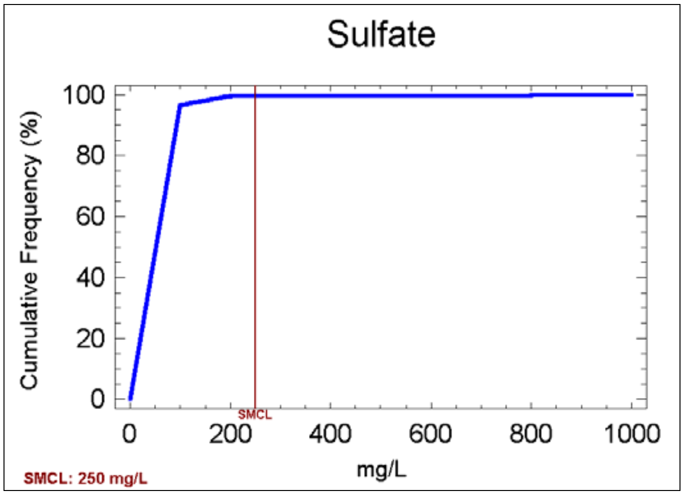


Figure F-16 Boxplot of sulfate measurements, BMU 2

Figure F-17 Cumulative frequency curve for sulfate, BMU 2

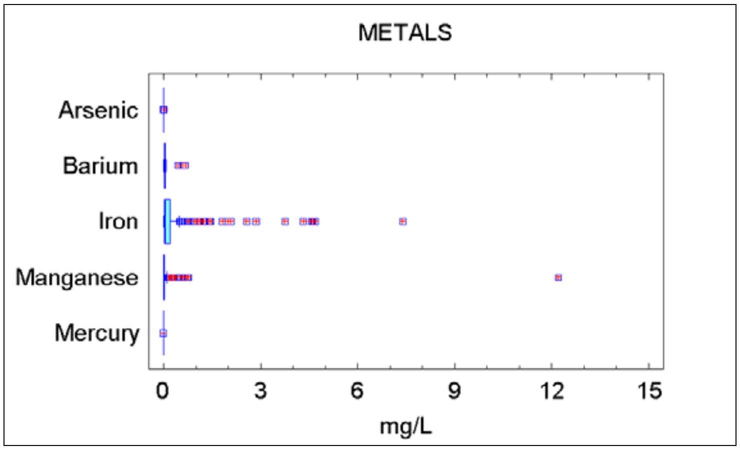


Figure F-18 Comparative boxplots of metals measurements

BMU2: METALS SUMMARY STATISTICS						
	ARSENIC					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	03/03/97	12/12/01	< 0.0020	< 0.0020	< 0.0020	< 0.0020
BLUEGRASS (INNER & OUTER):	03/03/97	12/12/01	< 0.0020	0.0040	< 0.0020	< 0.0020
MISSISSIPPIAN PLATEAU:	05/20/98	11/07/01	< 0.0020	0.0050	< 0.0020	< 0.0020
EASTERN COAL FIELD:	03/10/98	05/30/00	< 0.0020	< 0.0020	< 0.0020	< 0.0020
OHIO RIVER ALLUVIUM:	03/03/97	12/12/01	< 0.0020	0.0030	< 0.0020	< 0.0020
	BARIUM					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	03/03/97	12/12/01	< 0.0010	0.6720	0.0380	0.3900
BLUEGRASS (INNER & OUTER):	03/03/97	12/12/01	0.0080	0.4580	0.0280	0.0280
MISSISSIPPIAN PLATEAU:	05/20/98	11/07/01	0.0140	0.7600	0.0410	0.0390
EASTERN COAL FIELD:	03/10/98	10/03/01	0.0170	0.6720	0.0350	-
OHIO RIVER ALLUVIUM:	02/10/98	12/12/01	< 0.0010	0.0790	0.0475	0.0390
	IRON					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	03/03/97	12/12/01	< 0.0010	7.4000	0.0680	< 0.0050
BLUEGRASS (INNER & OUTER):	03/03/97	12/12/01	< 0.0050	7.4000	0.1070	0.0390
MISSISSIPPIAN PLATEAU:	05/20/98	11/07/01	0.0090	3.7700	0.1225	0.0180
EASTERN COAL FIELD:	03/10/98	05/30/00	< 0.0070	2.0900	0.0570	< 0.0070
OHIO RIVER ALLUVIUM:	02/10/98	10/03/01	< 0.0010	4.6100	0.0075	< 0.0050
	MANGANESE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	03/03/97	12/12/01	< 0.0010	12.2000	0.0100	< 0.0010
BLUEGRASS (INNER & OUTER):	03/03/97	12/12/01	< 0.0010	12.2000	0.0140	0.0040
MISSISSIPPIAN PLATEAU:	05/20/98	11/07/01	< 0.0010	0.2930	0.0070	0.0050
EASTERN COAL FIELD:	03/10/98	05/30/00	< 0.0010	0.0510	0.0060	0.0020
OHIO RIVER ALLUVIUM:	02/10/98	10/03/01	< 0.0010	0.7510	0.0155	< 0.0010
	MERCURY					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	02/10/98	12/12/01	< 0.000050	0.000056	< 0.000050	< 0.000050
BLUEGRASS (INNER & OUTER):	02/10/98	12/12/01	< 0.000050	< 0.000050	< 0.000050	< 0.000050
MISSISSIPPIAN PLATEAU:	05/20/98	11/07/01	< 0.000050	0.000056	< 0.000050	< 0.000050
EASTERN COAL FIELD:	03/10/98	05/30/00	< 0.000050	< 0.000050	< 0.000050	< 0.000050
OHIO RIVER ALLUVIUM:	02/10/98	10/03/01	< 0.000050	< 0.000050	< 0.000050	< 0.000050

Table E-19 Metals, Summary Statistics

BMU2: METALS SUMMARY TABLE

		ARSENIC	BARIUM	IRON[1]	MANGANESE [1]	MERCURY [2]
NUMBER OF SAMPLES	**TOTAL:**	225	226	226	226	225
BY REGION:	**BLUEGRASS (INNER & OUTER):**	108	109	109	109	108
	MISSISSIPPIAN PLATEAU:	48	48	48	48	48
	EASTERN COAL FIELD:	15	15	15	15	15
	OHIO RIVER ALLUVIUM:	54	54	54	54	54
NUMBER OF DETECTIONS	**TOTAL:**	10	225	197	197	1
	% DETECTS (vs SAMPLES):	4.00%	99.56%	87.17%	87.17%	0.44%
BY REGION:	**BLUEGRASS (INNER & OUTER):**	5	109	107	105	0
	MISSISSIPPIAN PLATEAU:	3	48	48	45	1
	EASTERN COAL FIELD:	0	15	13	12	0
	OHIO RIVER ALLUVIUM:	2	53	29	35	0
NUMBER OF SITES	**TOTAL:**	55	55	55	55	54
BY REGION:	**BLUEGRASS (INNER & OUTER):**	28	28	28	28	27
	MISSISSIPPIAN PLATEAU:	10	10	10	10	10
	EASTERN COAL FIELD:	5	5	5	5	5
	OHIO RIVER ALLUVIUM:	12	12	12	12	12
NUMBER OF SITES WITH DETECTIONS	**TOTAL:**	10	55	52	54	1
	% SITES W/DETECTIONS:	18.52%	100.00%	94.55%	98.18%	1.85%
BY REGION:	**BLUEGRASS (INNER & OUTER):**	5	28	28	28	0
	MISSISSIPPIAN PLATEAU:	3	10	10	9	1
	EASTERN COAL FIELD:	0	5	4	5	0
	OHIO RIVER ALLUVIUM:	2	12	10	12	0
NUMBER OF DETECTIONS ABOVE THE MCL	**TOTAL:**	0	0	39	35	0
	% DETECTIONS > MCL:	0.00%	0.00%	19.80%	17.77%	0.00%
	% SAMPLES > MCL:	0.00%	0.00%	17.26%	15.49%	0.00%
BY REGION:	**BLUEGRASS (INNER & OUTER):**	0	0	26	20	0
	MISSISSIPPIAN PLATEAU:	0	0	11	4	0
	EASTERN COAL FIELD:	0	0	1	1	0
	OHIO RIVER ALLUVIUM:	0	0	3	10	0

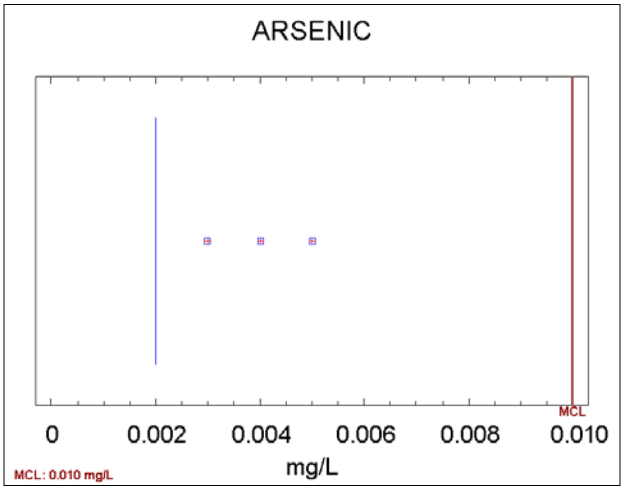
[1] SDWR used in absence of MCL

[2] 0002-1576 (Brueggemann Well) - no samples analyzed for mercury

	MCL (mg/L)	Secondary (mg/L)	Other
ARSENIC	0.010	-	-
BARIUM	2.000	-	-
IRON	-	0.300	-
MANGANESE	-	0.050	-
MERCURY	0.002	-	-

EPA uses T (not D) for MCL standards
Dissolved results were not considered in this study

Table E-20 Metals, Samples Summary



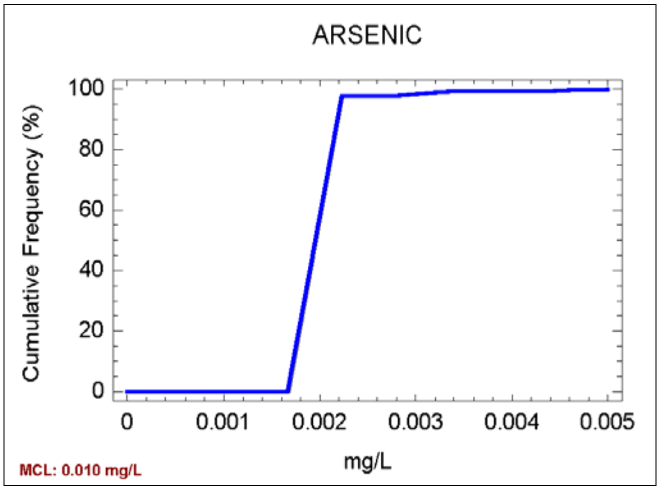
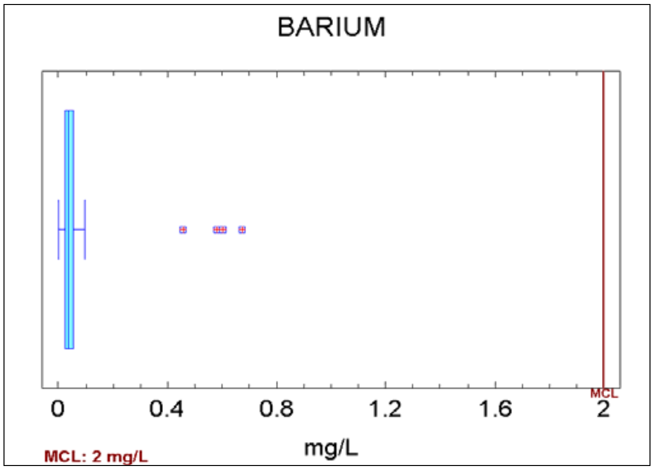


Figure F-21 Boxplot of arsenic measurements, BMU 2

Figure F-22 Cumulative frequency curve for arsenic, BMU 2



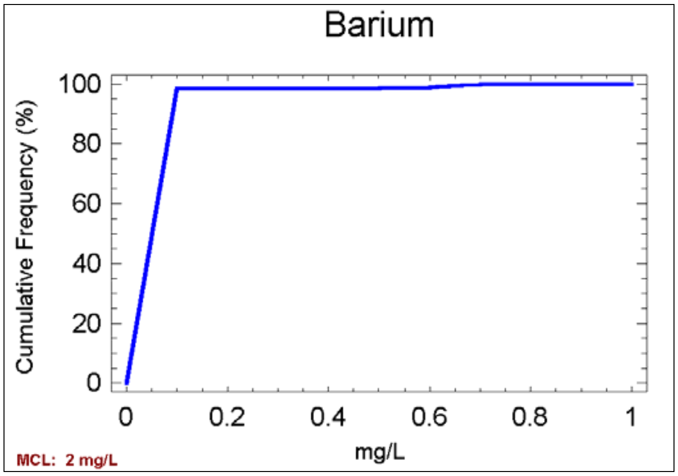
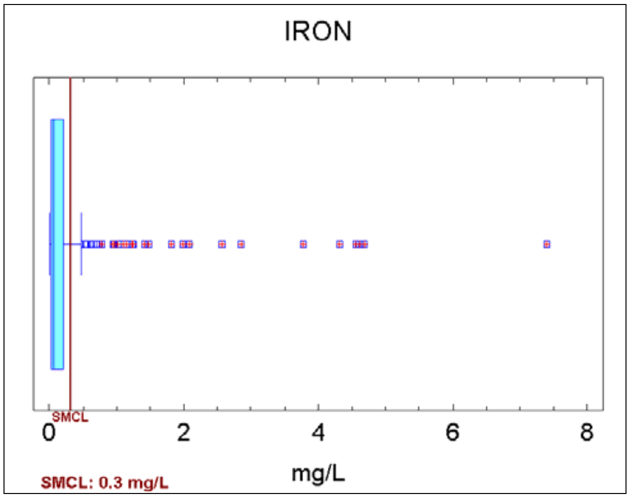


Figure F-23 Boxplot of barium measurements, BMU 2

Figure F-24 Cumulative frequency curve for barium, BMU 2



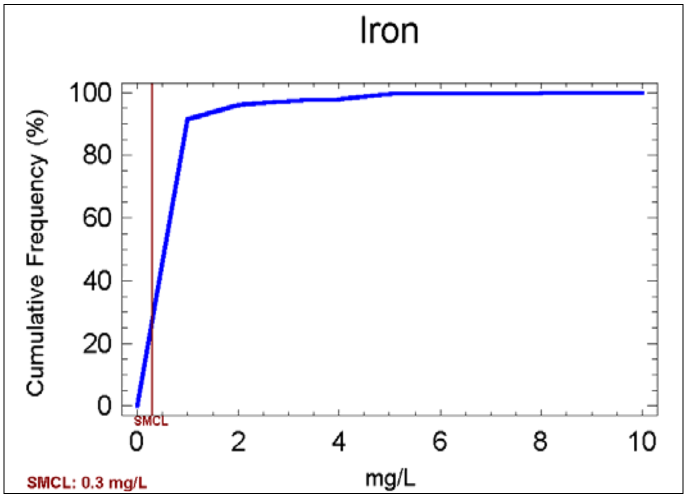


Figure F-25 Boxplot of iron measurements, BMU 2

Figure F-26 Cumulative frequency curve for iron, BMU 2

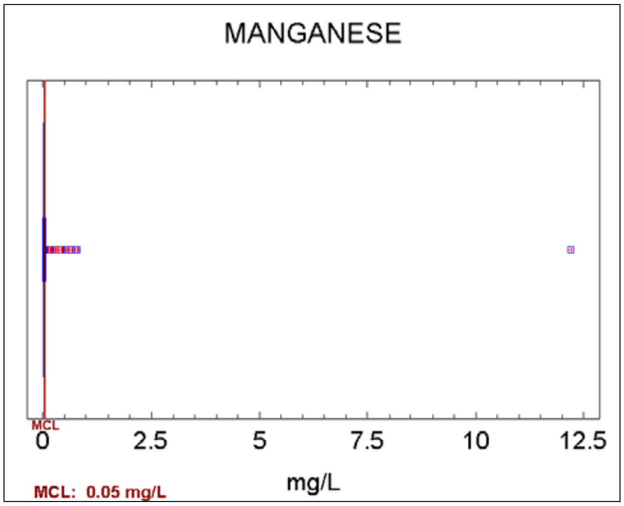


Figure F-27 Boxplot of manganese measurements, BMU 2

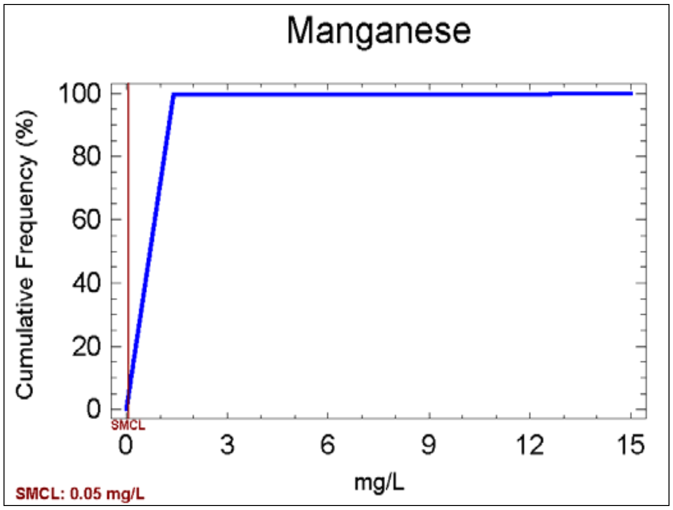


Figure F-28 Cumulative frequency curve for manganese, BMU 2

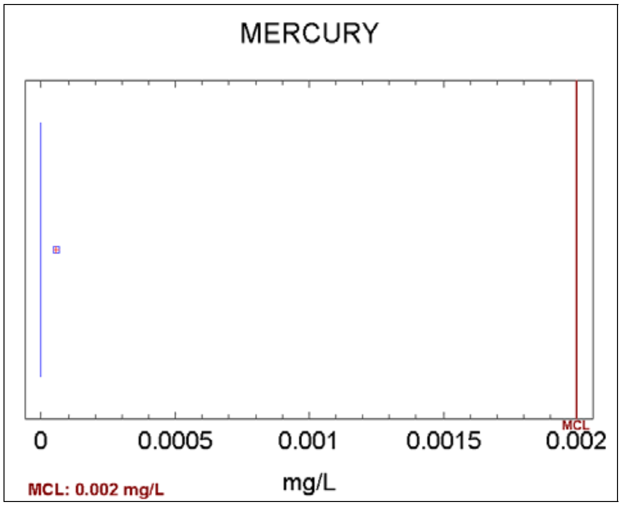


Figure F-29 Boxplot of mercury measurements, BMU 2

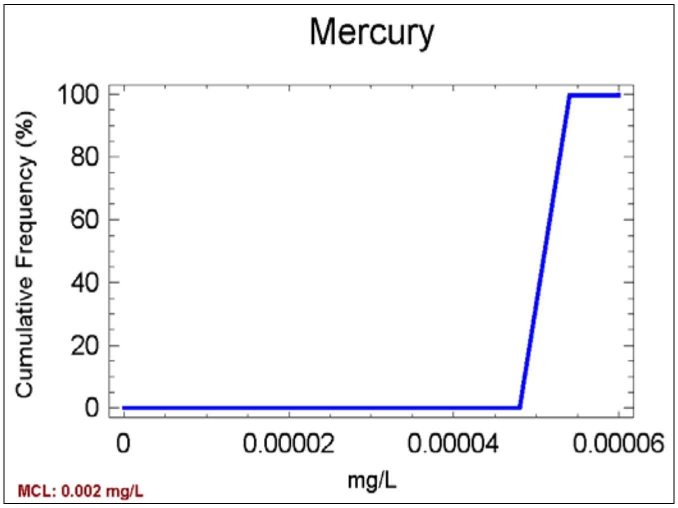


Figure F-30 Cumulative frequency curve for mercury, BMU 2

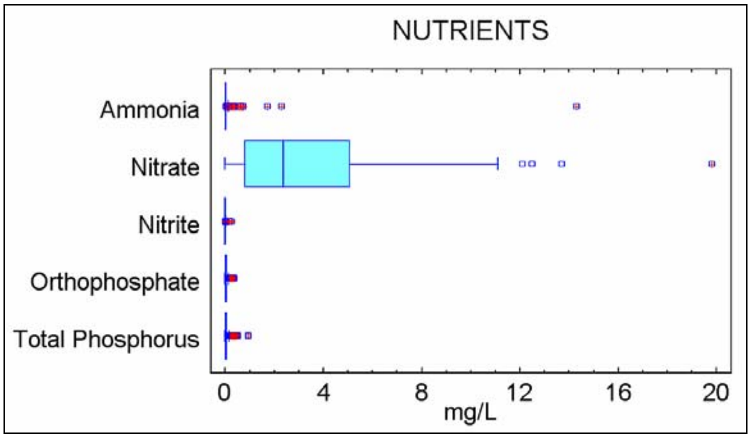


Figure F-31 Comparative boxplots of nutrients measurements

BMU2: NUTRIENTS SUMMARY STATISTICS

	AMMONIA					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**0.016**	**14.30**	**< 0.02**	**< 0.02**
BLUEGRASS (INNER & OUTER):	04/25/95	09/27/00	< 0.02	14.30	< 0.02	< 0.05
MISSISSIPPIAN PLATEAU:	04/25/95	10/11/00	< 0.02	0.15	< 0.02	< 0.05
EASTERN COAL FIELD:	05/08/95	05/30/00	< 0.02	0.74	< 0.05	< 0.02
OHIO RIVER ALLUVIUM:	04/25/95	10/04/00	0.016	0.72	< 0.02	< 0.02
	NITRATE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**< 0.02**	**19.80**	**2.38**	**< 0.007**
BLUEGRASS (INNER & OUTER):	04/25/95	04/17/00	< 0.007	19.80	2.76	< 0.007
MISSISSIPPIAN PLATEAU:	04/25/95	10/11/00	< 0.007	4.25	0.90	0.090
EASTERN COAL FIELD:	05/08/95	03/15/00	< 0.007	3.92	0.18	0.090
OHIO RIVER ALLUVIUM:	04/25/95	03/07/00	< 0.02	12.50	5.58	< 0.02
	NITRITE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**0.0006**	**0.259**	**0.002**	**< 0.02**
BLUEGRASS (INNER & OUTER):	04/25/95	04/17/00	< 0.02	0.259	0.002	< 0.02
MISSISSIPPIAN PLATEAU:	04/25/95	10/11/00	0.0006	0.014	0.00375	< 0.02
EASTERN COAL FIELD:	05/08/95	03/15/00	< 0.001	0.026	0.001165	< 0.02
OHIO RIVER ALLUVIUM:	04/25/95	03/07/00	< 0.001	0.175	0.002	< 0.02
	PHOSPHATE, ORTHO					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**< 0.003**	**0.387**	**0.019**	**< 0.059**
BLUEGRASS (INNER & OUTER):	04/25/95	09/27/00	< 0.059	0.387	0.021835	< 0.059
MISSISSIPPIAN PLATEAU:	04/25/95	10/11/00	< 0.003	0.108	0.01833	< 0.059
EASTERN COAL FIELD:	05/08/95	05/30/00	< 0.003	0.092	0.0905	< 0.059
OHIO RIVER ALLUVIUM:	04/25/95	10/04/00	< 0.003	0.216	0.021	< 0.059
	PHOSPHATE, TOTAL					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**< 0.005**	**0.95**	**0.022**	**< 0.121**
BLUEGRASS (INNER & OUTER):	04/25/95	03/08/00	< 0.005	0.506	0.0495	< 0.121
MISSISSIPPIAN PLATEAU:	04/25/95	10/11/00	< 0.005	0.228	0.009	< 0.121
EASTERN COAL FIELD:	05/08/95	03/15/00	< 0.005	0.4	0.01	< 0.121
OHIO RIVER ALLUVIUM:	04/25/95	03/07/00	< 0.005	0.95	0.0095	< 0.121

Table E-32 Nutrients, Summary Statistics

BMU2: NUTRIENTS SUMMARY TABLE

		AMMONIA	NITRATE	NITRITE	PHOSPHATE, ORTHO	PHOSPHATE, TOTAL
NUMBER OF SAMPLES	**TOTAL:**	287	287	287	287	287
BY REGION:	**BLUEGRASS (INNER & OUTER):**	126	121	121	134	116
	MISSISSIPPIAN PLATEAU:	54	54	54	61	51
	EASTERN COAL FIELD:	25	26	26	27	25
	OHIO RIVER ALLUVIUM:	82	80	81	97	76
NUMBER OF DETECTIONS	**TOTAL:**	77	268	135	215	143
	% DETECTS (vs SAMPLES):	26.83%	95.37%	47.87%	67.40%	53.36%
BY REGION:	**BLUEGRASS (INNER & OUTER):**	31	117	42	81	83
	MISSISSIPPIAN PLATEAU:	18	52	24	33	29
	EASTERN COAL FIELD:	7	22	12	19	10
	OHIO RIVER ALLUVIUM:	21	77	57	82	21
NUMBER OF SITES	**TOTAL:**	64	67	67	67	65
BY REGION:	**BLUEGRASS (INNER & OUTER):**	32	32	32	32	31
	MISSISSIPPIAN PLATEAU:	13	14	14	14	13
	EASTERN COAL FIELD:	6	6	6	6	6
	OHIO RIVER ALLUVIUM:	13	15	15	15	15
NUMBER OF SITES WITH DETECTIONS	**TOTAL:**	29	61	27	44	51
	% SITES W/DETECTIONS:	45.31%	91.04%	40.30%	65.67%	78.46%
BY REGION:	**BLUEGRASS (INNER & OUTER):**	12	30	9	20	27
	MISSISSIPPIAN PLATEAU:	7	13	5	8	10
	EASTERN COAL FIELD:	3	3	3	4	5
	OHIO RIVER ALLUVIUM:	7	15	10	12	9
NUMBER OF DETECTIONS ABOVE THE MCL	**TOTAL:**	32	12	0	-	-
	% DETECTIONS > MCL:	41.56%	4.48%	0.00%	-	-
	% SAMPLES > MCL:	0.20%	0.34%	0.00%	-	-
BY REGION:	**BLUEGRASS (INNER & OUTER):**	12	4	0	-	-
	MISSISSIPPIAN PLATEAU:	2	0	0	-	-
	EASTERN COAL FIELD:	5	0	0	-	-
	OHIO RIVER ALLUVIUM:	13	8	0	-	-

[1]Ortho-p is not currently regulated, but Texas has a surface water quality standard for ortho-p of 0.04 mg/L.

[2]Total-p is not currently regulated, but EPA water quality criteria state that phosphates should not exceed 0.100 mg/l in streams or flowing waters not discharging into lakes or reservoirs to control algal growth.

	MCL (mg/L)	Secondary (mg/L)
AMMONIA	0.110	-
NITRATE (as N)	10.000	-
NITRITE (as N)	1.000	-
ORTHOPHOSPHATE	-	-
TOTAL PHOSPHORUS	-	-

EPA uses T (not D) for MCL standards
Dissolved results were not considered in this study

Table E-33 Nutrients, Samples Summary

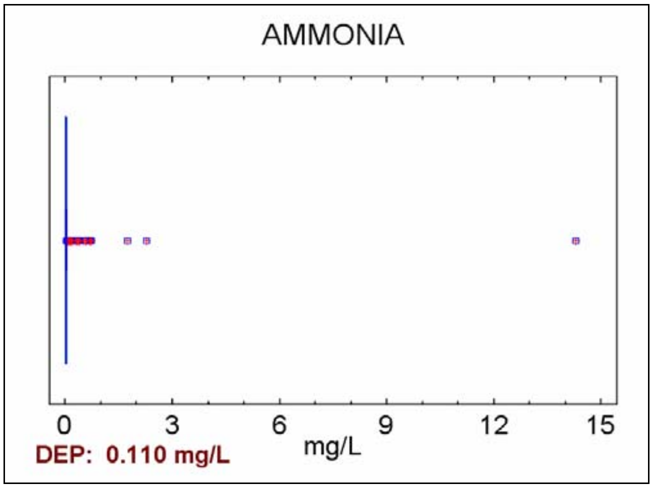


Figure F-34 Boxplot of ammonia measurements, BMU 2

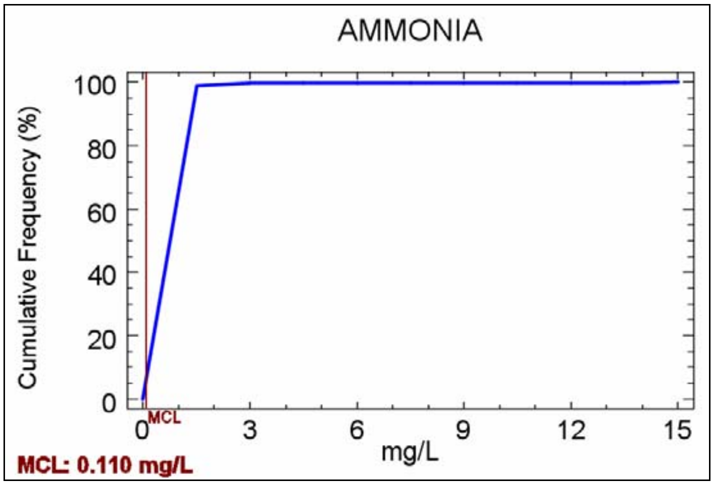


Figure F-35 Cumulative frequency curve for ammonia, BMU 2

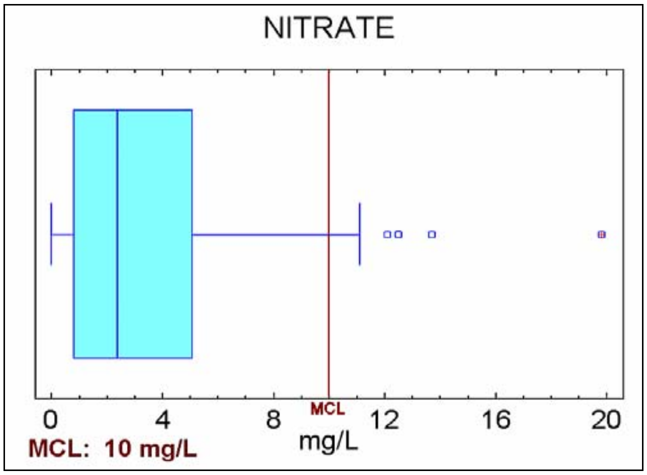


Figure F-36 Boxplot of nitrate measurements, BMU 2

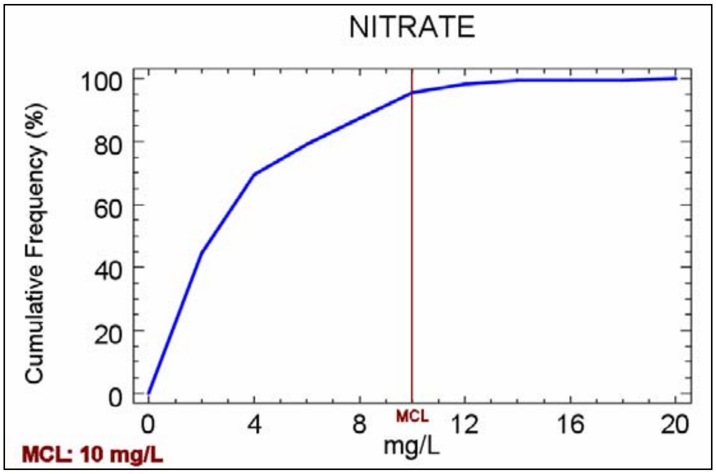


Figure F-37 Cumulative frequency curve for nitrate, BMU 2

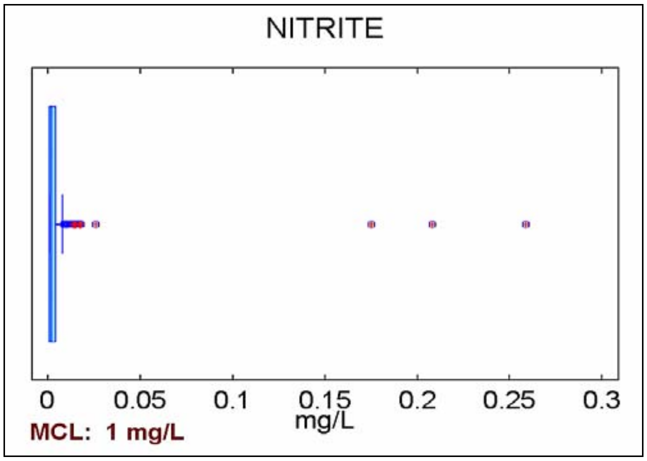


Figure F-38 Boxplot of nitrite measurements, BMU 2

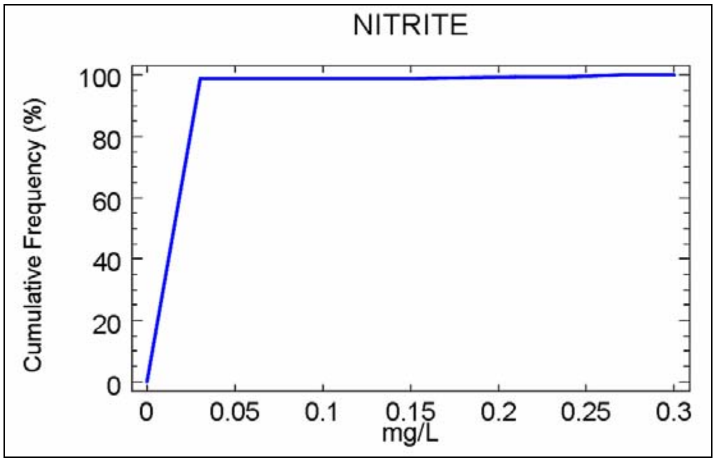


Figure F-39 Cumulative frequency curve for nitrite, BMU 2

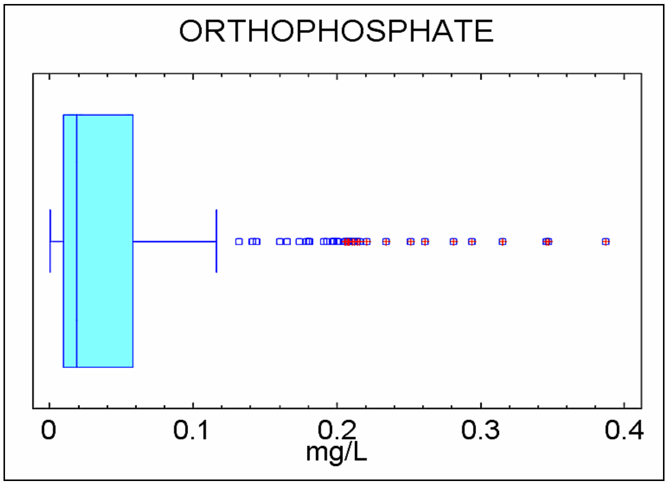


Figure F-40 Boxplot of orthophosphate measurements, BMU 2

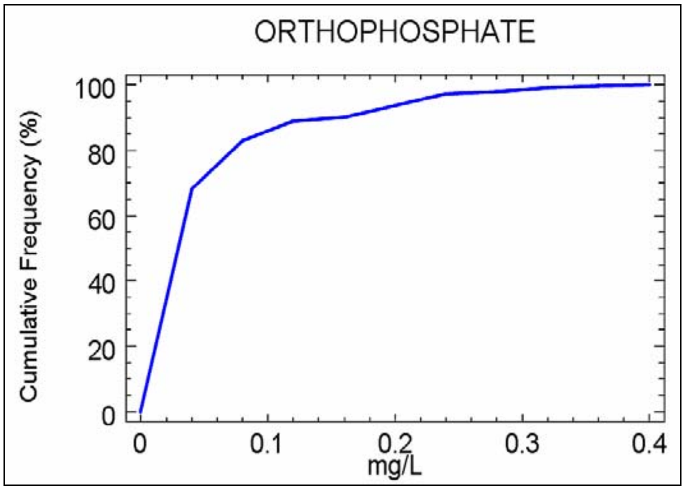


Figure F-41 Cumulative frequency curve for orthophosphate, BMU 2

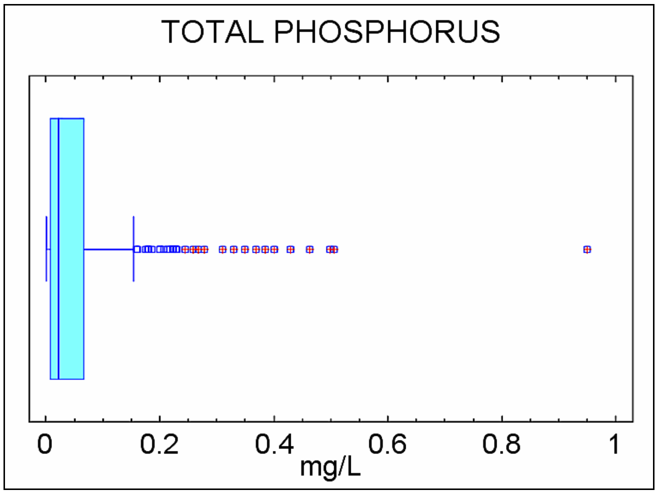


Figure F-42 Boxplot of total phosphorus measurements, BMU 2

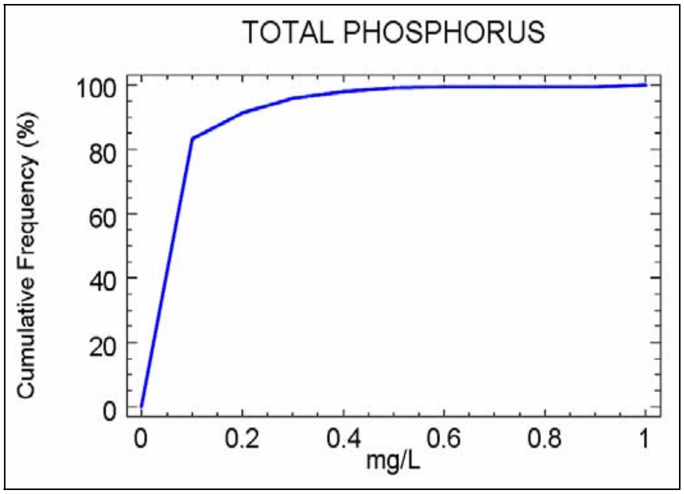


Figure F-43 Cumulative frequency curve for total phosphorus, BMU 2

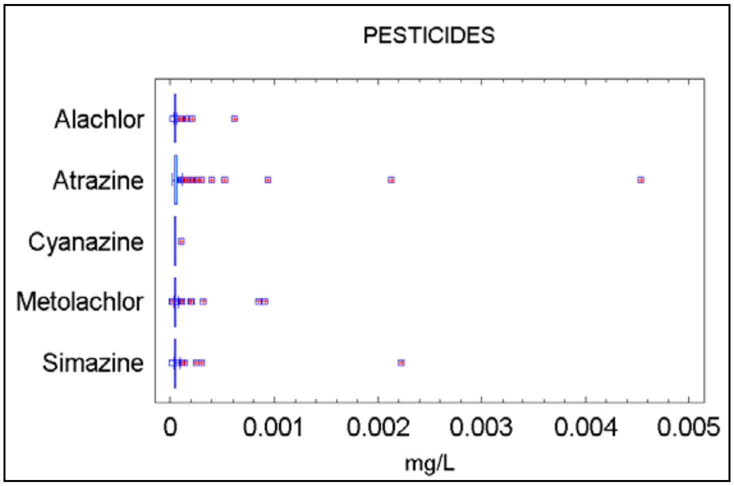


Figure F-44 Comparative boxplots of pesticides measurements

BMU2: RESIDUES SUMMARY STATISTICS						
	ALACHLOR					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**12/12/01**	**< 0.000020**	**0.000614**	**< 0.000040**	**< 0.000040**
BLUEGRASS (INNER & OUTER):	04/26/95	12/12/01	< 0.000020	0.000110	< 0.000040	< 0.000040
MISSISSIPPIAN PLATEAU:	04/26/95	11/07/01	< 0.000020	0.000614	< 0.000040	< 0.000040
EASTERN COAL FIELD:	05/08/95	05/30/00	< 0.000020	< 0.000060	< 0.000040	< 0.000040
OHIO RIVER ALLUVIUM:	04/26/95	10/03/01	< 0.000020	0.000033	< 0.000040	< 0.000040
	ATRAZINE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**12/12/01**	**0.000018**	**0.004535**	**< 0.000040**	**< 0.000040**
BLUEGRASS (INNER & OUTER):	04/26/95	12/12/01	0.000018	0.000523	< 0.000040	< 0.000040
MISSISSIPPIAN PLATEAU:	04/26/95	11/07/01	0.000019	0.004535	< 0.000040	< 0.000040
EASTERN COAL FIELD:	05/08/95	05/30/00	< 0.000040	< 0.000300	< 0.000050	< 0.000040
OHIO RIVER ALLUVIUM:	04/26/95	10/03/01	< 0.000040	< 0.000300	< 0.000050	< 0.000040
	CYANAZINE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**12/12/01**	**< 0.000040**	**< 0.000100**	**< 0.000040**	**< 0.000040**
BLUEGRASS (INNER & OUTER):	04/26/95	12/12/01	< 0.000040	< 0.000100	< 0.000040	< 0.000040
MISSISSIPPIAN PLATEAU:	04/26/95	11/07/01	< 0.000040	< 0.000100	< 0.000040	< 0.000040
EASTERN COAL FIELD:	05/08/95	05/30/00	< 0.000040	< 0.000100	< 0.000050	< 0.000040
OHIO RIVER ALLUVIUM:	04/26/95	10/03/01	< 0.000040	< 0.000100	< 0.000050	< 0.000040
	METOLACHLOR					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**12/12/01**	**0.000010**	**0.000908**	**< 0.000040**	**< 0.000040**
BLUEGRASS (INNER & OUTER):	04/26/95	12/12/01	0.000010	0.000908	< 0.000040	< 0.000040
MISSISSIPPIAN PLATEAU:	04/26/95	11/07/01	0.000019	0.000312	< 0.000040	< 0.000040
EASTERN COAL FIELD:	05/08/95	05/30/00	< 0.000040	< 0.000200	< 0.000050	< 0.000050
OHIO RIVER ALLUVIUM:	04/26/95	10/03/01	< 0.000040	< 0.000200	< 0.000050	< 0.000040
	SIMAZINE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**12/12/01**	**0.000017**	**0.002223**	**< 0.000040**	**< 0.000040**
BLUEGRASS (INNER & OUTER):	04/26/95	12/12/01	0.000030	< 0.000300	< 0.000040	< 0.000040
MISSISSIPPIAN PLATEAU:	04/26/95	11/07/01	0.000017	0.002223	< 0.000040	< 0.000040
EASTERN COAL FIELD:	05/08/95	05/30/00	< 0.000040	< 0.000300	< 0.000050	< 0.000040
OHIO RIVER ALLUVIUM:	04/26/95	10/03/01	< 0.000040	< 0.000300	< 0.000050	< 0.000040

Table E-45 Pesticides, Summary Statistics

BMU2: PESTICIDES SUMMARY TABLE

		ALACHOR	ATRAZINE	CYANAZINE[1 2]	METOLACHLOR[1]	SIMAZINE[2]
NUMBER OF SAMPLES	TOTAL:	342	342	314	342	320
BY REGION:	BLUEGRASS (INNER & OUTER):	143	143	132	143	136
	MISSISSIPPIAN PLATEAU:	68	68	64	68	64
	EASTERN COAL FIELD:	25	25	23	25	23
	OHIO RIVER ALLUVIUM:	106	106	95	106	97
NUMBER OF DETECTIONS	TOTAL:	11	53	0	34	10
	% DETECTS (vs SAMPLES):	3.22%	15.50%	0.00%	9.94%	3.13%
BY REGION:	BLUEGRASS (INNER & OUTER):	6	35	0	30	6
	MISSISSIPPIAN PLATEAU:	6	15	0	4	4
	EASTERN COAL FIELD:	0	0	0	0	0
	OHIO RIVER ALLUVIUM:	2	3	0	0	0
NUMBER OF SITES	TOTAL:	64	64	63	64	63
BY REGION:	BLUEGRASS (INNER & OUTER):	31	31	31	31	31
	MISSISSIPPIAN PLATEAU:	12	12	11	12	11
	EASTERN COAL FIELD:	6	6	6	6	6
	OHIO RIVER ALLUVIUM:	15	15	15	15	15
NUMBER OF SITES WITH DETECTIONS	TOTAL:	8	18	0	9	5
	% SITES W/DETECTIONS:	12.50%	28.13%	0.00%	14.06%	7.94%
BY REGION:	BLUEGRASS (INNER & OUTER):	3	13	0	7	4
	MISSISSIPPIAN PLATEAU:	3	2	0	2	1
	EASTERN COAL FIELD:	0	0	0	0	0
	OHIO RIVER ALLUVIUM:	2	3	0	0	0
NUMBER OF DETECTIONS ABOVE THE MCL	TOTAL:	0	1	0	0	0
	% DETECTIONS > MCL:	0.00%	6.67%	0.00%	0.00%	0.00%
	% SAMPLES > MCL:	0.00%	0.16%	0.00%	0.00%	0.00%
BY REGION:	BLUEGRASS (INNER & OUTER):	0	0	0	0	0
	MISSISSIPPIAN PLATEAU:	0	1	0	0	0
	EASTERN COAL FIELD:	0	0	0	0	0
	OHIO RIVER ALLUVIUM:	0	0	0	0	0

[1] **HAL used in absence of MCL**

[2] **0001-5022 (Flaherty Well) - no samples analyzed for cyanazine or simazine**

	MCL (mg/L)	HAL (mg/L)	Other
ALACHLOR	0.002	-	-
ATRAZINE	0.003	-	-
CYANAZINE	-	0.001	-
METOLACHLOR	-	0.100	-
SIMAZINE	0.004	-	-

Table E-46 Pesticides, Samples Summary

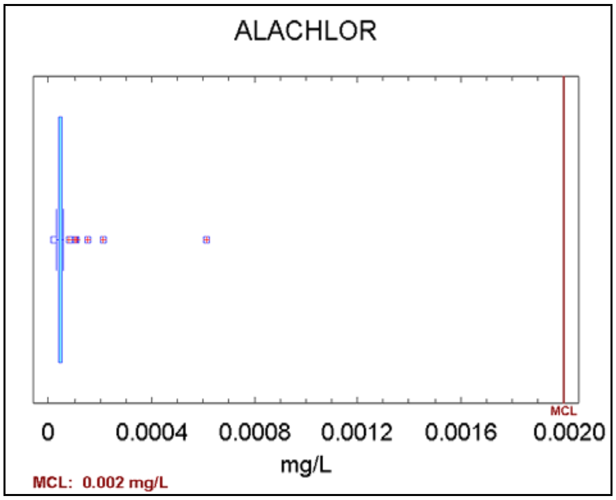


Figure F-47 Boxplot of alachlor measurements, BMU 2

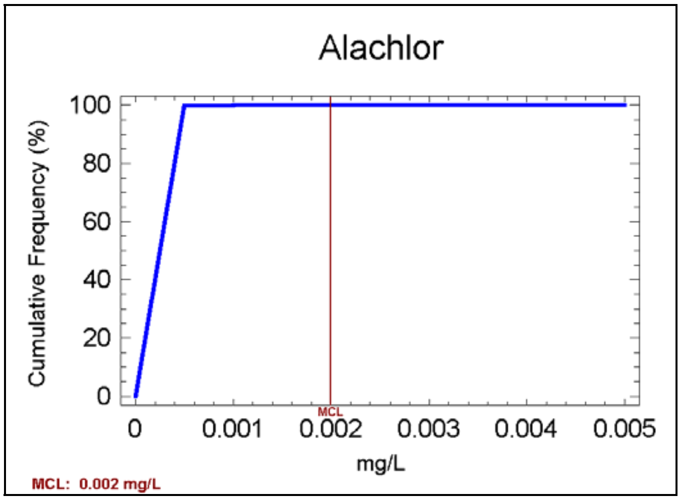


Figure F-48 Cumulative frequency curve for alachlor, BMU 2

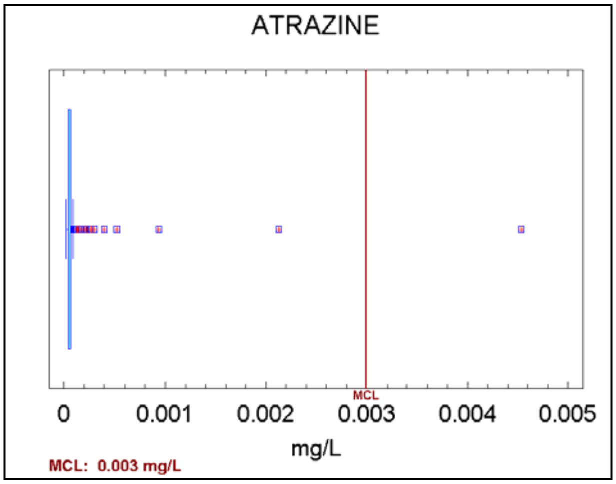


Figure F-49 Boxplot of atrazine measurements, BMU 2

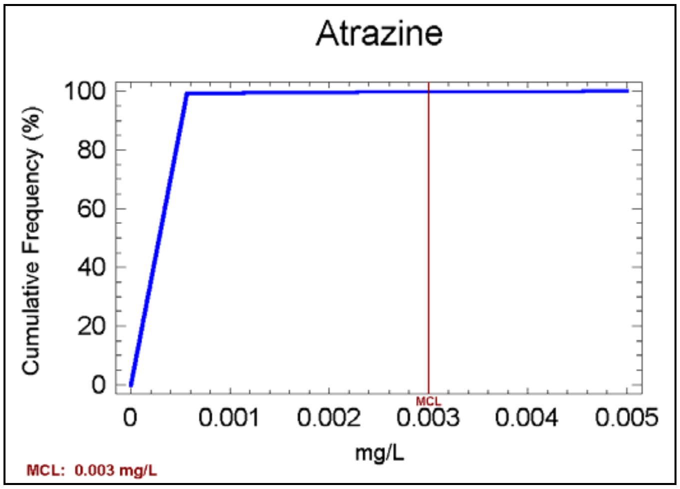


Figure F-50 Cumulative frequency curve for atrazine, BMU 2

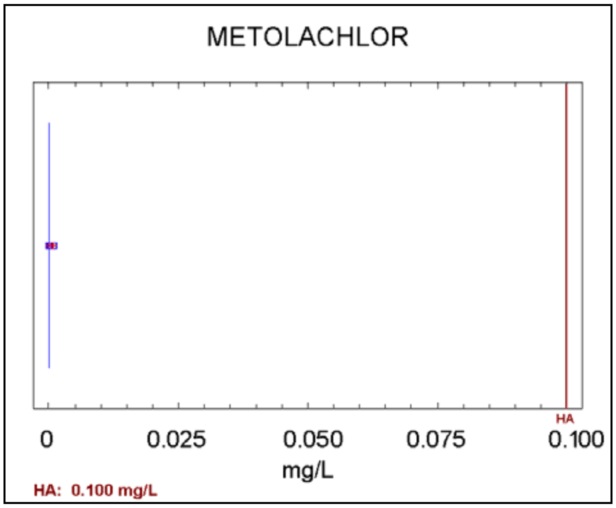


Figure F-51 Boxplot of metolachlor measurements, BMU 2

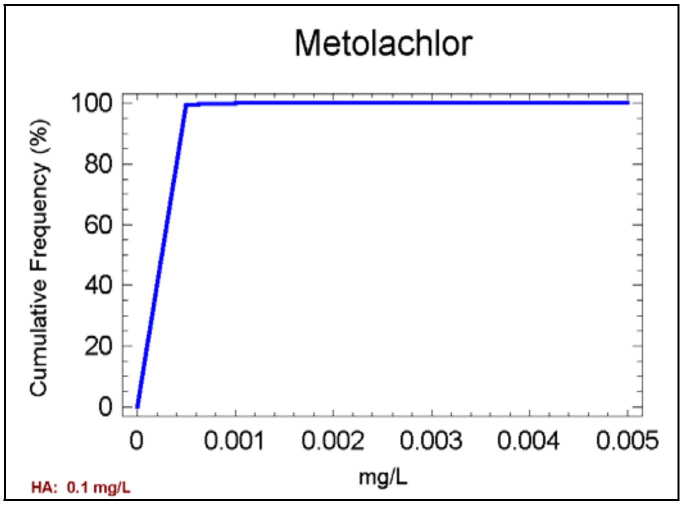


Figure F-52 Cumulative frequency curve for metolachlor, BMU 2

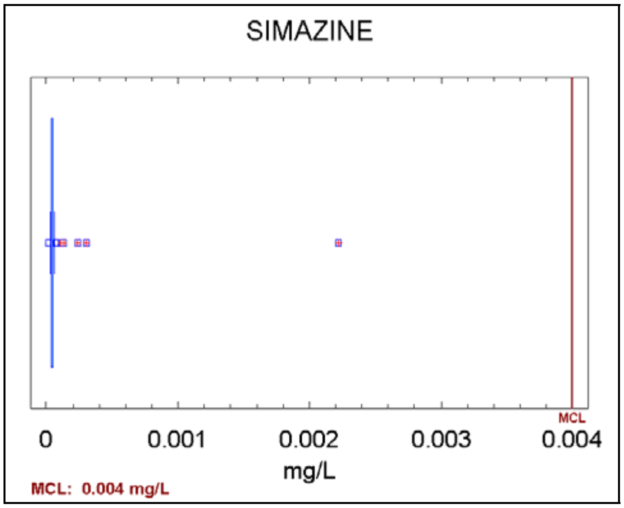


Figure F-53 Boxplot of simazine measurements, BMU 2

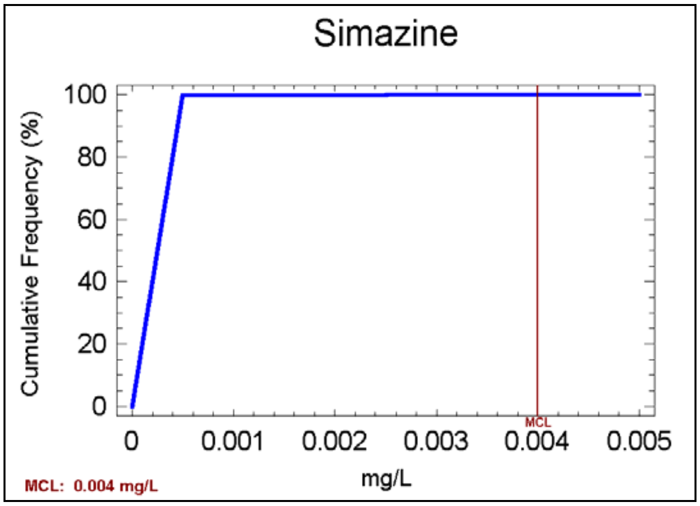


Figure F-54 Cumulative frequency curve for simazine, BMU 2

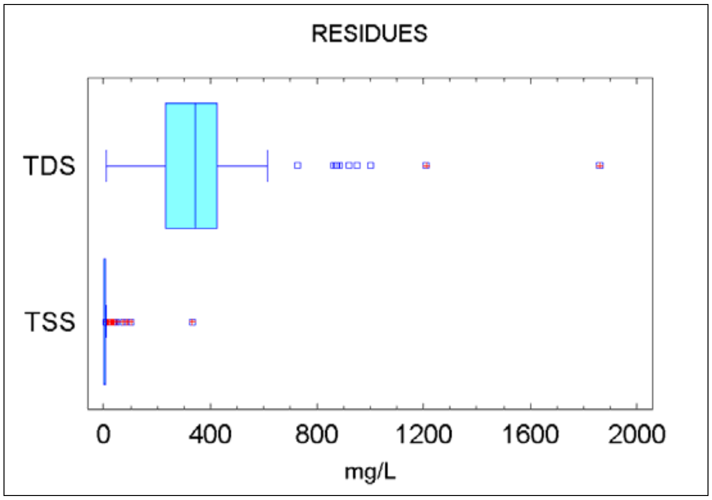


Figure F-55 Comparative boxplots of residues measurements

BMU2: RESIDUES SUMMARY STATISTICS						
	TDS (Total Dissolved Solids)					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**< 10**	**1860**	**342**	**234**
BLUEGRASS (INNER & OUTER):	04/26/95	09/27/00	46	1860	366	230
MISSISSIPPIAN PLATEAU:	04/26/95	10/11/00	24	422	234	234
EASTERN COAL FIELD:	05/08/95	05/30/00	20	450	140	96
OHIO RIVER ALLUVIUM:	04/26/95	10/04/00	< 10	1002	414	226
	TSS (Total Suspended Solids)					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**04/26/95**	**10/11/00**	**< 1**	**332**	**< 3**	**< 3**
BLUEGRASS (INNER & OUTER):	04/26/95	09/27/00	< 1	101	3	< 3
MISSISSIPPIAN PLATEAU:	04/26/95	10/11/00	< 1	41	3	< 3
EASTERN COAL FIELD:	05/08/95	05/30/00	< 1	332	< 3	< 3
OHIO RIVER ALLUVIUM:	04/26/95	10/04/00	< 1	31	< 3	< 3

Table E-56 Residues, Summary Statistics

BMU2: RESIDUES SUMMARY TABLE

		TDS	TSS[1]
NUMBER OF SAMPLES	**TOTAL:**	315	315
BY REGION:	**BLUEGRASS (INNER & OUTER):**	133	132
	MISSISSIPPIAN PLATEAU:	59	59
	EASTERN COAL FIELD:	27	27
	OHIO RIVER ALLUVIUM:	96	97
NUMBER OF DETECTIONS	**TOTAL:**	314	178
	% DETECTS (vs SAMPLES):	99.68%	56.51%
BY REGION:	**BLUEGRASS (INNER & OUTER):**	133	91
	MISSISSIPPIAN PLATEAU:	59	39
	EASTERN COAL FIELD:	27	14
	OHIO RIVER ALLUVIUM:	95	34
NUMBER OF SITES	**TOTAL:**	66	65
BY REGION:	**BLUEGRASS (INNER & OUTER):**	32	31
	MISSISSIPPIAN PLATEAU:	13	13
	EASTERN COAL FIELD:	6	6
	OHIO RIVER ALLUVIUM:	15	15
NUMBER OF SITES WITH DETECTIONS	**TOTAL:**	66	51
	% SITES W/DETECTIONS:	100.00%	78.46%
BY REGION:	**BLUEGRASS (INNER & OUTER):**	32	27
	MISSISSIPPIAN PLATEAU:	13	9
	EASTERN COAL FIELD:	6	6
	OHIO RIVER ALLUVIUM:	15	9
NUMBER OF DETECTIONS ABOVE THE MCL	**TOTAL:**	34	11
	% DETECTIONS > MCL:	10.83%	6.18%
	% SAMPLES > MCL:	10.79%	3.49%
BY REGION:	**BLUEGRASS (INNER & OUTER):**	17	7
	MISSISSIPPIAN PLATEAU:	0	2
	EASTERN COAL FIELD:	0	2
	OHIO RIVER ALLUVIUM:	17	0

[1] **Currently no water quality standard for TSS, but some KPDES permits use 35 mg/L for a monthly average**

	MCL (mg/L)	Secondary (mg/L)	Other
TDS	-	500	-
TSS	-	-	35

Table E-57 Residues, Samples Summary

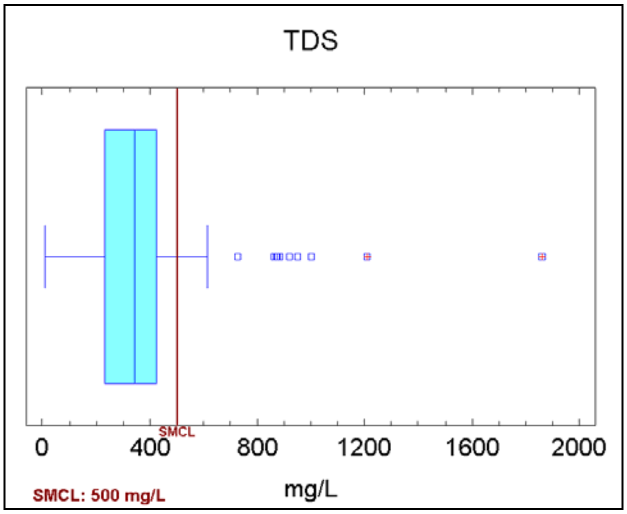


Figure F-58 Boxplot of TDS measurements, BMU 2

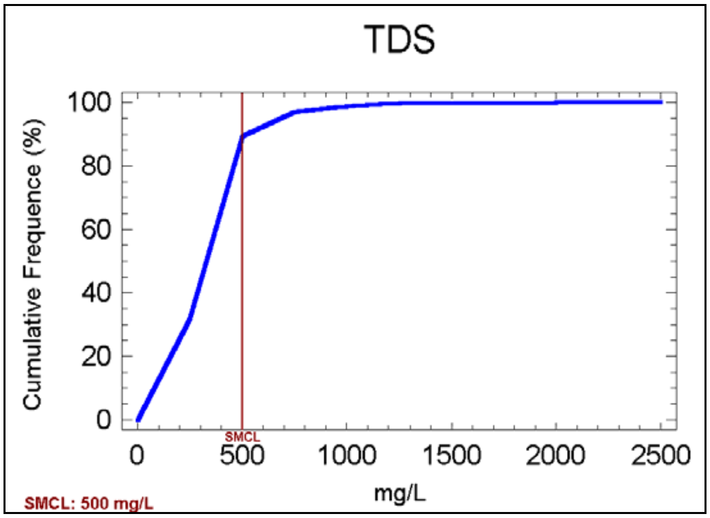


Figure F-59 Cumulative frequency curve for TDS, BMU 2

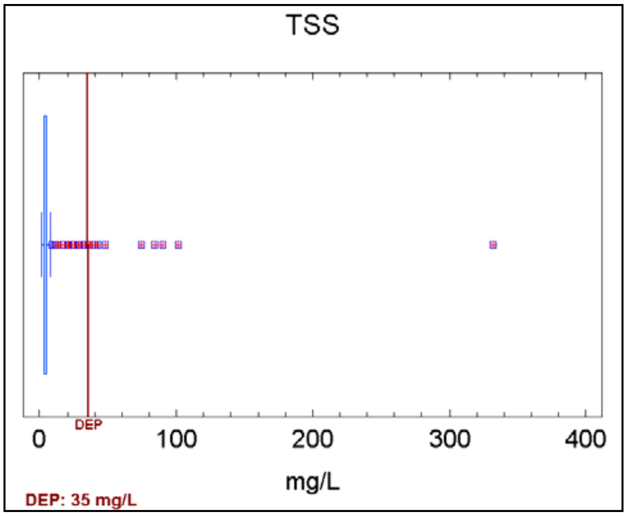


Figure F-60 Boxplot of TSS measurements, BMU 2

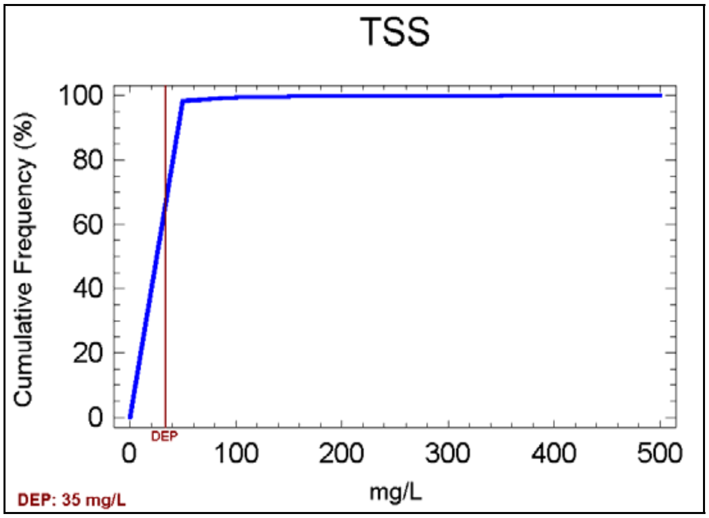


Figure F-61 Cumulative frequency curve for TSS, BMU 2

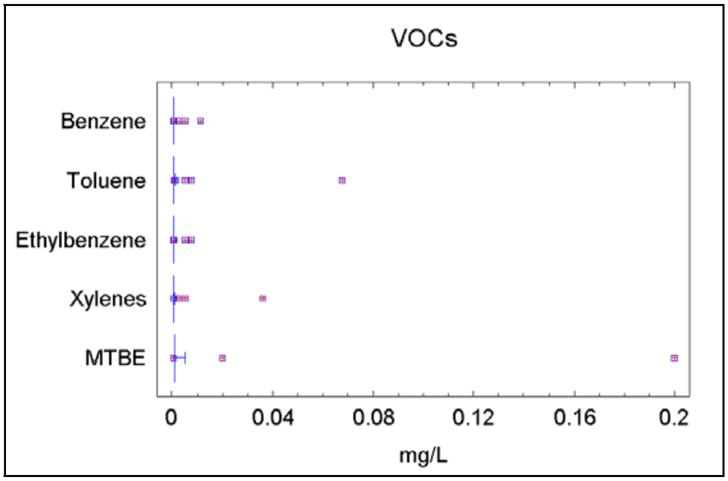


Figure F-62 Comparative boxplots of VOC measurements

BMU2: VOCS SUMMARY STATISTICS						
	BENZENE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**12/21/93**	**12/12/01**	**< 0.0005**	**0.0112**	**< 0.0005**	**< 0.0005**
BLUEGRASS (INNER & OUTER):	12/21/93	12/12/01	< 0.0005	0.0112	< 0.0005	< 0.0005
MISSISSIPPIAN PLATEAU:	02/04/97	11/07/01	< 0.0005	0.0009	< 0.0005	< 0.0005
EASTERN COAL FIELD:	03/29/99	05/30/00	< 0.0005	< 0.0005	< 0.0005	< 0.0005
OHIO RIVER ALLUVIUM:	10/08/96	10/03/01	< 0.0005	< 0.0005	< 0.0005	< 0.0005
	TOLUENE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**12/21/93**	**12/12/01**	**< 0.0005**	**0.0677**	**< 0.0005**	**< 0.0005**
BLUEGRASS (INNER & OUTER):	12/21/93	12/12/01	< 0.0005	0.0677	< 0.0005	< 0.0005
MISSISSIPPIAN PLATEAU:	02/04/97	11/07/01	< 0.0005	0.0010	< 0.0005	< 0.0005
EASTERN COAL FIELD:	03/29/99	05/30/00	< 0.0005	< 0.0005	< 0.0005	< 0.0005
OHIO RIVER ALLUVIUM:	10/08/96	10/03/01	< 0.0005	< 0.0005	< 0.0005	< 0.0005
	ETHYLBENZENE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**12/21/93**	**12/12/01**	**< 0.0005**	**0.0077**	**< 0.0005**	**< 0.0005**
BLUEGRASS (INNER & OUTER):	12/21/93	12/12/01	< 0.0005	0.0077	< 0.0005	< 0.0005
MISSISSIPPIAN PLATEAU:	02/04/97	11/07/01	< 0.0005	< 0.0005	< 0.0005	< 0.0005
EASTERN COAL FIELD:	03/29/99	05/30/00	< 0.0005	< 0.0005	< 0.0005	< 0.0005
OHIO RIVER ALLUVIUM:	10/08/96	10/03/01	< 0.0005	< 0.0005	< 0.0005	< 0.0005
	XYLENE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**12/21/93**	**12/12/01**	**0.00049**	**0.03610**	**< 0.00050**	**< 0.00050**
BLUEGRASS (INNER & OUTER):	12/21/93	12/12/01	< 0.00050	0.03610	< 0.00050	< 0.00050
MISSISSIPPIAN PLATEAU:	07/09/97	11/07/01	< 0.00050	0.00072	< 0.00050	< 0.00050
EASTERN COAL FIELD:	03/29/99	05/30/00	< 0.00050	< 0.00050	< 0.00050	< 0.00050
OHIO RIVER ALLUVIUM:	03/23/99	10/03/01	< 0.00050	< 0.00050	< 0.00050	< 0.00050
	MTBE					
	START DATE	END DATE	MIN	MAX	MEDIAN	MODE
TOTAL:	**12/21/94**	**12/12/01**	**0.0004**	**< 0.2000**	**< 0.0010**	**< 0.0010**
BLUEGRASS (INNER & OUTER):	12/21/94	12/12/01	0.0004	< 0.2000	< 0.0010	< 0.0010
MISSISSIPPIAN PLATEAU:	04/19/00	11/07/01	< 0.0010	< 0.0010	< 0.0010	< 0.0010
EASTERN COAL FIELD:	03/29/99	05/30/00	< 0.0010	< 0.0200	< 0.0105	-
OHIO RIVER ALLUVIUM:	03/23/99	10/03/01	< 0.0010	< 0.0200	< 0.0010	< 0.0010

Table E-63 VOCs, Summary Statistics

BMU2: VOCs SUMMARY TABLE

		BENZENE	TOLUENE	ETHYLBENZENE	XYLENE [1]	MTBE [2]
NUMBER OF SAMPLES	**TOTAL:**	92	92	92	86	81
BY REGION:	**BLUEGRASS (INNER & OUTER):**	37	37	37	34	31
	MISSISSIPPIAN PLATEAU:	29	29	29	27	25
	EASTERN COAL FIELD:	2	2	2	2	2
	OHIO RIVER ALLUVIUM:	24	24	24	23	23
NUMBER OF DETECTIONS	**TOTAL:**	4	6	3	4	1
	% DETECTS (vs SAMPLES):	4.35%	6.52%	3.26%	4.65%	1.23%
BY REGION:	**BLUEGRASS (INNER & OUTER):**	2	4	3	3	1
	MISSISSIPPIAN PLATEAU:	2	2	0	1	0
	EASTERN COAL FIELD:	0	0	0	0	0
	OHIO RIVER ALLUVIUM:	0	0	0	0	0
NUMBER OF SITES	**TOTAL:**	27	27	27	26	25
BY REGION:	**BLUEGRASS (INNER & OUTER):**	88	8	9	8	8
	MISSISSIPPIAN PLATEAU:	8	8	8	8	8
	EASTERN COAL FIELD:	2	2	2	2	2
	OHIO RIVER ALLUVIUM:	9	9	9	8	8
NUMBER OF SITES WITH DETECTIONS	**TOTAL:**	2	2	1	2	1
	% SITES W/DETECTIONS:	7.41%	7.41%	3.70%	7.69%	4.00%
BY REGION:	**BLUEGRASS (INNER & OUTER):**	1	1	1	1	1
	MISSISSIPPIAN PLATEAU:	1	1	0	1	0
	EASTERN COAL FIELD:	0	0	0	0	0
	OHIO RIVER ALLUVIUM:	0	0	0	0	0
NUMBER OF DETECTIONS ABOVE THE MCL	**TOTAL:**	1	0	0	0	0
	% DETECTIONS > MCL:	25.00%	0.00%	0.00%	0.00%	0.00%
	% SAMPLES > MCL:	0.28%	0.00%	0.00%	0.00%	0.00%
BY REGION:	**BLUEGRASS (INNER & OUTER):**	1	0	0	0	0
	MISSISSIPPIAN PLATEAU:	0	0	0	0	0
	EASTERN COAL FIELD:	0	0	0	0	0
	OHIO RIVER ALLUVIUM:	0	0	0	0	0

[1] 0003-9351 (W. Mason Well) - no samples analyzed for xylene

[2] MTBE first sample date is 12/21/94 (as compared to 12/21/93 for rest of VOCs)

	MCL (mg/L)
BENZENE	0.005
TOLUENE	1.000
ETHYLBENZENE	0.700
XYLENE	10.000
MTBE	0.050

Table E-64 VOCs, Samples Summary

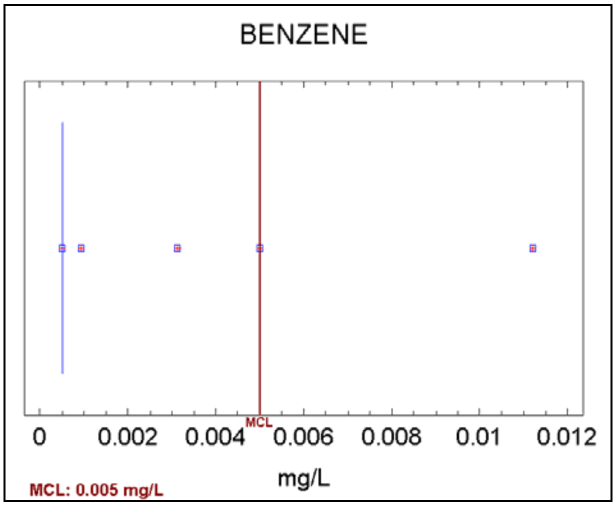


Figure F-65 Boxplot of benzene measurements, BMU 2

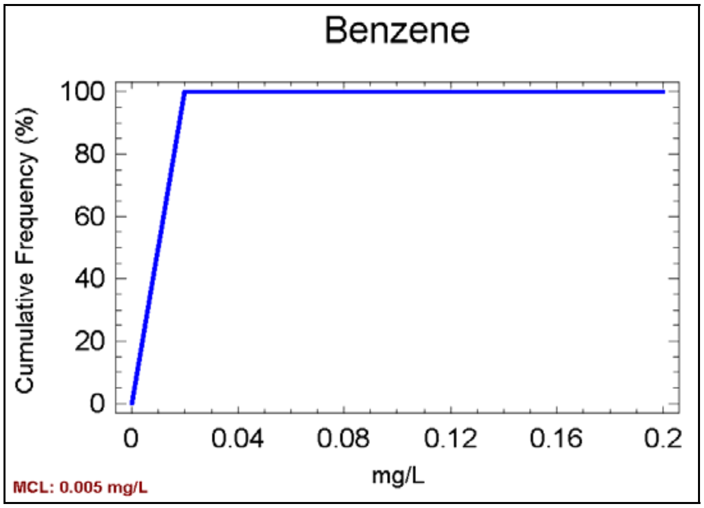


Figure F-66 Cumulative frequency curve for benzene, BMU 2

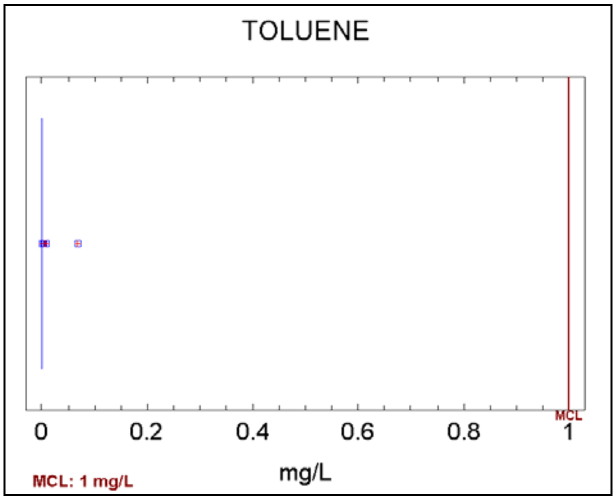


Figure F-67 Boxplot of toluene measurements, BMU 2

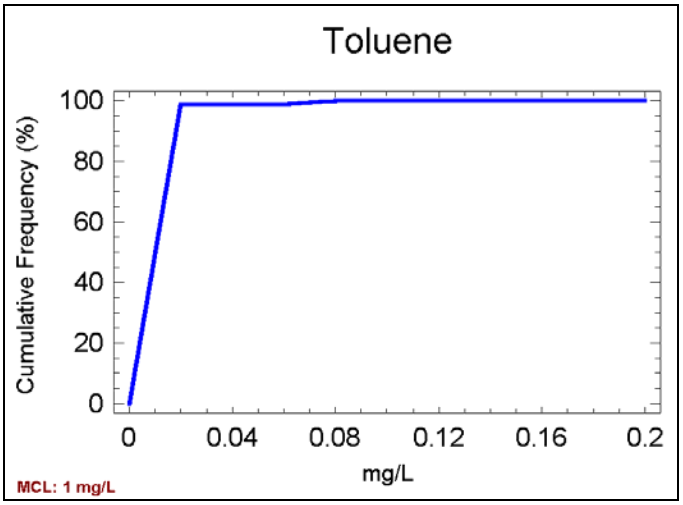


Figure F-68 Cumulative frequency curve for toluene, BMU 2

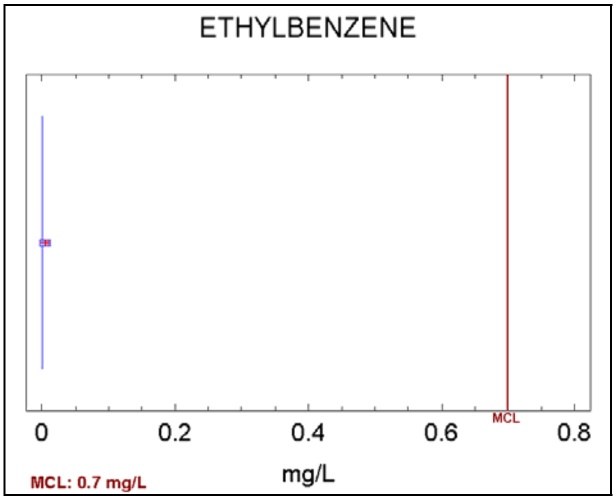


Figure F-69 Boxplot of ethylbenzene measurements, BMU 2

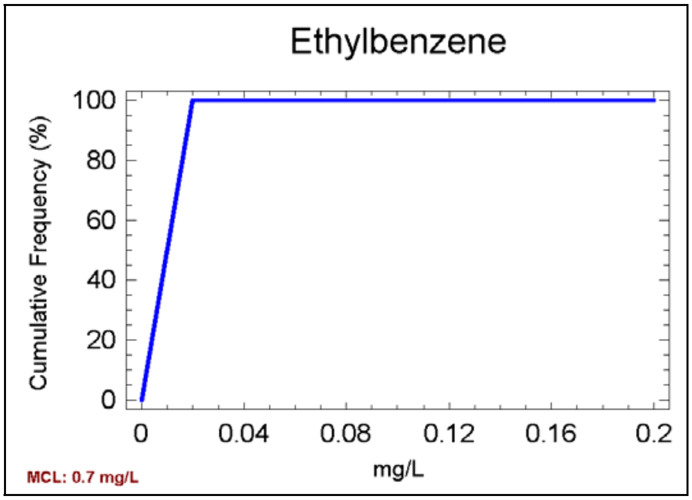


Figure F-70 Cumulative frequency curve for ethylbenzene, BMU 2

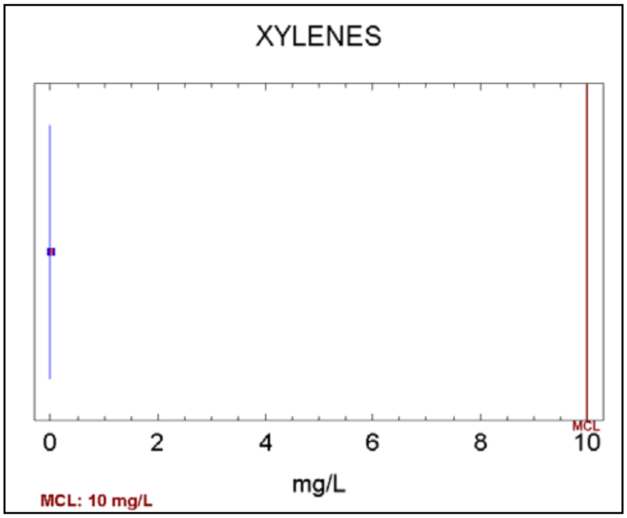


Figure F-71 Boxplot of xylenes measurements, BMU 2

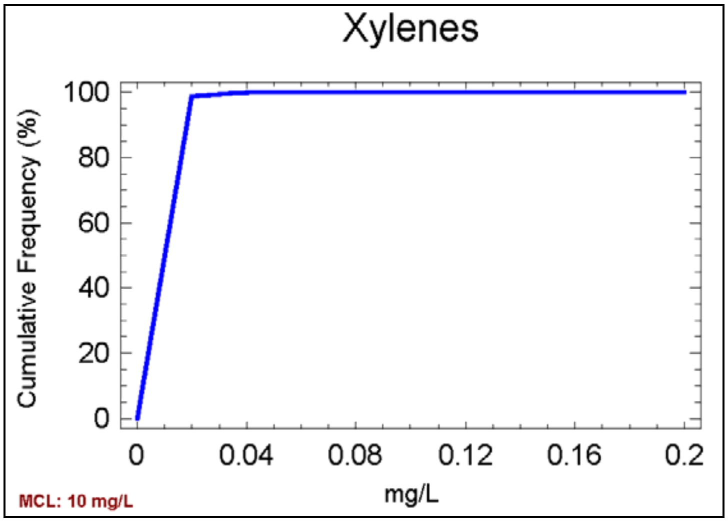


Figure F-72 Cumulative frequency curve for xylenes, BMU 2