# Groundwater Assessment for Nonpoint Source Pollution Impacts and Spring Basin Delineations within Sub-watersheds of the Salt River Basin: Beargrass Creek and Sinking Creek

## Final Report

By


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TABLE of CONTENTS

LIST of FIGURES

LIST of TABLES

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***Conversion Factors***

| Multiply | by | To obtain |
|---|---|---|
| acre | 43559.66 | $ft^2$ |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| gallon (gal) | 3.785 | liter (L) |
| gallon per minute (gpm) | 0.06308 | liter per second (L/s) |
| cubic feet per second ($ft^3/s$) | 0.02832 | cubic m per second ($m^3/s$) |
| $ft^3/s/mi^2$ (cfsm) | 10.931 | $L/s/km^2$ (lsk) |
| foot per mile (ft/mi) | 0.1894 | meter per km (m/km) |
| square mile ($mi^2$) | 640 | acres |
| $mi^2$ | 2.59 | $km^2$ |
| acre (ac) | 0.4047 | hectare (ha) |
| ounce (oz) | 28.35 | gram (g) |
| pound (lb) | 0.454 | kilogram (kg) |
| km | 0.621 | mi |
| $L/s/km^2$ | 0.0915 | $ft^3/s/mi^2$ |
| $km^2$ | 0.386 | $mi^2$ |
| meter | 3.28 | feet |
| $m^3/s$ | 35.31 | $ft^3/s$ |
| m/km | 5.28 | ft/mi |
| kg | 2.2 | lb |
| hectare | 2.471 | acre |

**EXECUTIVE SUMMARY**

The goal of this project was to assess groundwater within priority watersheds of Basin Management Unit (BMU) 2 (Salt and Licking River basins) relative to nonpoint source (NPS) pollution impacts. These watersheds were identified as impaired during the first monitoring cycle in the Salt and Licking River basins. Significant stream segments were found to be non-supporting for designated uses such as Aquatic Life Support and Primary Contact Recreation. Both of these priority watersheds are located in karst regions of Kentucky. Surface water and groundwater are conjunctive systems and this connection is especially direct in karst areas. Therefore, groundwater quantity and quality have a significant influence on surface water in these watersheds.

Beargrass Creek is located in central Jefferson County, Kentucky in the Outer Bluegrass Physiographic Region. The headwaters of Beargrass Creek rise in the east and flow roughly west to the Ohio River. Land use in the majority of this watershed is classified as urban/residential, commercial and industrial with major US Interstate corridor intersections. The area is predominantly underlain by Silurian- and Devonian-aged carbonate rocks, which are highly soluble and have developed significant karst drainage. The initial focus of this study was on dye-trace investigations and site selection. A total of 21 tracer tests were conducted to delineate 15 karst groundwater basins. This greatly expands the knowledge of karst groundwater flow within the watershed. In particular, tracer tests revealed groundwater piracy by the sanitary sewer system due to the age and poor condition of the infrastructure. During the groundwater investigation, several engineered diversions of groundwater into the sanitary sewer and storm drains were discovered. In some cases, this diversion has caused a loss of base flow (approximately 24%) in Beargrass Creek that would provide much needed dilution for this urban stream.

Following the dye-trace investigation 30 springs were chosen for water quality monitoring, including bench chemistry, major inorganic ions, metals, nutrients, residues, volatile organics and bacteria (*E. coli*). Chemical water quality parameters indicate nonpoint source impacts to groundwater from nutrients and pesticides. Primary Contact Recreation support was assessed using *E. coli* samples. *E. coli* values ranged from 7 to greater than 200,000 CFU/100 mL (Colony Forming Units per 100 mL), with a

median value of 276 CFU/100 mL. High *E. coli* values are hypothetically attributed to leaking sewers and combined sewer overflows.

Sinking Creek is located primarily in northern Breckinridge County, and extends into southwestern Meade and northern Hardin counties. These counties are located in the Mississippian Plateau Physiographic Region. The headwaters rise in southwestern Meade, northern Hardin and central Breckinridge counties and flow generally west-northwest to the Ohio River. Land cover in the watershed is predominantly forest and agriculture. Agricultural areas are mainly pasture land with minor amounts of row cropping. The watershed is primarily underlain by Mississippian-aged limestone and sandstone units. The oldest rock units (St. Louis and Ste. Genevieve limestone formations) are exposed in the eastern portion of the watershed. Moving west, up the Dripping Springs Escarpment, younger rocks in the section lie closer to the surface. Significant tracer tests had been conducted by previous researchers. The existing data were reviewed and augmented with 8 additional dye traces completed for this study. These data were digitized and included in the most recent Karst Atlas Map published by the Kentucky Geological Survey in 2009. Following the tracer tests, 8 springs were chosen for monitoring. The springs were monitored for chemical parameters only (bench chemistry, major inorganic ions, metals, nutrients, residues and volatile organics). Chemical water quality parameters indicate nonpoint source impacts to groundwater quality from nutrients.

## INTRODUCTION and BACKGROUND

The Kentucky Division of Water (DOW) 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." Under this system, the watersheds of the state are sub-divided into five Basin Management Units (BMUs). As part of the data gathering and assessment efforts of the watershed approach, the DOW-Watershed Management Branch assessed nonpoint source pollution impacts to groundwater within priority sub-watersheds of the Salt River Basin, which is within 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 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 DOW.

The DOW regularly collects ambient groundwater samples throughout the state. To date, the division has collected more than 5,000 samples from approximately 550 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 the Wellhead Protection Program, 4) development of Total Maximum Daily Loads (TMDLs) 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) Groundwater 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 assessment in areas lacking adequate information. The first cycle of assessment conducted by the DOW identified several priority watersheds within BMU

2. The former Groundwater Branch – now Groundwater Section of the Watershed Management Branch – was tasked with determining the influence of groundwater on surface water quality in these watersheds. Beargrass Creek and Sinking Creek, two watersheds within the Salt River Basin, were the focus of the groundwater study. Since both watersheds are in areas of well-developed karst drainage, tracer tests were conducted to delineate groundwater flow. Data were compared to the standards for Warm-water Aquatic Habitat and Primary Contact Recreation, set forth in 401 KAR 10:031. The number and frequency of samples collected at each site did not meet the criteria for an actual 305(b) assessment. However, these are the most applicable water quality standards to determine possible nonpoint source pollution impacts or other water quality problems, as well as to identify outstanding resources in these watersheds. Table 1 is a list of these standards taken from 401 KAR 10:031.

**Previous Investigations**

Webb and others (2002) conducted groundwater monitoring for nonpoint source impacts in BMU 2. This project included approximately 30 monitoring sites spread across both the Salt and Licking river basins. They found definite NPS impacts to groundwater from nutrients and pesticides, and possible NPS impacts from total dissolved solids and total suspended solids. 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 KGS (1969) has indexed the Hydrologic Atlases (HAs) and 7.5 minute Geological Quadrangle maps (GQs), prepared in cooperation with the United States Geological Survey (USGS), for the entire state. Geochemical data in the HAs are limited, and generally include only common metals and major inorganic ions.

Currens, Ray and others (1998, 2002, 2009) compiled the results from several karst groundwater basin investigations within BMU 2. Carey and Stickney (2001) prepared county groundwater resource reports, including general descriptions of groundwater quality. Based on groundwater sensitivity to contamination for the entire state, both of these priority sub-watersheds are highly sensitive to groundwater pollution (Ray and others, 1994).

## PHYSIOGRAPHIC and HYDROGEOLOGIC SETTING

BMU 2 covers more than 23,309 $km^2$ and includes the Salt and Licking River basins, as well as several other direct Ohio River tributaries. Both of these priority watersheds are direct Ohio River tributaries. Figure 1 illustrates the location of the priority watersheds, Sinking Creek and Beargrass Creek, within BMU 2 relative to Kentucky's Physiographic Regions (after Lobeck, 1930).

### Salt River Basin

The Salt River rises in Boyle County and flows generally northwest to its confluence with the Ohio River at West Point in Hardin County. The Salt River is approximately 201 km long and drains 7485 $km^2$ (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 Basin, the Ohio River Alluvium is an important aquifer and is sometimes considered as a unique physiographic region.

Groundwater flow in the Salt River Basin varies according to local geology. Following initial runoff of precipitation, groundwater discharging from storage provides base flow to surface streams, sustaining them during periods without rain.

### Karst Hydrology and Groundwater Sensitivity

Due to the characteristics of karst terranes, rates of groundwater recharge, flow velocities, and potential dispersion can be extremely high within the study areas. These groundwater systems can be rapidly recharged by widespread influx of precipitation and snow melt through soil macropores, runoff into sinkholes, and concentrated flow from losing and sinking streams. Groundwater flow velocity through conduits often matches runoff in surface channels, which may travel several miles per day. Likewise, karst groundwater flow can be dispersive, potentially distributing pollutants over broad areas, far from the source. Ray and others (1994) used three major hydrologic parameters, *recharge, flow,* and *dispersion*, to assess the groundwater sensitivity to pollution from surface activities in Kentucky.

Hydrogeological sensitivity was rated on a scale of 1 (low) to 5 (high), based on quantitative assessments of these three parameters. Documentation of conduit flow velocities in karst aquifers by numerous tracer tests was especially useful for rating the important *flow* component in a particular hydrologic setting. In the karst terranes of the Mississippian Plateau and Outer Bluegrass, *recharge* porosity can range up to several meters, which is exemplified by stream insurgence into a cave or vertical shaft. *Flow* velocity within trunk conduits may range from 10 m/hr at low flow to 800 m/hr during flood conditions (Ray & O'dell, 1993). *Dispersion* of contaminants within this karst aquifer is usually linear or bi-directional, but widespread to radial flow patterns do occur. Because of these extreme ranges, the two study areas are rated as “5” which is the most sensitive hydrogeologic setting for potential pollution from surface activities and nonpoint sources.

The relatively shallow karst aquifers of Kentucky, formed in dense Paleozoic carbonates, typically contain low to moderate long-term storage of groundwater (White, 1988). Most seasonal groundwater storage is within the soil/regolith cover, the underlying weathered bedrock zone called the *epikarst*, and in bedrock fractures. Long-term storage within the epikarst, commonly in the form of a perched water zone, continually seeps and percolates down fractures and shafts, and collects within the regional conduit drainage network. The karst flow system is typically an interconnected dendritic, or branched, horizontal network that discharges at large springs (Palmer, 1990). These convergent conduit networks tend to form distinct, contiguous groundwater drainage basins. Hydrologic interconnections between basins are typically localized along basin boundaries. However, inter-basin transfer from one trunk conduit to another may occur locally during overflow (high water) conditions. Near the basin discharge zone, divergent distributaries are common and are usually overflow networks (Ray, 1997). Perennial-flow distributaries are less common. Brown and Lambert (1963) and White and Schmidt (1966) have noted that karst drainage does deviate from surface drainage, sometimes passing beneath dividing ridges. Tracer tests across Kentucky have shown that karst drainage can also flow underneath streams.

Ray (2001) describes three major karst drainage basin types. Type 1 is the overflow allogenic karst basin, which contains losing streams that maintain surface overflow channels across the groundwater basin. Type 2 is the underflow allogenic karst basin that develops when sinking streams form blind valleys, all flow sinks into subsurface conduits and surface overflow is largely discontinued. Type 3 is the local autogenic karst basin that lacks sinking streams and is recharged primarily by infiltration through the land surface and sinkholes.

**Beargrass Creek Watershed**

The Beargrass Creek watershed is located in west-central Jefferson County, Kentucky and covers an area of 157 $km^2$. The highest elevation of 229 m above mean sea level (AMSL) occurs on the northeastern tip of the watershed boundary. The elevation of the creek's confluence with the Ohio River is approximately 131 m AMSL. The watershed is in the Outer Bluegrass Physiographic Region (Lobeck, 1930). This area is underlain by limestone, dolostone and shale of Ordovician, Silurian, Devonian and Mississippian ages. The majority of the Outer Bluegrass Region has only moderate to minor karst development. However, rock units within the Beargrass Creek watershed are very soluble and have well developed karst drainage. The creek has three main tributaries: Muddy Fork, Middle Fork and South Fork. The Muddy Fork is the northernmost tributary and rises in the Windy Hills area, northeast of St. Matthews. It flows generally westward to the confluence with the main stem of the creek, which is just east of the intersection of Interstates 64 and 71. The Middle Fork rises just west of Anchorage and flows westward to its confluence with the South Fork, just north of Cave Hill Cemetery. Weicher Creek is a minor tributary of the Middle Fork, originating near Hurstbourne Acres and flowing west to the confluence near the interchange of Interstates 64 and 264. The South Fork rises to the south of Hurstbourne Acres and flows west and northwest to the confluence with the Middle Fork. Other minor, unnamed tributaries are shown on the USGS topographic maps. Beargrass Creek discharges to the Ohio River just upstream of the Municipal Harbor and Towhead Island.

In the Beargrass Creek watershed 30 springs were monitored for groundwater tracing, water quality or both. Table 2 is a list of these springs with basic information and data collected for this study.

| AKGWA | Spring Name | Tracer Data | Water Quality Data | Latitude | Longitude | Elev. (m) | Base Flow (L/s) |
|---|---|---|---|---|---|---|---|
| 90001024 | Brown Cem. Culvert Spring | • | | 38.23583 | -85.63611 | 153 | 3 |
| 90001025 | Weicher Creek Diversion Spring | • | | 38.23556 | -85.63556 | 154 | 3 |
| 90001131 | Zehnderhouse Spring | • | | 38.21615 | -85.58923 | 195 | 0.1 |
| 90001138 | Farmington Spring | | • | 38.21472 | -85.66917 | 148 | 1 |
| 90001224 | Eleven Jones Spring | | • | 38.22266 | -85.72471 | 142 | 3 |
| 90001842 | A Sturgus Station Spring | • | • | 38.24556 | -85.61639 | 159 | **37*** |
| 90001887 | Breckinridge Spring | | • | 38.23 | -85.67028 | 158 | 3 |
| 90001889 | Windy Hills Springs | • | | 38.27319 | -85.63812 | 168 | 1 |
| 90002175 | Spring Station Spring | | • | 38.24611 | -85.67139 | 156 | 4 |
| 90002537 | Low Dutch Station Spring | • | | 38.23667 | -85.63469 | 153 | 1 |
| 90002934 | Oxmoor Spring | • | | 38.23961 | -85.60833 | 166 | 2.8 |
| 90002935 | Nunnlea Spring | • | • | 38.21867 | -85.58547 | 200 | 0.5 |
| 90002940 | Upper Oxmoor Spring | • | | 38.24164 | -85.60589 | 166 | 1.4 |
| 90002943 | Bowling Blvd Spring | • | • | 38.24581 | -85.62847 | 156 | 0** |
| 90002944 | Beargrass Creek Preserve Park Spring | | • | 38.24219 | -85.62958 | 156 | 3 |
| 90002945 | CSO 206 Spring | • | • | 38.23786 | -85.69389 | 136 | 4 |
| 90002947 | Confluence Spring | • | | 38.18831 | -85.64181 | 151 | 3 |
| 90002948 | Collins Spring | | • | 38.18764 | -85.64194 | 151 | 3 |
| 90002955 | Floyds Station Spring | | • | 38.23842 | -85.64653 | 162 | 1.5 |
| 90003355 | Buechel Spring | • | • | 38.1885 | -85.65575 | 146 | **7.6*** |
| 90003357 | A.B. Sawyer Gate Spring | • | • | 38.26179 | -85.58298 | 186 | 4 |
| 90003358 | Culvert Spring @ Genfab | • | | 38.15386 | -85.64984 | 146 | 14 |
| 90003363 | Mockingbird Valley Spring | • | • | 38.26941 | -85.68191 | 139 | 3 |
| 90003364 | Barret Spring | | • | 38.24886 | -85.69706 | 137 | 3 |
| 90003366 | Ray Spring | • | | 38.21203 | -85.62389 | 162 | 4 |
| 90003367 | Cypress Pointe Spring 1 | • | • | 38.24254 | -85.63194 | 156 | **5.1*** |
| 90003368 | Steinrock Spring | • | • | 38.25683 | -85.589916 | 178 | 0.25 |
| 90003753 | Culvert Spring @ Watterson | • | | 38.2438 | -85.62099 | 157 | *trickle* |
| 90003758 | Hole 10 Spring | • | | 38.22865 | -85.602017 | 181 | - - |

**Table 2. Sites Monitored in Beargrass Creek Watershed. * Actual base flow measurements. ** Spring ceases discharge in base flow conditions. All other base flow values are estimates. - - Hole 10 Spring is submerged and no flow estimates could be made.**

## Hydrogeologic Setting

Major geologic units and their influence on groundwater are described below in descending stratigraphic order. Units described on the USGS geological maps, but that occur only in minor outcrops are not discussed. These include the New Providence Shale (Mississippian), Waldron Shale (Silurian), Laurel Dolomite (Silurian) and Artificial Fill. The geologic unit descriptions below are all taken from Kepferle (1974a and 1974b). Figure 2 illustrates geology within the Beargrass Creek watershed, along with springs monitored for tracer tests and water quality.

### *Quaternary Deposits*

Five unique Quaternary Deposits are noted within the Beargrass Creek watershed. Alluvium is found in the middle and lower reaches of each fork and along the Ohio River. Ohio River Alluvium is an especially important aquifer and is utilized for a wide variety of water sources, including public drinking water. However, groundwater resources in this aquifer were not part of this study. Lacustrine deposits are found in the lower sections of each fork. Glacial outwash is shown along and south of the Ohio River on the western margin of the watershed. Loess and eolian sand is mapped as a single unit near the west end of the watershed as a band extending from the southwest to northeast, pinching out toward the northern extent. Terrace deposits occur in one isolated area near the southernmost point of the watershed, around Standiford Field. All of these units are described as various combinations of gravel, sand, silt and clay (Kepferle, 1974a and 1974b). In Figure 2 these Quaternary Deposits are shown as Undifferentiated.

*New Albany Shale*

The New Albany Shale is Devonian-aged and has one major outcrop in the north-central portion of the watershed and a minor outcrop in the south-central portion. Kepferle (1974b) describes the unit as a silty, carbonaceous shale that is olive to grayish-black in color. Weathered surfaces are yellowish brown to light gray and are thin and brittle. The areal extent of these outcrops is small and total thickness is on the order of 25 meters. Although shale would normally impede groundwater circulation, numerous sinkholes have been mapped and observed in areas where this unit is thin.

*Sellersburg and Jeffersonville Limestones*

The Devonian-aged Sellersburg and Jeffersonville Limestones are mapped as a single unit on the USGS geologic maps of this area. This unit underlies the majority of the Beargrass Creek watershed and numerous springs have been found discharging from these rock layers. These units are described as limestone and dolomitic limestone that are generally olive to gray in color and fossiliferous. Minor silts and shales are noted, as well as chert beds. Bedding is typically thin to very thin with occasional cross-bedding. Unit thickness varies from roughly 3 to 15 m (Kepferle, 1974a). These rock units are highly soluble and tend to form conduits along fractures and bedding planes.

*Louisville Limestone*

The Louisville Limestone is Silurian-aged and outcrops along the eastern watershed boundary and in valley bottoms in the lower part of the watershed. The rock unit is dolomitic, very fine grained and occurs in thin to thick beds. A shaly zone is reported near the top of the unit and cast fossils are common. Total unit thickness is on the order of 30 m. This unit is also highly soluble with numerous springs discharging from the upper portion, especially in valley bottoms located in the lower part of the watershed. Extensive underground quarrying of the Louisville Limestone has occurred on the eastern side of the city (Kepferle, 1974a). This site can now be explored as a tourist attraction.

*Geologic Structure*

No surface faults are mapped in the Beargrass Creek watershed. The most prominent geologic structures are in the form of a subtle, regional fold system. The Springdale Anticline, which plunges southwest, covers the northwestern half of the watershed. This feature transitions into the Lyndon Syncline, which is roughly sub-parallel and plunges to the southwest across the southeastern portion of the watershed (Kepferle, 1974a). Based on tracer tests conducted for this study these geologic features do not appear to have a regional influence on groundwater flow.

*Local Karst Hydrogeology*

The Sellersburg, Jeffersonville and Louisville limestones all have very high potential for karst development. This is evident based on the numerous springs and sinkholes throughout the watershed. High recharge porosity is shown by large cover-collapse sinkholes and losing stream swallets. Tracer tests have revealed rapid groundwater velocities, indicative of conduit flow.

## Land Use

Land use analysis within the study area is based on the 2001 National Land Cover Dataset for Kentucky. This dataset reports 14 unique land cover categories for the state. In this study, several of these related categories have been consolidated for simplicity and because their influences on groundwater should be similar. For instance, all intensity levels of developed areas (Low, Medium and High) are considered as one category: Urban/Residential. This category also includes commercial and industrial areas. Similarly, all forest types (deciduous, evergreen and mixed) and wetlands are treated as one land cover category. The predominant land cover in the Beargrass Creek watershed is Urban/Residential, as seen below in table 3. Since the geochemical character of the karst aquifer-forming rock units is similar, land cover type should have the strongest influence on differences in groundwater quality seen in study area springs.

| Land Cover | Percent of basin area | Potential Contaminants |
|---|---|---|
| Agriculture, including row crop production and livestock grazing | 3 | Pesticides, nutrients (esp. nitrate-N), salts/chloride, volatile organics, pathogens, sediment |
| Urban/Residential, commercial and industrial | 73 | Pesticides, volatile organics (BTEX and MTBE), chlorides, pathogens, nutrients |
| Forest and wetlands | 24 | Metals, pesticides, nutrients, sediment, pH |

**Table 3. Land Cover in Beargrass Creek Watershed**

Related to land cover, another strong influence on groundwater quantity and quality in the watershed is impervious cover. This area roughly coincides with Urban/Residential cover and occupies nearly the same percentage of the land surface. Impervious cover impedes water infiltration and causes increased surface runoff, effectively decreasing groundwater recharge areas. The runoff may gather pollutants as it flows down-gradient, eventually reaching a surface stream. Tracer testing has identified several losing reaches of streams that would allow for direct insurgence of polluted runoff with no filtration before entering the karst groundwater system. Excessive impervious cover can have detrimental effects on groundwater quantity and quality.

## Groundwater Use

Current groundwater usage is very limited within this watershed. There are only two permitted groundwater withdrawals within the Beargrass Creek watershed and both are for industrial purposes. Due to widespread urbanization and drinking water infrastructure there are no known domestic well or spring users in the study area. Additionally, some residents have reported that a local government ordinance prohibits the drilling of water-supply wells for any domestic purpose. However, anecdotal information from local residents indicates that there are a few domestic drinking water wells in use throughout the watershed. To date the authors have not been able to find official information on such an ordinance.

Historically, groundwater use was widespread, and this is still evident based on the numerous stone spring houses and spring boxes around the city of Louisville. Some of these can be seen along major transportation corridors while others are tucked away in neighborhoods. Many have been refurbished or preserved and protected.

**Sinking Creek Watershed**

The Sinking Creek watershed is located mainly in Breckinridge County, Kentucky with its headwaters extending slightly into western Meade and northern Hardin counties. The creek rises on the southern fringes of Breckinridge County and flows west-northwest to its confluence with the Ohio River. Numerous short-segment sinking streams occur on the eastern fringe of the watershed and have been shown through tracer tests to drain mainly to springs in the lower part of the watershed. However, some of these sinking streams have been traced to springs in adjacent watersheds. The watershed covers 620 $km^2$, all of which is within the Mississippian Plateau Physiographic Region, on the eastern edge of the Western Coal Field (Lobeck, 1930). The watershed is primarily underlain by Mississippian-aged limestone with minor sandstone units. Well-developed karst drainage is prevalent throughout the watershed. The highest elevation of 300 m AMSL occurs on the eastern divide at Bee Knob Hill, near Flaherty, Kentucky in Meade County. The elevation at the mouth of Sinking Creek, where it meets the Ohio River, is 117 m AMSL.

Main tributaries to Sinking Creek include Sugar Tree Run on the north side and Shot Pouch Creek, Hardins Creek and Dorridge Creek flowing from the south. All of these tributaries are located in the lower portion of the watershed. Tributaries in the upper portion of the watershed are typically short, unnamed sinking streams, many of which have been dye traced (Ray and others, 2009).

Sixteen springs (table 4) in this watershed were monitored water quality, dye tracing or both.

| AKGWA | Spring Name | Tracer Data | Water Quality Data | Latitude | Longitude | Elev. (m) | Base Flow (L/s) |
|---|---|---|---|---|---|---|---|
| 90000856 | Hardin Springs | • | • | 37.85278 | -86.40444 | 122 | **48*** |
| 90000858 | Parks Spring | • | • | 37.88778 | -86.35333 | 142 | 8.5 |
| 90001027 | Fiddle Spring | • | | 37.81306 | -86.29194 | 162 | **26.1*** |
| 90001859 | Burtons Hole Spring | • | • | 37.89889 | -86.46111 | 117 | **42*** |
| 90002961 | Cutoff Spring | • | • | 37.8125 | -86.48614 | 140 | **6.8*** |
| 90002962 | O'Reilly Spring | • | • | 37.83487 | -86.42585 | 210 | 1.1 |
| 90002963 | Jarboe Spring | | • | 37.82994 | -86.48497 | 183 | 0.6 |
| 90003360 | Shot Pouch Spring | • | | 37.88225 | -86.48331 | 117 | **6.5*** |
| 90003361 | Finley Spring | | • | 37.80925 | -86.48036 | 186 | 1.3 |
| 90003362 | Adkins Spring | | • | 37.90094 | -86.47419 | 117 | 4 |
| 90003372 | Blackburn Spring | | • | 37.79078 | -86.38581 | 213 | 0.1 |
| 90003374 | Fentress Spring | | • | 37.79955 | -86.43062 | 210 | 0.1 |
| 90003554 | Bluehead Spring | • | | 37.76917 | -86.25306 | 171 | 10 |
| 90003555 | Dowell Spring | • | | 37.83799 | -86.42093 | 216 | 0.6 |
| 90003561 | Dowell Spring #2 | • | | 37.83783 | -86.42008 | 216 | 0.85 |
| 90003563 | Thornhill Spring | • | | 37.8354 | -86.43798 | 207 | 0.3 |

**Table 4. Sites Monitored in Sinking Creek Watershed. * Actual base flow measurement. All other base flow values are estimates.**

## Hydrogeologic Setting

The study area is located in the southeastern corner of the Eastern Interior Basin (or Illinois Basin) (Sable and Devers, 1990). Major geologic units and their influence on groundwater are described below in descending stratigraphic order. Various member groupings occur in the literature for rock formations in the study area. The discussion below represents a simplified stratigraphic series and detailed information is not given for all formations and members. With the exception of *Quaternary Deposits*, all other geologic units discussed are Mississippian-aged and part of either the Chesterian or Meramecian series. Figure 3 illustrates geologic units within the Sinking Creek watershed, along with springs monitored for tracer tests and water quality.

### *Quaternary Deposits*

Four unique Quaternary units are described in the various geologic maps of the watershed: Alluvium, Younger Alluvium, Older Alluvium and Lacustrine & Terrace Deposits. Alluvium is found in most of the valley bottoms throughout the watershed. Younger Alluvium, Older Alluvium and Lacustrine & Terrace Deposits are mapped only in the valleys adjacent to the Ohio River. All of these are characterized by varying amounts of silt, sand, gravel and clay with fluvial and colluvial origins

(Crittenden and Hose, 1965 and Hose, Sable and Hedlund, 1963). These units are illustrated as undifferentiated Quaternary deposits in Figure 3. Groundwater resources from alluvial aquifers were not assessed for this study.

*Leitchfield Formation and Glen Dean Limestone*

Several individual members compose the Leitchfield Formation and most of the USGS geologic maps refer to it as the Buffalo Wallow Formation and Tar Springs Sandstone. The unit is predominantly shale with significant sandstone bodies and minor limestones (Crittenden and Hose, 1965). The underlying Glen Dean Limestone is predominantly limestone with minor amounts of shale. Both of these units occur along ridge tops on the western and northwestern watershed divides. Although not typically mapped as a single unit, these two are illustrated as such for simplicity and because their occurrences are minor. None of the study area springs occur in these rocks.

*Hardinsburg Sandstone*

The Hardinsburg Sandstone is described as an argillaceous sandstone and shale (Hose and others, 1963). It occurs on slopes along the western and northwestern watershed divides and caps ridge tops in the southwestern portion of the watershed. This unit does not contain any study area springs.

*Haney Limestone*

Amos (1976a) describes this unit as having thin-bedded shale and siltstone in the upper portion that inter-tongues with the underlying limestone. He further characterizes the limestone as light to medium gray, with minor shale partings and very fossiliferous. Numerous, small springs have developed in the Haney Limestone where it outcrops in the western portion of the watershed. These springs tend to discharge from the base of the unit, near the contact with the underlying Big Clifty Sandstone, which has relatively low permeability and inhibits deeper groundwater circulation (Quinlan and others, 1983). The Haney Limestone is relatively pure and highly soluble. Karst is well developed within this unit, though the springs and solution channels are relatively small compared with other karst-forming carbonates in the Mississippian Plateau. However, Three Springs, located near Mammoth Cave, discharges from the

Haney Limestone and has peak flows on the order 85 L/s (Brown, 1966). Several study area springs discharge from this rock unit.

*Big Clifty Sandstone*

Hose and others (1963) describe this unit as sandstone and shale. The sandstone is fine grained and sometimes silty. The shale is mainly light gray and contains minor coal streaks. Amos (1976a) describes this unit as predominantly sandstone with interbedded shale and siltstone in the upper and lower portions. The Big Clifty typically occurs on low ridges and hillsides, mainly in the western portion of the watershed. None of the study area springs discharge from this unit.

*Girkin Formation*

The Girkin Formation is made up of several alternating members of limestone, sandstone, shale and siltstone (Amos, 1976a). These members occur in valley bottoms in the western part of the watershed and are exposed in the broad plain in the eastern part of the watershed, sometimes as isolated knobs atop the underlying Ste. Genevieve Limestone. Only one study area spring discharges from the Girkin Formation and occurs near the top of the formation, most likely in the Beech Creek Limestone Member. The Beech Creek is described as medium to light-gray and fine to medium-grained. In some areas it is mapped along with the underlying Elwren Sandstone as a single unit (Crittenden and Hose, 1965).

*Ste. Genevieve Limestone*

A few of the springs investigated in this study formed within the Ste. Genevieve Limestone. The Ste. Genevieve is described as thick-bedded, light-colored, medium- to coarse-grained, oolitic and bioclastic calcarenite; and light-colored to gray, bioclastic calcirudite; gray calcilutite; and gray, very finely crystalline dolomite. Minor amounts of chert occur as nodules, thin beds and stringers, and siliceous replacements of fossiliferous beds (Sable & Dever, 1990). The Lost River Chert is a distinctive 1-3 m thick zone of nearly continuous chert that occurs at, or near, the base of the Ste. Genevieve Limestone. This chert is highly fossiliferous with fenestrate bryozoans, brachiopods, and gastropods (Amos, 1976a). It is nearly indistinguishable from surrounding light gray limestone when freshly exposed, but when weathered reveals characteristic porous blocks of chalky white chert stained with red soil. Because of its resistance to corrosion, this chert bed is suspected to perch water bodies such as the Waterworks Spring Basin, near Bowling Green, Kentucky (Moody and others, 2000). It also decreases sinkhole density where it underlies the surface, such as the Bristow Plain east of Bowling Green (Quinlan & Ewers, 1981). This unit occurs as a broad plain in the eastern portion of the watershed and is exposed in valley bottoms where creeks have incised the overlying rocks.

*St. Louis Limestone*

St. Louis Limestone consists of a very fine-grained, micritic, cherty, argillaceous, and dolomitic limestone. It is characteristically gray to dark gray, fossiliferous, and thick bedded to massive (Sable & Dever, 1990). The upper part of the St. Louis Limestone is highly cherty, which helps to locally perch groundwater. None of the study area springs occur in this unit and it has only minor outcrops in the eastern-most portion of the watershed.

*Geologic Structure*

The northern extent of a major limb of the Rough Creek Fault System is mapped in the eastern half of the watershed. Local names include the Cave Spring Fault and Locust Hill Fault. Rocks generally dip gently to the west at approximately 3m/km (Amos, 1976b). Faulting seems to have some influence on regional groundwater flow in the watershed, as several tracer tests are inferred to run sub-parallel to the fault trend. Bedrock dip seems to have some influence as well, in that tracer tests generally follow either the strike or dip direction. No attempts were made as part of this study at in-depth analysis or correlation between groundwater flow directions and geologic structures.

*Local Karst Hydrology*

The Ste. Genevieve and Haney limestones are the major karst-forming units within the study area. As noted in the discussion above, the Ste. Genevieve is widely known for extensive and intense karst development. Although the Haney Limestone is readily soluble, karst development tends to be limited by the unit's areal extent and capping by the overlying Hardinsburg Sandstone.

## Land Use

Land use analysis in the Sinking Creek watershed is based on the same data source and criteria as those previously described for Beargrass Creek. Again, the geochemical character of the karst aquifer-forming rock units is similar, thus, land cover type should have the strongest influence on differences in groundwater quality seen in study area springs. The predominant land cover in Sinking Creek watershed is forest and wetlands (table 5).

| Land Cover | Percent of basin area | Potential Contaminants |
|---|---|---|
| Agriculture, including row crop production and livestock grazing | 36 | Pesticides, nutrients (esp. nitrate-N), salts/chloride, volatile organics, pathogens, sediment |
| Urban/Residential, commercial and industrial | 4 | Pesticides, volatile organics (BTEX and MTBE), chlorides, pathogens, nutrients |
| Forest and wetlands | 60 | Metals, pesticides, nutrients, sediment, pH |

**Table 5. Land Cover in Sinking Creek Watershed**

## Groundwater Use

Of the sixteen springs monitored for this study, only six are currently used. Two of them serve as livestock water supplies and four are utilized as domestic drinking water sources. There are no DOW-permitted groundwater withdrawals in the watershed. However, groundwater withdrawals for crop irrigation do not require permitting and may occur without reporting. There are a total of 577 water wells registered in the DOW Groundwater Database within the watershed. Of these, 511 wells are reported as being used for private, domestic water supplies. Another 30 are reportedly used for livestock watering and three are shown as industrial supplies. Historically, as many as 12 wells were listed as being used for public water supplies, most notably several wells owned by the City of Irvington. However, it appears that there are currently no wells in the study area being used for public water supplies. There are 19 water wells in the watershed for which no type of usage is indicated. The three remaining wells are part of a domestic, open-loop geothermal system. There are no Wellhead Protection Areas within the watershed.

## MATERIALS and METHODS

### Introduction

This study represents an updated approach for assessing groundwater resources in the karst regions of Kentucky. Historical Nonpoint Source (NPS) groundwater assessments conducted by the DOW generally took one of two forms: 1) Thirty monitoring sites (wells and springs) spread throughout a major river basin, sampled quarterly over the course of one year, or 2) Fewer monitoring sites in a sub-watershed sampled 6 to 8 times over the course of one year in hopes of creating a more statistically valid dataset. Samples were analyzed for a broad range of parameters, including bulk parameters, major inorganic ions, nutrients, metals, pesticides, volatile organic compounds and occasionally bacteria. Both of these approaches served to increase knowledge of ambient groundwater conditions and impacts from NPS pollution. However, due to aspects such as sampling frequency and parameters analyzed, the data were not directly comparable to surface water data in the same watersheds.

As previously noted, groundwater and surface water are interconnected systems. These connections are especially pronounced in regions of well-developed karst drainage. Thus, a new approach for groundwater assessment in karst areas was desired. This project was intended to address discrepancies between surface water and groundwater data sets by integrating surface water assessment protocols into a groundwater study.

Groundwater quality sample results were compared with the Surface Water Standards found in 401 KAR 10:031 for Warm-water Aquatic Habitat and Primary Contact Recreation (LRC, 2011). The parameters assessed are shown in Table 1, which is a simplified checklist created for this project. Ten analytes are listed as “NO DATA” in the *Impairment Level* column. These analytes were not requested for analysis due to an oversight. However, their omission did not preclude evaluation. Physicochemical samples were not collected in a manner that would allow for the inclusion of monitored springs in the *Integrated Report to Congress*, which is used for 305(b) Assessments and 303(d) listing as impaired waters. Bacteria samples were collected monthly from each spring in the Beargrass Creek watershed during the months of April through October 2007. Springs in the Sinking Creek watershed were not assessed for bacteria due to holding time limitations.

## Sample Collection Methods

Consistent with the DOW's other ambient groundwater monitoring efforts, samples of fresh, untreated groundwater were collected at each spring 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 DOW's Kentucky Ambient/Watershed Water Quality Monitoring Standard Operating Procedure Manual, prepared by the Water Quality Branch (2002). Parameters to be measured, volume required for analysis, container type and preservative are shown on the attached Chain-of-Custody Form (Appendix IV).

Major inorganic ions and bulk parameters are used to establish background groundwater chemistry and to measure impacts from nonpoint pollution sources such as abandoned mine lands and abandoned hydrocarbon production operations. Nutrients and total organic carbon are used to measure impacts from agricultural operations (ammonia-N, nitrate-N, nitrite-N, total phosphorous and orthophosphate) and/or improper sewage disposal (nitrates, ammonia). 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.

Pathogen samples were collected and preserved in accordance with the procedures outlined by the Beckmar Laboratory in Louisville, Kentucky. These samples were analyzed for Total Coliform and *E. coli* bacteria. Bacteria determine impacts from agricultural operations and failing septic and sewer systems. Bacteria sources could not be differentiated based on the analyses conducted. Parameters to be measured, volume required for analysis, container type and preservative are shown on the attached Chain-of-Custody Form (Appendix IV).

All samples collected to meet grant commitments were analyzed by the Environmental Services Branch (ESB) and Beckmar Laboratories according to appropriate U.S.EPA methods.

### Graphical Methods

Maps created to display assessment results utilize color-coded points, based on each spring's apparent or estimated use support level, overlain on a simplified land use map with political boundaries, major surface streams and applicable karst groundwater basin boundaries.

Maps showing tracer tests results conform to the standards used in the Kentucky Karst Atlas map series published by the KGS with the DOW. This dye-trace map legend can be found in Figure 4. However, inferred groundwater flow routes derived from traces conducted prior to this study are uniquely identified so they can be distinguished from the current investigations. Tracer data and stream coverage are displayed in color overlain on black and white 7.5-minute topographic quadrangles. All maps were created with ArcGIS 10 software using data obtained from the Kentucky Geography Network, DOW and data files created by the authors specifically for this project.

## Site Selection

The Groundwater Section selected sites based on numerous criteria. Preference was given to springs that had not been previously assessed for water quality parameters. Springs were selected for monitoring using base-flow discharge measurements and estimates to insure that only those with perennial groundwater flow were utilized.

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 landowner permission to access the site.

A unique eight-digit identification number catalogs springs maintained in the DEP's database. All springs used in this study had been previously identified and inventoried. The spring inventory form notes details of the site, including owner's name and address, location, spring development, yield and topographic map location. The data are then entered into DEP's electronic database and forwarded to the Groundwater Data Repository at the KGS. The spring forms are scanned and stored in a database as an indexed electronic image.

**Tracer Test Methods**

Qualitative groundwater tracer tests, as described by Quinlan (1986) and Aley (2002), were conducted using four non-toxic fluorescent dyes. The names of dyes used in this study are shown in bold, below in table 4:

| Dyes Used | Trade Name | Color Index | Number of Injections |
|---|---|---|---|
| **SRB** (Sulforhodamine B) | Ricoamide Red XB | Acid Red 52 | 18 |
| **Eosine** | 15189 Eosine OJ | Acid Red 87 | 26 |
| **Uranine** (Fluorescein) | Uranine Conc (Disodium Fluorescein) | Acid Yellow 73 | 4 |
| **RWT** (Rhodamine WT) | Keyacid Rhodamine WT | Acid Red 388 | 3 |

**Table 6. Fluorescent Tracer Dyes Used and Number of Injections for each**

These fluorescent dyes are optimal for use in groundwater basin delineation because of non-toxicity, availability, analytical detectability, moderate cost, and ease of use (Schindel and others, 1994; Field and others, 1995). The quantity of fluorescent dye used for these tests was determined empirically over several years of field experience. Prior to fieldwork, powdered dye was dissolved in water at a concentration of approximately 60 g per L. For uranine and eosine, this liquid-dye mixture was injected into active stream swallet sites at a rate of about 1 L per km (equivalent to 60 g of powdered dye per km) of expected flow distance. Depending on conditions, up to twice as much SRB and RWT dye was used for equivalent flow distances. Greater quantities of dye were used at dry sinkhole sites flushed with hauled water or during high-flow conditions.

Activated carbon samplers adsorbed and accumulated the fluorescent dyes as they flowed through monitored sites. In some cases, when the dye receptor was missing, dye presence was determined by analysis of water samples. The carbon dye receptors were deployed in flowing water in springs, streams, and caves by use of a modified "gumdrop" anchor (Quinlan, 1986), or a brick fitted with a vinyl-clad copper wire and commercially available trot line clip for securing the receptors (Figure 5).

Background dye receptors were usually deployed, exchanged, and analyzed prior to dye injection in the study area. These background dye receptors served as controls for comparison with subsequently recovered receptors. In a few cases prior background assessment was omitted in order to take advantage of unusual or emergent field opportunities to inject dye. In those cases, background water samples were carefully collected on the same day as the expedited dye injection. Dye receptors were typically exchanged weekly.

For analytical processing, samples of the retrieved carbon dye receptors were rinsed with tap water and eluted at room temperature for at least 15 minutes in a solution of 50% 1-propanol, 30% de-ionized water, and 20% ammonium hydroxide ($NH_4OH$) (Smart Solution). The eluted samples were processed at the DOW's Groundwater Laboratory and analyzed for absence or presence and relative intensity of dye present using a scanning spectrofluorophotometer. The DOW's Shimadzu RF-5301 PC instrument was purchased in 1998 and a computer sequence for analyzing dye samples was programmed by Peter Edstein, then PhD candidate at Eastern Kentucky University. All results of dye analyses are archived electronically. Figure 6 shows typical dye curves analyzed on the spectrofluorophotometer. The horizontal position of a dye peak indicates the fluorescence wavelength, which identifies the type of dye. The vertical height of the curve indicates the relative fluorescence intensity of the recovered dye and thus the qualitative confidence level of the positive dye recovery.

Positive dye recovery was determined when fluorescence intensity exceeded background by four times (4X), although fluorescence of positives typically exceeded background by more than 10X. Dye trace results were recorded on DOW Dye-Trace Record Forms. These documents include dye injection site information and a detailed record of each dye receptor recovered during the study and are available upon request.

## Documentation of Tracer Tests

During this project, 51 reconnaissance groundwater tracer tests were conducted for the purpose of basin delineation and verification or modification of HUC boundaries. The results of these investigations are discussed individually for each basin, and are listed under abbreviated dye trace ID numbers such as 04-07 (Year-sequence of dye injection; the second author, now retired, was the principal investigator for all tests). Analyzed dye intensity level from recovered dye receptors is indicated by the following symbols, which represent the qualitative confidence level of a dye recovery and hydrologic connection:

| | |
|---|---|
| – | Negative result |
| ? | Inconclusive (< 4X background) |
| + | Positive (> 4X background; < 1000 intensity units) |
| ++ | Very Positive (1000-10,000 intensity units) |
| +++ | Extremely Positive (> 10,000 intensity units) |

An inconclusive result indicates that dye was apparently recovered at less than the standard criterion of 4X the background level. Two or more successive dye detections at less than the criterion of 4X the background level may be judged to be a positive recovery in certain situations. The desire to use minimal quantities of tracer dye sometimes resulted in lower than desired levels of dye detection. In some cases water samples were assessed to compare with activated carbon samples or when a dye receptor was missing at the monitoring site.

New tracer data for a total of 34 springs, in both study area watersheds, are described below. A map of each karst watershed shows the final results of flow path interpretation and delineation – where completed – of the approximate basin boundary. Diagrams are presented on US Geological Survey 7.5-minute quadrangle base maps. Inferred groundwater flow routes are illustrated as minimum straight line to curvilinear distances, which are less than actual conduit pathways. Some basin boundary segments are delineated based on topographic divides where tracer data are lacking. The dashed boundary line indicates the imprecise nature of karst groundwater divides. Groundwater recharge about 300 m on either side of a mapped divide should be assumed to potentially drain to both neighboring basins.

## RESULTS and DISCUSSION

All chemical and biological data assessed were collected by DOW. This study includes 120 physicochemical samples collected from 26 sites. The physicochemical data were augmented with samples collected for the Ambient Groundwater Monitoring Network. This yields a total of 145 physicochemical samples from 27 sites that were used to assess groundwater quality in the Beargrass and Sinking creeks' watersheds. In the Beargrass Creek watershed, 139 *E. coli* samples were collected from 18 sites. These water quality data were compared with criteria set forth by the Kentucky Water Quality Regulations (401 KAR 10:031). As previously mentioned, some parameters were inadvertently omitted and physicochemical sampling frequency did not meet the requirements of the 305(b) Assessment or 303 (d) Listing criteria. Additionally, benthic macroinvertebrates were not assessed at any of the springs. Where applicable, surrogate indicators were used as much as possible. For instance, nutrient data were used to supplement absent dissolved oxygen data. In other instances, supplemental indicators were not available and these analytes could not be assessed. Ultimately, data were adequate to draw meaningful – though not absolute – conclusions relative to nonpoint source impacts on use support levels for Warm-water Aquatic Habitat (WAH) at all study springs and Primary Contact Recreation (PCR) at springs in the Beargrass Creek watershed.

**General Water Chemistry.** The two parameters that fall under this category are alkalinity (as $CaCO_3$) and pH. Bicarbonate is formed in surface water and groundwater when carbonic acid, formed through hydration of atmospheric $CO_2$, dissociates to $H^+$ and bicarbonate (Ford and Williams, 1989). This reaction allows for increased solubility of the carbonate minerals (i.e. calcite and dolomite) present in the karst aquifer, which provides another source of bicarbonate and increased alkalinity in the water discharging from springs. Conversely, runoff entering the karst aquifer through sinkholes and stream sinks would have relatively low alkalinity and provide dilution, temporarily decreasing alkalinity of the groundwater. The water quality standard (401 KAR 10:031) stipulates that alkalinity shall not be reduced by more than 25%, making it a relative standard according to typical water chemistry at individual sites. The relative acidity or alkalinity of water is reported as pH, which is "*the negative base-10 log of the hydrogen-ion activity in moles per liter*" (Hem, 1985). This is essentially the concentration of the hydronium ion, which is more easily expressed with logarithmic units than with the traditional milligrams per liter (mg/L) due to especially low concentrations. pH units are dimensionless and range from 0 to 14, with a pH of 7 being neutral. pH values below 7 are acidic and represent higher concentrations of hydronium ions, whereas values above 7 are alkaline and represent lower concentrations of hydronium ions. The pH of water can impact its overall quality with regards to corrosivity, ability to dissolve materials, taste and overall usefulness for industrial functions. The normal range of pH for aquatic systems is 6 to 9 (401 KAR 10:031).

**Inorganic Anion.** Chloride was the only inorganic anion assessed for this evaluation. Chloride ($Cl^-$) is the most common ionic form of the element chlorine, accounting for approximately 75% of all chlorine in the earth's crust, atmosphere and hydrosphere. Chloride occurs naturally in rocks and soil and thus, all natural waters contain chloride, though typically in small amounts (Hem, 1985). Chloride also occurs in sewage, industrial brines and in urban runoff from road salt application. Naturally-occurring chlorides associated with brines from oil production can contaminate aquifers if oil wells are improperly constructed or abandoned or if brines are not properly disposed, but this is not an issue in the study area. The standards in 401 KAR 10:031 for Acute and Chronic exposures are 1,200 mg/L and 600 mg/L, respectively.

**Metals.** The metals assessed for this study include arsenic, cadmium, copper, iron, lead, mercury, nickel, selenium, silver and zinc. Metals are common as trace constituents of soils and sedimentary rocks, including limestone, dolostone, coal and black shales (Dever, 2000; USGS, 2002b; Tuttle and others, 2001). In water, low pH values and higher dissolved oxygen content increase the dissolution of metals. Common anthropogenic nonpoint sources of metals include mining, urban runoff, industrial operations, land farming of sewage and other waste and emissions from coal-fired power plants. The provenance of high concentrations of metals in groundwater is sometimes difficult to interpret and may indicate point sources, nonpoint sources, or natural sources. The standards in 401 KAR 10:031 for cadmium, copper, lead, nickel, silver and zinc are based on calculations that utilize the hardness values for each sample collected and analyzed. Numeric standards are applied to arsenic, iron, mercury and selenium. Arsenic has an acute exposure limit of 0.34 mg/L and a chronic limit of 0.15 mg/L. For iron, the acute exposure is limited to 4 mg/L and chronic exposure to 1 mg/L. Acute mercury exposure is 1.7 mg/L and chronic exposure is 0.91 mg/L. The standards for selenium are 20 mg/L (Acute) and 5 mg/L (Chronic).

**Nutrients.** The nutrients assessed for this study include ammonia (as N), nitrate (as N), nitrite (as N), orthophosphate (as P) and total phosphorus. All of these nutrients occur naturally in the environment but also have anthropogenic sources. Excessive nutrient enrichment of surface water, or eutrophication, can lead to excessive plant growth. This is problematic because the explosion of plant growth and their eventual death and decay can reduce the amount of dissolved oxygen available to aquatic animal life (USGS, 2008).

Ammonia ($NH_3$) occurs naturally through the decay of organic matter, such as plants and animal waste. The main anthropogenic source of ammonia found in groundwater is from ammonia-based fertilizers. Nitrate ($NO_3$) occurs in the environment through various natural and man-made sources: decomposing organic matter, nitrogen-fixing plants, human and animal waste, nitrogen fertilizers and atmospheric deposition from combustion. In this report nitrate is reported as the equivalent molecular nitrogen (nitrate-N). Nitrite ($NO_2$) occurs naturally in the environment from many of the same sources as nitrate. However, nitrite is unstable and tends to quickly convert to nitrate through oxidation. Orthophosphate-P (ortho-P) is the final product of the dissociation of phosphoric acid ($H_3PO_4$). Ortho-P occurs naturally through organic decomposition and from phosphate minerals, such as apatite, found in phosphatic limestone. Anthropogenic sources of ortho-P include concentrated animal waste, detergents, some organic pesticides and fertilizers. Total phosphorus is the sum of organic and inorganic phosphorus and has sources similar to ortho-P (US EPA, 2006 & Webb and others, 2002).

The standards in 401 KAR 10:031 include an acute exposure limit for unionized ammonia only, which is based on a calculation utilizing the ammonia (as N), pH and field temperature of each sample. As previously discussed there are no standards for the other nutrients assessed and result values are compared to a relative scale derived from previous research in the Salt River Basin. Calculating median values from groundwater sites in the Salt River Basin used by Webb and others (2002), the resulting nutrient index values for groundwater are as follows: Nitrate (as N) < 2.03 mg/L; Nitrite (as N) < 0.009 mg/L; Ortho-P < 0.059 mg/L and Total Phosphorus < 0.025 mg/L.

**Pesticides.** This analyte group includes organic chemicals that fall under the subcategories of herbicides, insecticides and fungicides. The pesticides assessed for this study include Aldrin, alpha-Endosulfan, beta-Endosulfan, Chloropyrifos, Dieldrin, Endrin, gamma-BHC (Lindane), Heptachlor, Heptachlor epoxide, Malathion, Methoxychlor, Mirex, Pentachlorophenol, Toxaphene and 4,4'-DDT. Each of these has its own unique acute and/or chronic exposure limits in 401 KAR 10:031 (Table 1). Pesticides are not naturally-occurring chemicals. Therefore, their presence in groundwater would indicate some degree of contamination and potential nonpoint source impacts. As such, their presence – even when found below the applicable standards – is considered as a negative impact on groundwater quality.

**Polychlorinated Biphenyls (PCBs).** PCBs are organochlorine chemicals that were widely manufactured and used until being banned in 1979. While no longer produced, PCBs may still be present in various products made prior to 1979 and can be released through improper maintenance and disposal or leaks (US EPA, 2012). PCBs do not degrade easily and can be carried over long distances and remain in the environment for very long periods of time. The water quality standards in 401 KAR 10:031 stipulate a chronic exposure limit of 0.0014 µg/L (micrograms per liter) – or 0.0000014 mg/L – for total PCBs. Although PCBs were not detected in any of the samples analyzed for this study, the laboratory's Limit of Quantification was 0.11 µg/L, which is nearly 100 times higher than the chronic standard. Thus, the data are insufficient to evaluate this parameter.

**Residues.** Total dissolved solids (TDS) and total suspended solids (TSS) were the residues assessed for this study. The standard set forth for each in 401 KAR 10:031 merely states, "*No adverse effects on* *aquatic life*." Because aquatic organisms were not evaluated in these springs it is difficult to determine whether or not the concentrations detected are problematic.

TDS analysis measures the residue remaining from a water sample following filtration through a 1.5 µm (micron) filter and evaporation of the sample in an oven at 180º C. The residue represents the TDS (in mg/L) in the original sample (Todd Adams, ESB Lab, oral comm., 2008). TDS measurement may provide a general indication of water quality. However, because individual parameters are not identified, its usefulness for this purpose is limited.

TSS analysis measures the residue captured by a 1.5 µm filter after drying the filter to a constant weight in an oven at 103º C. The difference in filter weight between pre- and post-filtration represents the TSS (in mg/L) in the original sample (Todd Adams, DES Lab, oral comm., 2008). Runoff from industrial, agricultural or urban areas can suspend solids and carry them into groundwater systems via stream swallets and sinkholes. Elevated TSS can "*…reduce water clarity, degrade habitats, clog fish gills, decrease photosynthetic activity and cause an increase in water temperature*" (MMSD, 2002).

**Bacteria (*E. coli*).** *Escherichia coli* (*E. coli*) is a type of coliform bacterium present in the digestive tract of most warm-blooded animals and therefore is a good indicator of fecal contamination (US EPA, 2006). Fecal contamination of groundwater in a karst region can occur via livestock or pet excrement, or through the human waste infiltrating the subsurface from failing septic systems or leaking sewer lines. Due to the potential for rapid infiltration and high groundwater velocities in karst regions, contamination of this sort can be carried swiftly through the system with little or no natural attenuation. Most strains of *E. coli* are not harmful and merely serve as indicators of potential contamination, but some strains "*…produce a powerful toxin and can cause severe illness*" (US EPA, 2006). *E. coli* bacteria are measured in colony-forming units (CFU) per 100 mL of water. The standard in 401 KAR 10:031 states that if 20% or more of the sample results are over 240 CFU/100mL then the water is not safe for Primary Contact Recreation (PCR).

**Water Quality Results – Beargrass Creek**

*Warm-water Aquatic Habitat*

**General Water Chemistry.** Based on alkalinity (as $CaCO_3$), three springs appear to be impaired and five others seem to be partially impaired. However, since these waters are derived from a limestone aquifer (carbonate rock), it is not surprising to find high alkalinity and significant fluctuation in concentrations following runoff events. All samples fell within the standard range of pH 6 – 9.

**Inorganic Anion.** Chloride was detected in all spring samples throughout the study area. However, none of the detections exceeded either the acute or chronic standards.

**Metals.** Result concentrations for metals were generally low and in many cases were not detected at all. Additionally, no metals exceeded their respective acute standards. However, iron was found over the chronic standard of 1 mg/L in 5 samples at 2 different springs - Farmington Spring and AB Sawyer Spring. Although sufficient to consider these two springs partially impaired, its impact on the watershed appears minimal.

**Nutrients.** Nutrients are definitely the most problematic analyte group relative to groundwater quality at springs evaluated in this watershed. Calculations for unionized ammonia showed that all of these samples met the standard. However, data were insufficient to make a determination at two sites (CSO 206 Spring and Spring Station Spring). Nitrate (as N) was found over the comparative index value of 2.03 mg/L in 80% of the samples collected. In fact, the median value for all springs in the Beargrass Creek Watershed was 2.6 mg/L and the maximum value, measured at Farmington Spring, was 4.74 mg/L. Relative to Nitrite (as N), the comparative index value was below the Limit of Quantification for most samples. While this renders the dataset insufficient for a determination, this parameter was not detected in most of the analyses. Ortho-P values exceed the comparative index of 0.059 mg/L in 24% of samples collected and the median value of samples from this study was 0.06 mg/L. Total Phosphorus values were consistently high, with 96% of samples exceeding the comparative index value of 0.025 mg/L. The median value for this study was 0.06 mg/L (more than double the standard) and the maximum value, detected at CSO 206 Spring, was 0.47 mg/L.

**Pesticides.** None of the 15 pesticides evaluated for this assessment exceeded their respective chronic or acute standards. However, five of the pesticides were detected at low levels a total of 51 times in 14 of the study area springs – only Beargrass Preserve Park Spring, Barrett Spring and Steinrock Spring did not have pesticide detections. The most common detection was the termiticide Dieldren, which was detected 36 times at nine of the springs. This is concerning because Dieldren was banned in 1987 and it is unclear whether these detections are due to recent application or environmental persistence (TOXNET, 2012). The next most common was the fungicide Pentachlorophenol, which was detected eight times at seven different springs. The insecticide 4-4' DDT was detected three times at three springs – this is somewhat concerning in light of its strict regulation since the early 1970s (TOXNET, 2012). Heptachlor epoxide was found in three samples at two springs. This compound is a metabolite of Heptachlor, which is used as a termiticide and for fire control (TOXNET, 2012). The insecticide Chlorpyrifos was detected only once. The map in Figure 7 shows the occurrence of pesticide detections at springs in the Beargrass Creek Watershed.

**Polychlorinated Biphenyls (PCBs).** Although the laboratory's *Limit of Quantitation* (or *Quantification*) was above the chronic standard for total PCBs, analysis results did not show any detections. While this is insufficient for assessment, it would seem to indicate that PCBs are not a major contaminant of concern within the watershed.

**Residues.** Evaluation of dissolved and suspended solids is problematic due to the lack of biological indicator assessment. Eleven of the springs showed TDS values that were consistently below 500 mg/L, which is the Secondary Drinking Water Regulation (SDWR) standard used by the US EPA for treated drinking water supplies (US EPA, 2006). Six of the springs had TDS values that were consistently at or above 500 mg/L. This would seem to indicate that negative impacts from TDS are at least plausible. TSS values were generally low (less than 10 mg/L), but occasional spikes at or above 100 mg/L were reported. Similarly, these data seem to indicate that negative impacts from TSS are plausible.

*Primary Contact Recreation (PCR)*

**Bacteria (*E. coli*).** Only Breckinridge Spring met the criteria to be fully supporting for PCR based on *E. coli* results. The other 17 springs assessed were found to be impaired (Figure 8). The highest values were observed at CSO 206 Spring, with a maximum value reported as greater than 291,960 CFU/100 mL. However, many results from several springs were well over the standard of 240 CFU/100 mL.

**Water Quality Results – Sinking Creek**

*Warm-water Aquatic Habitat*

**General Water Chemistry.** Only one spring, Burtons Hole Spring, showed minor impacts due to alkalinity reduction of greater than 25%. The overall effect on the health of the watershed would be minimal. All samples were within the standard range of pH 6 – 9.

**Inorganic Anion.** Chloride was detected in all spring samples throughout the study area. However, none of the detections exceeded either the acute or chronic standards.

**Metals.** Result concentrations of metals were generally low and in many cases were not detected at all. Additionally, no metals exceeded their respective acute or chronic standards.

**Nutrients.** Nutrients are definitely the most problematic analyte group relative to groundwater quality at springs evaluated in this watershed. Calculations for unionized ammonia showed that all springs met the water quality standard. Nitrate (as N) was found over the comparative index value of 2.03 mg/L in 44% of the samples collected. However, the median value for all springs in the Sinking Creek Watershed was 1.5 mg/L. The maximum value was 6.27 mg/L, which occurred at Finley Spring. Relative to Nitrite (as N), the comparative index value was below the limit of quantification for most samples. Although this renders the dataset insufficient for a determination, most analytical results did not detect this parameter. Ortho-P values exceed the comparative index of 0.059 mg/L in 18% of samples collected and the median of samples from this study was 0.06 mg/L. Total Phosphorus values were generally high, with 47% of samples exceeding the comparative index value of 0.025 mg/L. The median value for springs in this watershed was 0.022 mg/L (just below the index value) and the maximum value of 0.77 mg/L occurred at Finley Spring.

**Pesticides.** None of the pesticides evaluated were found over their respective standards in any of the samples. However, there were six detections of three unique pesticides (Chlorpyrifos, gamma-BHC and Pentachlorophenol) at three of the 10 springs. Adkins Spring had single detections of Chlorpyrifos and gamma-BHC and two detections of Pentachlorophenol. Pentachlorophenol was also detected at Finley Spring and Burtons Hole Spring, though only once at each site.

**Polychlorinated Biphenyls (PCBs).** Although the laboratory's *Limit of Quantitation* (or *Quantification*) was above the chronic standard for total PCBs, analysis results did not show any detection. Although this is insufficient for absolute assessment, it does seem to indicate that PCBs are not a major contaminant of concern within the watershed.

**Residues.** Evaluation of dissolved and suspended solids is problematic due to the lack of biological indicator assessment. All of the springs but one showed TDS values that were consistently below 500 mg/L, which is the SDWR standard used by the US EPA for treated drinking water supplies (US EPA, 2006). Only one sample result from Hardin Springs showed TDS above 500 mg/L. This would seem to indicate that negative impacts from TDS are at least plausible, though not likely. TSS values were generally low (less than 5 mg/L), but occasional spikes of 25 mg/L or greater were reported. Similarly, these data seem to indicate that negative impacts from TSS are plausible, though not likely.

## Groundwater Tracing Investigations

Of the 51 groundwater tracer tests conducted, 37 were recovered in 34 springs, for a 72% success rate. Seven of the lost dye injections were later found to be due to groundwater infiltration of the sanitary sewer, which is discussed in depth below. Additionally, through replication and expanded monitoring, resurgence springs were verified for four more of the initially lost dye injections. Ultimately, only three of the dye injection points used in this study could not be traced to the spring(s) (or possibly sanitary sewers) where they discharge. This yields recovery of tracer tests from 34 of the 37 injection sites, for a site-based success rate of 92%.

A unique four-digit identification number is provided for each spring referenced in this study. This number is derived from the DOW's Consolidated Groundwater Database ID system. For example, Oxmoor Spring (ID # 9000-**2934**) is identified simply as Oxmoor (2934). Brief descriptions of the 29 basin discharge springs are given below with dye-trace data, basic measurements, and figures showing digital photographs and maps. Figure 4 is a legend for the tracer data illustrated on these basin maps, which conforms to the Kentucky Karst Atlas Map Series published by KGS. Non-recovered dye injections from sites that were ultimately successful are described under the appropriate spring heading or section. The dye injections that occurred at sites where recovery was never attained are described under a separate section. In the descriptions below, reference to an *unmapped spring* means the spring does not appear on published topographic or geologic maps.

**Previous Tracer Testing**

Prior to this study, limited groundwater tracer testing had been conducted within the Beargrass Creek watershed. The earliest known work was conduced by Angelo George (written communication, November, 2000), who traced a stream swallet of the Middle Fork Beargrass Creek, at the east side of the Lyndon Road bridge [N38.253810°/W85.600241°], to Sturges Spring House (sic) in June, 1971. This dye trace indicated that A'Sturgus Station Spring [N38.245422°/W85.616410°] is primarily the resurgence of a 1.7 km subterranean cutoff of the Middle Fork Beargrass Creek.

In October, 1998, Ogden Environmental, Inc., of Nashville, TN, traced a sinkhole in the Lyndon area [N38.259111°/W85.598571°] to A'Sturgus Station Spring, 2.21 km to the southwest, which Ogden called "Mall Spring".

Later in 1999 the DOW conducted additional dye tests in the vicinity in order to determine the discharge destination of two Class V drainage wells. On 5/4/99, SRB was injected into the Lyndon Fire Hall Class V [N38.259200°/W85.602018°], and flushed with 1900 L of water. This feature is a drainage pit excavated 4.5 m into cavernous bedrock behind the Lyndon Fire & Rescue Station at 8126 New LaGrange Road. The test was inconclusive due to dilution from a rainstorm and was replicated with a greater quantity of dye on 5/24/99 (99-29-JAR Rep). Within 45 hrs, A'Sturgus Station Spring, 1.98 km to the southwest, was very positive for SRB (++) indicating a flow velocity of >1.1 km/day.

On the same day eosine was flushed into Sheve Class V, a 0.3 m diameter vertical drain tile set about 1.5 m deep onto limestone bedrock [N38.257317°/W85.599958°]. Inflow capacity was determined to be just less than 1.25 L/s. This test was likewise inconclusive due to dilution from the rainstorm and was replicated with a greater quantity of dye on 5/24/99 (99-30-JAR Rep). Within 45 hrs, A'Sturgus Station Spring, 2.0 km to the southwest, was very positive for eosine (++) indicating a flow velocity of >1.1 km/day.

In addition to dye tests from the two Class V drainage wells, the stream swallet of the Middle Fork Beargrass Creek was tested with Uranine. In 1999, the much earlier dye test of this flow route by Angelo George was not known. Confirming the earlier test, A'Sturgus Station Spring was very positive for uranine (++) within 21 hrs, indicating a flow velocity of >80 m/hr. Most of the dye had exited the spring within 21 hrs, documenting very rapid and efficient flow through this subterranean cutoff route.

## Spring Descriptions with Summary of New Tracer Tests within the Beargrass Creek Basin

### A'Sturgus Station (1842)

***A'Sturgus Station Spring***, which is located in the northwest corner of the Jeffersontown Quadrangle, is unmapped on the topographic quadrangle but is shown on the geologic quadrangle [N38.245422°/W85.616410°]. It is located 0.6 km south-southeast of Interchange 20 of the Watterson Expressway and US 60. The spring rises within a stone-walled pool adjacent to a springhouse built ca. 1788 (Figure 9). Historical photographs indicate that this spring may have also been called Lynn Station. It discharges from the top of the Sellersburg and Jeffersonville Limestones (Moore, Kepferle, and Peterson, 1972), at about 159 m AMSL. Base-flow discharge of A'Sturgus Station Spring was gaged on 9/7/04 at 39.9 L/s and on 8/23/05 at 34.8 L/s. Based on numerous observations of high flow events, the finite capacity of the cutoff conduit may restrict flood peak to about 0.5 $m^3/s$. This is without doubt the largest known spring in Jefferson County.

**Dye Test 09-01**

*February 4, 2009:* Two existing watershed boundaries had been found, one produced by the Louisville/Jefferson County Information Consortium (LOJIC) and the other by the USGS (official HUC boundary presented in this report). LOJIC's delineation attributes drainage from the Lyndon area to Goose Creek. An intermittently flowing surface channel can be observed from the location at Devonshire Apartments, passing beneath the L & N Railroad to the north and trending toward Goose Creek. The USGS watershed boundary delineation attributes this area to Beargrass Creek. This test was designed to determine which watershed boundary delineation was correct. However, it should be noted that the dye traces described above, conducted by Ogden Environmental and DOW, had already shown that a significant portion of this area drained to A'Sturgus Station Spring.

During a runoff event induced by snow melt, 113 g of eosine were injected into ***Darbyshire Swallet @ Devonshire Apts*** [N38.262893°/W85.599834] with an estimated 1.5 L/s of natural flow**.** This swallet is in a losing reach of the intermittent unnamed tributary to Goose Creek, which is the adjacent watershed to the north. Dye receptors were placed at A'Sturgus Station Spring, two stream sites in the lower reach of the intermittent UT to Goose Creek and one in the sanitary sewer main nearest the injection point.

On the first dye receptor exchange (2/12/09), 8 days after the injection, A'Sturgus Station Spring was extremely positive (+++) for eosine and all other monitored sites were negative. The sanitary sewer was only monitored for 2 hours and 45 minutes after the dye injections, but based on previous experience (discussed later in this section) that was ample time for dye to reach the receptor had sewer infiltration occurred. On the second exchange (3/5/09) all sites were negative for eosine. Presumably this flow route was highly efficient and all tracer dye had been discharged by the time of the first dye receptor exchange.

This test confirmed that during base flow conditions the USGS watershed delineation is correct. Additionally, only during high flow events would surface runoff exceed the capacity of the underlying groundwater system and allow surface overflow to Goose Creek. The map in Figure 10 shows all tracer data for A'Sturgus Station Spring Basin, which includes tracer data for sub-basins of Steinrock and A.B. Sawyer Gate springs, described below.

**Steinrock (3368)**

***Steinrock Spring*** is located in the southwest portion of the Anchorage Quadrangle, about 0.5 km northwest of the Shelby Campus of the University of Louisville. Steinrock is a rising spring located within a partially surviving old stone springhouse, adjacent to the residence of the owner (Figure 11). The spring has been back-ponded by a decorative pool with a low concrete dam across the pool's discharge channel. Also, the receiving stream, Middle Fork Beargrass Creek, is artificially elevated about one meter by a minor dam and road-crossing just downstream of the pool.

Steinrock Spring discharges from the top of the Louisville Limestone (Kepferle, Wigley, and Hawke, 1971) at about 178 m AMSL [N38.25695°/W85.58991°], but is not mapped on the topographic or geologic maps. However, Hydrologic Investigations Atlas 22 (Palmquist and Hall, 1960) maps a spring at this location - the only spring shown within the Beargrass Creek watershed. The older Hydrologic Investigations Atlas 8 (MacCary, 1956) provides an estimated discharge rate for this spring at 0.25 L/s (4/3/53). When the spring was inventoried for the current study on 6/15/04, a discharge of 5.5 L/s was estimated. However, during low-flow conditions, flow reverses into the pool and spring orifice from the creek. This reversal is made possible by the artificial impoundment that raises the spring discharge elevation. Consequently, an unknown auxiliary distributary discharge point must lie downstream of the spring and the dam across Beargrass Creek to accommodate this circulation. A zone of rip-rap lines the left bank just downstream of the dam and is the likely area of the hidden discharge. This spring is upstream of the swallet on the Middle Fork of Beargrass Creek that Angelo George traced to A'Sturgus Station Spring in 1971, which makes this a sub-basin of A'Sturgus Station Spring.

**Dye Test 04-11**

*June 29, 2004:* During low-flow conditions, 55 g of eosine were injected at **U of L/US 60 Sinkhole**, 0.4 km west of the US 60/Hurstbourne Parkway intersection [N38.24710°/W85.58122°]. With the help of the

Lyndon Fire Department, about 1700 L of flush water was withdrawn by hose directly from a nearby fire hydrant. The eosine was injected into a minor soil collapse located within a large shallow depression adjacent to US 60. Five springs and stream locations were monitored for the dye.

Within two days and on the first exchange, A'Sturgus Station Spring was positive for eosine (+) and the Middle Fork Beargrass Creek above the swallet known to drain to A'Sturgus Station Spring was very positive for eosine (++). The dye entered the creek upstream of these two monitoring points (Steinrock Spring was not exchanged on this date). Five days later (7/6/04) Steinrock Spring, 1.32 km to the northwest, was positive for eosine (+), whereas Middle Fork Beargrass Creek above Steinrock was negative. This result showed that the primary dye discharge point was Steinrock Spring. A month later (8/4/04) Steinrock Spring was still positive for eosine (+).

**Dye Test 06-23**

*October 24, 2006:* During low-flow conditions, 70 g of eosine were injected at **Forum 3 Pool** [N38.25193°/W85.57577°], 1.4 km east-southeast of Steinrock Spring, where about 1.5 L/s of flow was sinking at a terminal pool within a rip-rapped drainage channel. Steinrock Spring and Middle Fork Beargrass Creek above the spring were monitored for this trace because a previous dye trace (04-11) recovered at Steinrock Spring established the western boundary and likely destination for this test.

Three days later (10/27/08), Steinrock Spring was very positive for eosine (++), whereas Middle Fork Beargrass Creek was negative. A water sample collected at Steinrock Spring on this date contained an eosine intensity level 50 times greater than the background water sample. Steinrock Spring was very positive (++) or positive (+) for eosine on the next three exchanges. This test establishes that the headwaters of Steinrock Spring include the unnamed losing stream that extends to the southeast as far as 2 km.

## A.B. Sawyer Gate (3357)

***A.B. Sawyer Gate Spring*** is a gravity spring draining from a low, wide conduit located near the southwest corner of A.B. Sawyer Park at about 186 m AMSL [N38.261793°/W85.582976°](Figure 12). The spring is located at the base of the Sellersburg and Jeffersonville Limestones (Kepferle, Wigley, and Hawke,

1971) and is unmapped on the Anchorage Topographic and Geologic maps. This spring also drains to the Middle Fork of Beargrass Creek, upstream of the swallet traced by Angelo George, making it a sub-basin of the larger A'Sturgus Station Spring Basin. Discharge ranges from about 4-40 L/s. The spring is fed from the northeast by a sinking stream that resurfaces in two karst windows, one of which is intermittent.

**Dye Test 04-19**

*November 17, 2004:* During moderate flow conditions 42 g of eosine were injected at **Fenley Development Sink**, a large Class V drainage well lined with shot rock [N38.270285°/W85.575960°]. Seven springs, karst windows, and streams were monitored for this test. Based on topography, this sink is approximately 0.5 km north of the watershed divide and the sinking stream should drain northwest to Goose Creek. Also, local residents reported that someone had conducted a dye test from this site that went to Goose Creek, although no documentation was available.

Within two days A.B. Sawyer Gate Spring, 1.18 km to the southwest, was extremely positive for eosine (+++), as was Sawyer Karst Window (+++), located about 300 m to the northeast of the main discharge spring. An intermittent karst window, a short distance to the north-northeast, was observed to be flowing and was monitored during this first exchange. Three days later, A.B. Sawyer Gate Spring and Sawyer Karst Window were both positive for eosine (+), while the intermittent karst window was inconclusive, probably due to minimal flow. All other sites were negative for eosine, including a minor cave spring (Luking Cave) draining to Goose Creek. Goose Creek at the next bridge downstream was also negative for eosine, although backgrounds of Uranine and SRB were detected. The dye recovery at A.B. Sawyer Gate Spring 44.6 hr after injection indicated a flow velocity >26.5 m/h. This test confirmed karst flow deviation from the watershed boundary and resulted in the addition of approximately 1 $km^2$ of drainage area to the Beargrass Creek watershed.

## Bowling Blvd. (2943)

***Bowling Blvd. Spring*** is channeled through a 1.2-m diameter culvert at the northeast corner of the Louisville East Quadrangle, just west of Bowling Blvd. and Mall St. Matthews

[N38.24583°/W85.62848°] (Figure 13). This spring is not mapped on the topographic and geologic maps. The natural spring feature may lie somewhere beneath the parking lot of the mall and should discharge from the Sellersburg and Jeffersonville Limestones (Kepferle, 1974) at an elevation of about 155 m AMSL. High flow discharge reaches about 85 L/s, however, flow ceases during very dry weather. Since the estimated basin for this spring is 4.1 $km^2$, it should exhibit significant base flow. The most likely explanation for this loss of base flow is infiltration into the sanitary sewer.

**Dye Test 04-10**

*June 15, 2004:* During low flow conditions, about 28 g of eosine were injected at **Swallet @ St. Matthews Park**, located at the east end of Blenheim Road [N38.255553°/W85.624340°]. Four sites were monitored. Within three days, Bowling Blvd. Spring, 1.14 km to the south-southwest, was very positive for eosine, while the three other sites were negative. Eleven days later Bowling Blvd. Spring was again very positive for eosine, while the other sites were likewise negative. The storm drain at Stonehenge showed an inconclusive trace of eosine, however, the dye injection site along the losing stream in St. Matthews Park at Beachwood Village would overflow through the storm drain. Any residual dye from the injection site could thus have been transported through the storm drain. Thirty-six days later Bowling Blvd. was inconclusive for eosine and the test was ended. Results are presented on the map in Figure 14.

## Cypress Point Springs #1, 2, 3 and 4 (3367, 3760, 3761, 3762)

***Cypress Point Springs*** are free-draining gravity springs located just southeast of the Cypress Point Apartments, on a northwest bend of the Middle Fork Beargrass Creek, at the following coordinates:

(#1) N38.242544°/W85.631940°

(#2) N38.242494°/W85.632281°

(#3) N38.241991°/W85.632750°

(#4) N38.241857°/W85.633005°

These springs are unmapped on the Louisville East Topographic and Geologic Quadrangle maps and emerge as a 120-m wide distributary, which appears to behave as two adjacent groundwater basins with overflow interconnections (Figure 15). The springs emerge from the Sellersburg and Jeffersonville Limestones (Kepferle, 1974) at an elevation of about 155 m AMSL. High flow discharge of #1 Spring ranges from about 50-80 L/s before it is back-ponded by the Middle Fork Beargrass Creek. Low flow of #1 Spring was gaged on 9/7/04 at 5.1 L/s, which is greater than the combined discharge of the other 3 springs. # 4 Spring may be an overflow spring that runs dry during low flow conditions. #1 Spring was originally detected from a prominent undulation of the two-foot contour interval on the Louisville LOJIC Interactive map, and was verified by a field check.

**Dye Test 06-21**

***October 17, 2006:*** During moderate flow conditions, 42 g of SRB were injected at **St. Matthews Elementary School Sinkhole**. The sinkhole is located just to the east of St. Matthews Elementary School, adjacent to the Waggener School athletic field, on the Louisville East Quadrangle [N38.246111°/W85.638910°]. The sinkhole was fed by a schoolyard drainage ditch and a clay tile that discharged a trickle flow into the rip-rap of the sinkhole. The sinkhole is located in the apparent basin of Cypress Pointe Spring #1 (formerly inaccurately called Low Dutch Station Spring). Four additional springs were monitored for this test. Four exchanges over the next three weeks failed to recover the SRB.

**Dye Test 06-21 Replication (Rep)**

***February 5, 2008:*** A replication of the previous test was conducted with 85 g of SRB into runoff entering the sinkhole swallet at 5.6 L/s. In addition to Cypress Point Spring #1, Cypress Point Springs #3 and #4 were also monitored during five exchanges over two weeks. However, only inconclusive results were recorded for Cypress Point Spring #3, and a second replication was required.

**Dye Test 06-21 Rep II**

***February 22, 2008:*** A replication of the previous tests was conducted with 0.5 L of Rhodamine WT into runoff entering the sinkhole swallet at 0.3 L/s. All four Cypress Pointe Springs were monitored during three exchanges over five weeks. Within three days #2 Spring was very positive for Rhodamine WT (++), and #3 Spring was positive (+), whereas #1 and #4 springs were inconclusive (?). After an additional eight days all four springs were very positive (++). All bugs were removed on April 1$^{st}$ and #1

Spring was negative (-), #2 Spring was positive (+), and #3 and #4 springs were very positive (++). The dye was interpreted to mainly discharge from #2, #3, and #4 springs, but also overflow to #1, the larger basin.

**Dye Test 08-01**

*January 4, 2008:* During moderate flow conditions, 455 g of eosine were flushed into the **Bonner Avenue Collapse** using 4550 L of water from a nearby fire hydrant. The DOW was informed of the cover collapse, located beneath a sidewalk along Bonner Avenue (N38.25340°/W85.63839°), by the St. Matthews City Engineer, and the dye injection was assisted by St. Matthews municipal employees. This cover collapse was an emergent event and in order to inject dye prior to sinkhole repair by the city, background water samples were collected from seven spring and stream locations on the same day as the dye injection. Also, a sanitary sewer 100 m south of the collapse was visually monitored during the dye injection and a charcoal packet was deployed in the sewage stream.

Within three days Cypress Pointe #1 Spring (N38.242544°/W85.631940°) was extremely positive for eosine (+++), while six other monitored sites were negative. The sanitary sewer 100 m south of the collapse was also negative. Eosine recovered in the water sample from Cypress Pointe #1 Spring was 400 times greater than the eosine water background collected on 1/4/08. The tracer dye traveled 1.35 km at a rate of >450 m/d. By 2/25/08 dye levels in Cypress Pointe #1 Spring had receded to positive for eosine (+). On 1/11/08 water samples were collected from Cypress Point #2 and #3 springs; #2 Spring was positive (+) and #3 Spring was inconclusive (?) for eosine. Cypress Point #3 Spring remained inconclusive or negative on charcoal receptors until 4/1/08, while #2 Spring was positive (+) on 2/25, very positive (++) on 3/5 and positive (+) on 4/1. These results added further evidence of a karst distributary. Figure 14 is a map of the results of these tracer tests.

## Mockingbird Valley (3363)

***Mockingbird Valley Spring*** is a gravity spring draining from a root-reinforced soil cavity at the head of a former decorative pool that has been silted with alluvium (Figure 16). Located about 0.8 km north-

northwest of the junction of Mockingbird Valley Road and Brownsboro Road, the spring discharges from the base of the Louisville Limestone (Kepferle, 1974) at about 139 m AMSL [N38.269408°/W85.681913°], and is unmapped on the Jeffersonville Topographic and Geological Quadrangles. The discharge ranges from 3-50 L/s.

**Dye Test 06-19**

*September 20, 2006:* During low flow conditions, 42 g of SRB were injected at **Crescent Hill Golf Course Swallet**, where minor flow was disappearing into a stream bed [N38.259278°/W85.67533°]. This losing point was located about 60 m upstream of the primary sinkhole swallet, which was dry at the time of dye injection. This dye injection was located within the apparent basin of Mockingbird Valley Spring (1.2 km to the north-northwest), which was monitored along with five additional spring and stream sites.

A heavy rain occurred two days after injection and the dye receptor placed in the creek channel below the inflow of Mockingbird Valley Spring was lost in the high flow. The first dye receptor exchange occurred five days after injection, and the loss of the receptor was discovered. Analysis revealed no SRB at the other monitoring locations. To avoid future high flow problems in the main channel, the Mockingbird Valley Spring dye receptor location was moved to the spring head.

Due to the lost dye receptor, it was assumed that if SRB had passed through Mockingbird Valley Spring it had been missed. Therefore, on September 29$^{th}$ a duplication of the dye injection was conducted during moderate flow conditions from the primary swallet about 60 m to the north-northwest of the initial injection. About 85 L/s of flow was entering the primary swallet and about 28 g of SRB were used in this second injection. However, dye receptors that had been exchanged that day but not analyzed prior to the second injection ultimately revealed that Mockingbird Valley Spring was very positive for SRB (++). This was apparently residual dye from the first injection on September 20$^{th}$. Seven days after the second injection, Mockingbird Valley Spring was extremely positive for SRB (+++), while the additional five monitoring points were negative (Figure 17). SRB was recovered at the spring two additional times until monitoring ceased on November 1$^{st}$.

## Windy Hills (1889)

***Windy Hills Springs*** are located in the southeast portion of the Jeffersonville Quadrangle, 0.5 km southeast of the Zachary Taylor National Cemetery, but are not mapped on the topographic and geologic maps. Windy Hills Springs are distinguished as *Windy Hills* (east) and *Newstadt* (west) and discharge at about 168 m AMSL [east- N38.273197°/W85.637755°; west- N38.273096°/W85.638117°]. The east spring (*Windy Hills*) discharges through a horizontal steel pipe or well casing, while the west spring (*Newstadt*) discharges through rock slabs into a shallow channel in the edge of a residential yard. Both springs have minor discharges of about 0.5 L/s, and are located at the top of the Louisville Limestone (Kepferle, 1974).

**Dye Test 04-06**

*April 22, 2004:* During moderate flow conditions, about 15 g (0.5 oz) of eosine were injected into the swallet of **Taylor Spring** (1912), a minor karst window formerly developed with a springhouse [N38.274791°/W85.638285°]. Four nearby sites were monitored for this test. Four days later, Newstadt Spring (west), 175 m to the south, was extremely positive for eosine (+++); nearby Windy Hills Spring (east) was positive (+), and flow in an intervening storm drain was extremely positive (+++) (Figure 14). Goose Spring, located about 0.5 km to the southwest was negative.

## Oxmoor (2934)

***Oxmoor Spring*** is located in the northwestern portion of the Jeffersontown Quadrangle and is unmapped on the topographic map, but is mapped on the corresponding geologic map. It discharges at about 166 m AMSL [N38.23962°/W85.60834°] from a maintained spring house to the south side of an unnamed tributary of the Middle Fork of Beargrass Creek. Discharging from the Sellersburg and Jeffersonville Limestones (Moore, Kepferle, and Peterson, 1972), Oxmoor Spring is a developed, perennial spring rising within a compartment of the spring house. Figure 18 shows the Oxmoor Spring house and spring run. On 12/17/99 the spring discharge was estimated at 2.8 L/s, but flow may increase to five times that quantity during high flow conditions.

### Upper Oxmoor (2940)

***Upper Oxmoor Spring*** is located about 340 m upstream and to the northeast of Oxmoor Spring. It is a rising spring that also discharges on the south side of an unnamed tributary of the Middle Fork of Beargrass Creek, through a short spring run. This spring is unmapped and undeveloped (Figure 19). It discharges at about 168 m AMSL from the Sellersburg and Jeffersonville Limestones [N38.24166°/W85.60590°]. On 3/2/04 its discharge was estimated at 1.4 L/s, but flow can increase to about 30 L/s.

**Dye Test 04-02**

*April 14, 2004:* During moderate flow conditions, 15 g of SRB were injected into a swallet at **Sayback Ditch** [N38.23748°/W85.60196°], 0.6 km east-southeast of Oxmoor Spring. At this location, approximately 7 L/s of surface flow was infiltrating into a rock-lined channel. Within one day (on the first dye receptor exchange (4/15/04), both Oxmoor Spring (0.6 km to the west-northwest) and Upper Oxmoor Spring (0.6 km to the north-northwest) were positive for SRB (+) (Figure 20). Dye exited the system rapidly because both sites were negative on the second exchange, four days later.

### Culvert Spring above Watterson (3753)

***Culvert Spring above Watterson*** is a channelized gravity spring located on the left bank of the Middle Fork Beargrass Creek just upstream of the Watterson Expressway Bridge [N38.24380°/W85.62099°]. This spring is located at about 157 m AMSL and is not mapped on the Jeffersontown Topographic and Geologic Quadrangle maps. A minor amount of groundwater discharges from a large-diameter concrete culvert, which primarily functions as a subsurface storm drain along the northeastern boundary of the interchange. Creek water back-ponds within the culvert during moderate flow levels of the creek. Bedrock is composed of the Sellersburg and Jeffersonville Limestones (Moore, Kepferle, and Peterson, 1972).

**Dye Test 07-25**

*December 19, 2007:* During moderate flow conditions, 85 g of SRB were injected into **Interchange Sinkhole**, a small sinkhole developed in a drainage ditch within the northeastern corner of the I-64/ I-264 Interchange (N38.23953°/W85.62223°). This test was designed to map groundwater flow within the vulnerable interchange area. Three sites were originally monitored for this test, but by 12/24 all sites were negative (-). The study area was expanded by two additional sites and a replication of this test was undertaken on 12/26.

**Dye Test 07-25 Rep**

*December 26, 2007:* A water sample from a culvert spring draining to Middle Fork Beargrass Creek above Watterson Expressway showed a background of SRB on 12/26. This site was included and increased the monitored locations to six. During moderate flow conditions, 115 g of eosine were re-injected into local runoff flowing into **Interchange Sinkhole**. Two weeks later eosine was detected in Middle Fork Beargrass Creek above Low Dutch Station Spring, but the Culvert Spring bug was not exchanged on this day. Two days later, Culvert Spring above Watterson, 0.5 km to the north-northeast, was very positive for eosine (++) and was likewise positive (+) after three additional days, on 1/14/08 (Figure 14). The three sites originally monitored for this test were again negative (-). Although Culvert Spring was connected to an apparently natural sinkhole formed in soil, it is unclear how much of the local flow system is merely intermittent storage draining through the roadside ditch during winter conditions.

## Brown Cemetery Culvert (1024)

**Brown Cemetery Culvert Spring** is a channelized gravity spring located about 1 meter above the left bank of the Middle Fork of Beargrass Creek, right next to Weicher Creek Diversion Spring [N38.23569°/W85.63596°]. The spring is at an elevation of 153 m AMSL and is unmapped on the Louisville East Topographic and Geological Quadrangles. Bedrock is composed of the Sellersburg and Jeffersonville Limestones (Kepferle, 1974). A moderate amount of groundwater (3 L/s) discharges from a large-diameter concrete culvert. Based on results of the tracer tests described below, this spring is a diversion of groundwater from the Low Dutch Station Spring (2537) Basin into the storm drain. Furthermore, this is an intentional diversion of groundwater into the storm water system.

### Weicher Creek Diversion (1025)

**Weicher Creek Diversion Spring** is a channelized gravity spring located about 2 meters above the left bank of the Middle Fork of Beargrass Creek just downstream of the I-64 bridge [N38.23564°/ W85.63550°]. The spring is at an elevation of 154 m AMSL and is unmapped on the Louisville East Topographic and Geological Quadrangles. Bedrock is composed of the Sellersburg and Jeffersonville Limestones (Kepferle, 1974). A moderate amount of groundwater (3 L/s) discharges from a large-diameter concrete culvert. Based on results of the tracer tests described below, this spring is a diversion of groundwater from the Low Dutch Station Spring (2537) Basin into the storm drain. Furthermore, this is an intentional diversion of groundwater into the storm water system. Figure 21 is a photograph of Brown Cemetery Culvert and Weicher Creek Diversion springs.

### Low Dutch Station (2537)

**Low Dutch Station Spring** is a gravity spring located approximately 70 m off the left bank of the Middle Fork of Beargrass Creek (Figure 22), just upstream of the I-64 bridge [N38.23667°/W85.63469°]. The spring is only 20 m north of the interstate and at an elevation of 153 m AMSL. It is not mapped on the Louisville East Topographic and Geological Quadrangles. The spring discharges from a small conduit formed by dissolution along a bedding plane in the Sellersburg and Jeffersonville Limestones (Kepferle, 1974). Groundwater discharge from this spring has been significantly diminished by diversion to the two previously described culvert springs.

**Dye Test 08-03**

*January 11, 2008:* During moderate flow conditions, 1.0 L of Rhodamine WT was injected into a small soil cavity (**Bag Job @ 1-64/I-264 Interchange**) adjacent to Watterson Expressway exit ramp #12 (N38.23658°/W85.62469°). About 10 L of nearby puddle water was collected in a plastic trash bag and used to help flush the dye. The hole was also accepting some local seepage. Two channelized springs and a natural spring nearly a kilometer to the west, located near the I-64 bridge over Middle Fork Beargrass Creek, were monitored for this test.

Within three days Weicher Creek Diversion Spring (N38.23564°/W85.63550°) and Brown Cemetery Culvert Spring (N38.23569°/W85.63596°) were both very positive for Rhodamine WT (++), and Low Dutch Station Spring (N38.23667°/W85.63469°) was inconclusive (?) at 2.2 times background. Both channelized springs were extremely positive (+++) on 1/16 and 1/25, and very positive (++) on three exchanges until 4/1. The natural spring feature, Low Dutch Station Spring, was very positive (++) on 1/16 and 1/25, but inconclusive on four more exchanges until 4/1. Most of the water from this groundwater basin was being diverted through the channelized springs. These data, along with data from test #07-25 rep, indicate that a groundwater divide exists beneath the I-64/I-264 interchange.

**Dye Test 08-04**

*January 14, 2008:* During moderate flow conditions, 140 g of eosine were injected into **Watterson Sinkhole #3** (N38.23513°/W85.62545°) and was flushed with 750 L of hauled water. Two channelized springs and a natural spring, about 0.6 kilometer to the west were monitored for this test. Within two days Weicher Creek Diversion Spring (N38.23564°/W85.63550°) and Brown Cemetery Culvert Spring (N38.23569°/W85.63596°) were both extremely positive for eosine (+++), and Low Dutch Station Spring (N38.23667°/W85.63469°) was positive for eosine (+). Also, two water-bearing concrete culverts below drop-box inlets (middle V-shaped and upper flat) along the westbound lane of I-64 were sampled for water on 1/16 and determined to be very positive for eosine *[These drop-box drainage features along the interstate have been engineered to intercept groundwater drainage from the Low Dutch Station Spring Basin, as well as surface runoff from the surrounding area. They discharge that water at the two channelized springs along the Middle Fork Beargrass Creek. Because of the perennial groundwater flow through this storm-drain system, the Middle Fork Beargrass Creek is especially vulnerable to spills that enter the drop boxes along this section of the interstate]*.

Due to only a two-day monitoring period between 2/5 and 2/7, dye recovery was inconclusive (?) at all three sites on 2/7. Otherwise, eosine recovery at Weicher Creek Diversion Spring and Brown

Cemetery Culvert Spring was extremely positive (+++) to very positive (++) during four exchanges until 4/1. Low Dutch Station Spring was either very positive (++) or positive (+) until 4/1. These data suggest that the channelized springs and the storm drains feeding them are intercepting the bulk of groundwater flow that formerly discharged at Low Dutch Station Spring (Figure 23). Presumably, this groundwater diversion into storm drains was initiated during the original construction of I-64.

**Hole 10 (3758)**

***Hole 10 Spring*** is located in the headwaters of Weicher Creek, at the northwest corner of the Jeffersontown Quadrangle. About 750 m northeast of St. Mark Church, this spring is within the Oxmoor Country Club where it is partially back-ponded by a small lake at an elevation of about 181 m AMSL [N38.22862°/W85.602467°]. It discharges from the Louisville Limestone and is mapped on the geologic quadrangle (Moore, Kepferle, and Peterson, 1972), although it is absent from the corresponding topographic quadrangle. The spring feature monitored in this study appears to be an overflow spring where a minor bedrock slot is back-ponded by the lake (Figure 24). The main spring orifice appears to lie beneath 1-2 m of impounded water and was probably the spring feature mapped by Kepferle prior to lake construction.

**Dye Test 04-01**

*April 14, 2004:* During moderate flow conditions, 55 g of eosine were injected into a minor sinking stream named **Bullitt Estate Swallet** [N38.229553°/W85.597083°], 1.45 km southeast of Oxmoor Spring. Four nearby spring and stream sites were monitored for this dye injection. However, after two exchanges of negative dye receptors over five days, it was assumed that the relevant groundwater discharge point was not among the monitored locations.

**Dye Test 04-01 Rep**

*February 14 2008:* A replication of the above dye injection at **Bullitt Estate Swallet** was conducted with six springs and streams south of I-64 being monitored. During moderate flow conditions, 85 g of eosine were re-injected at the swallet. Within four days, on the first dye-receptor exchange, Hole 10 Spring 0.5 km to the west-southwest, was extremely positive for eosine (+++). The five additional sites were negative. Four days later, the second exchange at Hole 10 Spring was inconclusive for eosine and negative by February 25th. This dye injection, which was north of I-64, passed southwest beneath the interstate to the partially back-ponded spring on Oxmoor Country Club (Figure 23).

### Nunnlea (2935)

***Nunnlea Spring*** is a channelized spring discharging from a 1.2 m diameter metal culvert near the intersection of Hurstbourne Circle and Hurstbourne Parkway [N38.218455°/W85.585427°]. The spring discharges from the top of the Louisville Limestone (Moore, Kepferle, and Peterson, 1972) at an elevation of about 200 m AMSL (Figure 25), and is unmapped on the Jeffersontown Topographic and Geological Quadrangle maps. Discharge ranges from 0.5-15 L/s.

### Zehnderhouse (1131)

***Zehnderhouse Spring*** issues from a large prominent springhouse located near the intersection of Hurstbourne Parkway and Taylorsville Road (Figure 25). The spring discharges from the top of the Louisville Limestone (Moore, Kepferle, and Peterson, 1972) at about 195 m AMSL [N38.216145°/W85.589230°]. The spring is not mapped on the Jeffersontown Topographic Map but is mapped on the corresponding geologic map. Discharge is minor and ranges from about 0.1-3 L/s.

**Dye Test 06-20**

*October 2, 2006:* During moderate flow conditions, 200 g of eosine were injected at the **CarMax Sinkhole Collapse.** The sinkhole collapse shown in Figure 25 is located near the CarMax auto dealership off Hurstbourne Parkway, just south of I-64 Interchange 15, on the Jeffersontown Quadrangle (N38.22016°/W85.58054°). This collapse occurred suddenly after a flood event on 9/23/06, when the area received about 15-18 cm of heavy rain. The sinkhole area was about 20 $m^2$ and had a depth in excess of 3 m (Doug Zettwoch of the USGS reported that he probed the sinkhole slump material to bedrock, at a depth of about 5.5 m). The walls of the sinkhole exposed terra rosa soil, including occasional chert fragments. This material resembled terra rosa typical of well-developed Mississippian-limestone karst of western Kentucky. The mapped bedrock unit (unexposed) is Louisville Limestone (Moore, Kepferle, and

Peterson, 1972), a dolomitic limestone that dips to the west-southwest at about 7.5 m/km. Soil cover is described as "*probably less than 10 ft thick* (3 m)*; locally may include unmapped residuum of overlying Devonian limestones*".

Improper storm drain construction is the apparent trigger of this cover collapse. A local drainage channel terminates in a storm drain inlet grate about 5.5 m from the collapse. This drain is apparently connected to the storm drain collection chamber exposed by the collapse. However, a man-hole cover is elevated above the chamber by three courses of stacked concrete blocks. When storm waters flooded the storm drain system, water flushed between the lose blocks and rapidly infiltrated the surrounding soil. Waterborne debris could be observed jammed between the blocks on the inside of this makeshift man-hole riser. The heavy outflow of water from the storm drain rapidly flushed into an existing soil void overlying the bedrock, triggering the collapse. Had the manhole riser been properly sealed into the storm drain piping, it is unlikely that this soil collapse would have occurred. Storm drain infrastructure located in highly sensitive karst terrane, including much of the Louisville area, should be inspected and properly sealed to limit these costly sinkhole collapses.

This rapid-response dye injection was conducted nine days after the collapse, prior to any repair of the new sinkhole. Mike Unthank and Doug Zettwoch of the USGS provided assistance and transported 2270 L of flush water for this dye injection. The sinkhole lies within the estimated basin of Nunnlea Spring, a channelized spring 520 m to the west-southwest of the collapse. Because this test was a rapid-response dye injection conducted prior to sinkhole repair, a water background sample was taken from Nunnlea Spring, and four additional streams and springs were monitored with charcoal just prior to the eosine dye injection.

Within 42 hours Nunnlea Spring was very positive for eosine (++), and was extremely positive (+++) within four days. Dye in a water sample collected four days after injection exceeded the eosine background intensity by 83 times. Dye discharged by this spring showed a consistent recession over the next ten weeks. The initial groundwater velocity documented by this trace was >296 m/d. The documented flow route traversed 35% of the estimated basin length. The sizable soil void suggested by the collapse and the rapid groundwater velocity verify a high hydrogeologic sensitivity rating (Ray, Webb, and O'dell, 1994). This fact is notable because the local landscape contains few sinkholes or other surface features indicative of well-developed karst.

Four days after eosine injection, a water sample was collected from the minor Zehnderhouse Spring, about 0.9 km to the west-southwest of the sinkhole. The background was low for eosine, however, it increased somewhat in the next two water samples collected over 18 days, and a charcoal receptor was deployed on November 1st. On November 6th and December 1st, low positives for eosine were detected on dye receptors at Zehnderhouse Spring (three additional monitoring locations were negative during this study). This result was surprising since the spring's discharge was very minor. However, this also suggested that Nunnlea Spring originated due to road construction by channelization of groundwater formerly draining to Zehnderhouse Spring. The hypothesis that Zehnderhouse Spring was the former lone discharge point for the local groundwater basin may explain the construction of the large springhouse at this site (Figure 26).

## Ray (3366)

***Ray Spring*** is an unmapped gravity spring located 0.83 km south-southeast of the intersection of Hikes Lane and Taylorsville Road [N38.212246°/W85.624122°]. This spring discharges from the top of the Louisville Limestone (Moore, Kepferle, and Peterson, 1972) at about 158 m AMSL (Figure 27). Discharge ranges from 4-15 L/s. The spring flow was reportedly diminished by construction activities within the drainage basin, although loss of flow is more likely caused by short-cut leakage to the receiving stream channel.

**Dye Test 06-22**

*October 20, 2006:* During moderate flow conditions, 28 g of SRB were injected at the swallet of **Taylor Karst Window**, located between Taylorsville Road and Martha Avenue [N38.21763°/W85.61720°]. Four springs and streams were monitored for this test with a water background sample collected from Ray Spring. Ray Spring, 0.86 km to the southwest, was the most likely resurgence point. Four days after dye injection Ray Spring was extremely positive for SRB (+++), and was also positive (+) eight days later (Figure 28). The other three sites were negative for SRB. BTM Engineering reported that heavy rain during a construction phase, caused the development of a natural sinkhole in a retention basin 0.6 km to the northeast of Taylor Karst Window. This apparently contributed turbid water to the karst window. This reported "turbidity trace" is considered a valid inferred groundwater connection in this case, but due to a lack of runoff into the basin during fieldwork, the flow route has yet to be confirmed by a controlled tracer test. Nevertheless, the reported flow route is shown on the map and identified as "turbidity trace".

### Culvert (2952)-Confluence (2947)

***Culvert Spring*** is an unmapped spring located on the east-central portion of the Louisville East Quadrangle, about one km southeast of Buechel (Figure 29). It discharges as a gravity spring, which has been channelized through a metal culvert [N38.18808°/W85.64254°]. The spring discharges from the Louisville Limestone through alluvium and/or artificial fill at about 151 m AMSL. Discharge is minor, ranging from about 3-15 L/s.

***Confluence Spring*** is an unmapped spring located on the east-central portion of the Louisville East Quadrangle, about one km southeast of Buechel (Figure 30). It discharges as a natural gravity spring through alluvium, but must be supplied by conduit flow developed in the Louisville Limestone. The spring is located at about 151 m AMSL [N38.18832°/W85.64183°]. Discharge is minor, ranging from about 3-15 L/s.

**Dye Test 04-04**

*April 15, 2004:* During moderate flow conditions, 55 g of eosine were injected at **Buechel Park North Swallet** [N38.19400°/W85.63498°]. The dye was introduced into about 10 L/s of flow sinking into a swallet in the north bank. Four days later Culvert Spring and Confluence Springs, located approximately 0.9 km to the southwest, were both extremely positive for eosine (+++). Other stream sites draining those springs were also positive for dye. Buechel and Collins springs were negative. Confluence Spring, a natural gravity spring, and Culvert Spring, a channelized spring, appear to be a perennial distributary for this flow system (Figure 31).

## Buechel (3355)

***Buechel Spring*** is located on the east-central portion of the Louisville East Quadrangle, about one km southwest of Buechel. It is not mapped on either of the topographic or geologic quadrangle sheets. This spring rises as a 4-5 m wide bluehole, just north of an unnamed tributary of South Fork Beargrass Creek [N38.18851°/W85.65575°]. The spring discharges from the Sellersburg and Jeffersonville Limestones (Kepferle, 1974) at about 146 m AMSL. Low flow discharge was gaged on 9/7/04 at 7.6 L/s and ranges up to about 170 L/s. Figure 32 contains photographs showing the spring from two directions during moderate flow conditions.

**Dye Test 04-03**

*April 14, 2004:* During moderate flow conditions, 28 g of SRB were injected at **Perma Drive Class V** [N38.19704°/W85.64584°], a minor stream sinking into a grated drainage structure, 1.3 km to the northeast of Buechel Spring. This Class V Drainage Well was first inventoried by Crawford and Groves (1984) during an EPA-funded study mapping Class V features in several cities of Kentucky. This dye injection was opportunistic in order to utilize natural flow entering the drainage structure. The site had been visited previously times during times of no inflow. Consequently, five spring and stream monitoring locations were located and established *after* the fortuitous dye injection. During this process, Buechel Spring was originally discovered in a forested bottomland during a traverse down an unnamed tributary of South Fork Beargrass Creek.

Dye receptors were exchanged the day following dye introduction. Buechel Spring was very positive for SRB (++), indicating that dye traveled 1.3 km in less than 22.5 hrs. At the next exchange, which was conducted four days later, SRB recovery at Buechel Spring was inconclusive. This suggested that most of the dye exited the system within the first day. The four other monitoring locations were negative for SRB during this test. These data suggest that the conduit feeding this spring is relatively large and functions as an efficient groundwater transport system. The map in Figure 31 shows these results.

**Culvert Spring @ Genfab (3358)**

***Culvert Spring @ Genfab*** is a channelized spring draining to Fern Creek, which is the adjacent watershed to the south of Beargrass Creek. The spring is located in the southeast portion of the Louisville East Quadrangle about one km southeast of Newburg. This spring is unmapped on the topographic and geologic maps for this quadrangle. It discharges from the Louisville Limestone at about 146 m AMSL [N38.15386°/W85.64984°] through a 2-ft diameter culvert to a short spring run to Fern Creek (Figure 33). Spring discharge on 5/4/04 was estimated at 14 L/s. The spring location was originally obtained from data provided by Angelo George.

**Dye Test 04-05**

*April 22, 2004:* During moderate flow conditions, 28 g of SRB were injected into a losing stream (**Woodhaven County Club Trib.**) disappearing beneath a concrete gutter, just east of Fegenbush Road [N38.17028°/W85.63989°]. This dye injection was conducted to evaluate the recharge area of Collins Spring, 1.9 km to the north, and the possibility of karst deviation from surface hydrologic boundaries. Four days later Collins Spring and three additional monitoring sites were negative for SRB. Therefore, the monitoring area was expanded to include four sites to the south in Fern Creek drainage. A replication (**Dye Test 04-05 Rep**) was conducted on 5/4/04, and within two days Culvert Spring @ Genfab was positive for SRB (+), 2.0 km to the south-southwest (Figure 31). Three of the additional sites, including Fern Creek upstream of Culvert Spring @ Genfab were negative for SRB.

This result supports a dye trace recovery at this spring during Phase I research conducted by Brown and Caldwell Environmental Engineering and Consulting at the General Electric Appliance Park in 2001. In that study, dye injected into Appliance Park Cave (site #66) was recovered in the above-mentioned spring that was identified in that study as Location #76 (spring left side of tributary, west of Wastewater Treatment Plant 2). Dye from this injection was also recovered in two additional minor channelized culvert springs just upstream of the main Culvert Spring @ Genfab, and at two monitoring wells (MW-1 & 2) south of Building 6, which lay between the main dye injection and recovery points. Groundwater velocity was calculated at 1,019 m/day during that test.

The dye injected at the losing stream at Woodhaven County Club Tributary may have traveled through the Appliance Park Cave, en route to the above described discharge points on Fern Creek. However, the cave stream was not monitored in this study. Two additional tracer tests by Brown and Caldwell from the west portion of the Appliance Park were recovered at Ditch Blue Spring (3359), up to 1.85 km to the south-southwest.

**Sanitary Sewer – Karst Interactions**

Throughout the course of tracer tests conducted within the Beargrass Creek watershed for this study, several traces were not initially recovered. Following these attempts, new groundwater flow hypotheses were formulated and follow-up tracer tests were conducted. Ultimately, it was discovered that in some cases groundwater was infiltrating the sanitary sewer system. In two situations, groundwater was entering the sewer lines due to needed repairs. A third was an intentional diversion of groundwater into the sanitary sewer. Although not confirmed, other groundwater losses to the sanitary sewer are suspected. In the verified cases it was confirmed that all groundwater base flow in the immediate vicinity was being pirated by the sanitary sewer, effectively diverting groundwater that would otherwise discharge to Beargrass Creek. Based on this information it is estimated that 24% of groundwater base flow is diverted from the natural flow system to the sanitary sewers. This additional base flow could provide much needed dilution for Beargrass Creek and potentially improve surface water quality. These tracer tests are discussed below and shown on the maps in Figures 34 and 37.

*Case 1: Losing Stream at Hurstbourne Country Club*

**Dye Test 04-12**

*June 29, 2004:* During low flow conditions 28 g of SRB were injected at **Losing Stream @ Hurstbourne**, on the downstream portion of Hurstbourne Country Club [N38.243567°/W85.595966°].

The main hypothesis was that this stream loss would flow to the northwest and contribute to A'Sturgus Station Spring. Four additional springs and streams were monitored for the dye. However, after three exchanges of negative dye receptors over 36 days, it was assumed that the relevant groundwater discharge point was not among the monitored locations.

**Dye Test 04-18**

*October 8, 2004:* During low flow conditions, 55 g of SRB were injected at **Losing Stream (Bedrock Slot) @ Hurstbourne**, about 0.3 km upstream of the swallet utilized in trace 04-12. Therefore, this test was essentially a replication of the earlier dye injection but with better inflow. This swallet is a well-defined bedrock crevice in the left bank where much of the creek flow was rapidly infiltrating [N38.243567°/ W85.595966°]. This test was designed with four monitoring points to the southwest. However, after two exchanges of negative dye receptors over 10 days, it was assumed that the relevant groundwater discharge point was again not among the monitored locations.

**Dye Test 06-26**

*November 27, 2006:* In an attempt to resolve the lost dye traces from the **Losing Stream @ Hurstbourne**, 285 g of SRB were introduced into the "bedrock slot" [N38.242126°/ W85.593385°]. In this test 15 stream and spring locations were monitored, specifically along the main stem of Middle Fork Beargrass Creek. The revised hypothesis was that an underflow route discharged at an unknown point along the middle to lower reach of the creek.

Unfortunately, ten exchanges over seven weeks resulted in only inconclusive SRB detections. A water sample from Brown Cemetery Culvert Spring prior to dye injection suggested an SRB background. On 11/30 an apparent SRB background appeared at both Brown Cemetery Culvert Spring and Weicher Creek Diversion Spring, and at Weicher Creek Diversion Spring on 12/1 and 12/18, but not at Brown Cemetery Culvert Spring (Brown Cemetery Culvert Spring was later found to be hydrologically connected to Weicher Creek Diversion Spring; see 08-03 & 08-03). Also, a low background of Rhodamine WT appeared at Weicher Creek Diversion Spring on 12/21 and 12/27, suggesting some form of multiple dye contamination in the vicinity of Weicher Creek Diversion Spring. Consequently, the inconclusive SRB detections were considered very questionable and the test was replicated with a different dye.

**Dye Test 06-26 Rep**

*December 15, 2006:* During low flow conditions, the previous tests were replicated with 450 g of eosine in order to evaluate the apparent background of SRB. Six sites were monitored, mainly in the vicinity of Weicher Creek Diversion Spring. After negative receptors for eosine in four exchanges over two weeks, the previous questionable SRB detections were confirmed to be from a different source.

**Dye Test 06-26 Rep II**

*January 23, 2007:* A decision was made to test another hypothesis relative to the **Losing Stream @ Hurstbourne**. A structural trough named the Lyndon Syncline is mapped about 2 km west of the losing stream (Moore, Kepferle, and Peterson, 1972). This trough deviates from a southwesterly direction to a southerly direction in the vicinity of Buechel and passes beneath Buechel Spring. The difference in elevation between the losing stream and Buechel Spring is about 27 m. This replication was designed to test the hypothesis that flow from the losing steam follows the trough about 9 km to the southwest and discharges at Buechel Spring or a nearby location. This hypothesis was tested by injecting 450 g of eosine into the previously mentioned "bedrock slot" with 13 sites ultimately monitored, the most distant site being 16 km to the southwest. However, by April 3rd, the test ended after four exchanges with negative dye recovery. In total, this was the fifth failure to recover dye injected at the Losing Stream @ Hurstbourne.

**Dye Test 07-04**

*April 3, 2007*: During low flow conditions, 225 g of eosine were injected at **Losing Stream @ Hurstbourne**. This injection was conducted to test the hypothesis that dye was entirely diverted to the sanitary sewer by infiltration. This hypothesis, along with the Lyndon Syncline hypothesis, was originally conceived by Robert Blair. The sewer hypothesis was initially resisted by the second author due to the superior bedrock swallet dye injection site, and the assumption that dye should enter a bona fide groundwater conduit discharging at a karst spring. Reasoning suggested that even if some dye was pirated by the sanitary sewer, the groundwater system should retain at least a portion of the injected dye.

In addition to monitoring two channelized springs, a down-gradient sanitary sewer main was accessed at manholes located near Oxmoor Woods, 0.9 km to the west, and Camden Oxmoor, 2.2 km to the west-southwest. This test was attempted earlier in February but the Oxmoor Woods manhole cover was frozen in place and could not be removed. These sanitary sewers were monitored in the traditional method with charcoal packets attached to tethered bricks. Background dye receptors were deployed in the Oxmoor Woods sewer main locations and found to be negative for eosine. However, this monitoring method was less than optimal due to sewage solids quickly draping across the brick and cord, possibly shielding the charcoal from open access to passing flow.

At the first receptor exchanges, eight hrs and eight and ½ hrs after dye injection, both Oxmoor Woods and Camden Oxmoor dye receptors were extremely positive for eosine (+++), while Brown Cemetery Culvert Spring and Weicher Creek Diversion Spring were negative. Dye receptors in the sewer locations were removed the next day (4/4/07), and were positive for eosine (+), and the test was effectively ended (Brown Cemetery Culvert Spring and Weicher Creek Diversion Spring were not exchanged on 4/4/07, but were ultimately recovered and analyzed on 7/18/07 and found to be negative for eosine). This important dye test confirmed the Blair Sewer Hypothesis and verified that the sanitary sewer system was completely pirating base flow groundwater related to the Losing Stream @ Hurstbourne (Figure 34). This revelation stimulated reevaluation and replication of other lost dye tests in this study.

*Case 2: Weicher Creek Swallet at Dannywood Road*

**Dye Test 04-17**

*October 8, 2004:* During low flow conditions, 55 g (2 oz) of eosine were injected at **Weicher Creek Swallet**, just downstream from Dannywood Road [N38.23040°/ W85.61611°], where a trickle of flow was disappearing adjacent to a sewer pipe crossing beneath the creek. The main hypothesis was that this stream loss would flow about 1.8 km to the northwest to channelized springs on the Middle Fork

Beargrass Creek. A total of five springs in the vicinity were monitored for this test. However, after two dye receptor exchanges over 10 days yielded negative results, it was assumed that the relevant groundwater discharge point was not among the monitored locations.

**Dye Test 07-20**

*July 18, 2007:* During low flow conditions, 85 g of eosine were injected at **Dannywood Swallet** [N38.22976°/W85.61562°], about 75 m upsteam of Weicher Creek Swallet (04-17). Five times as much stream flow was sinking at Dannywood Swallet compared to the earlier dye injection point. Also, no sewer pipe was visible crossing the stream channel at the current injection site, which was located just upstream of the Dannywood Road bridge. Three sites, including Weicher Creek Diversion Spring were monitored twice over five days with no dye recovery.

**Dye Test 07-20 Rep**

*January 25, 2008:* During lowflow conditions, 15 g of eosine were injected at **Dannywood Swallet**, where 1.5 L/s of water was sinking beneath a sheet of ice. This losing reach of Weicher Creek was tested to map the source of channelized springs draining to Middle Fork Beargrass Creek, near the I-64 bridge. Prior to injection, one hour of background monitoring was conducted with a dye receptor in a sewer main about 70 m to the northwest. This background detector was later determined to be negative for eosine. In order to save time, the background was not analyzed prior to the test. As a precaution, eosine was used for this test because it had not been observed in previous sewage monitoring. The monitoring of the sewer main was conducted using two methods for comparison: **a)** traditional charcoal packet attached to a trotline clip, secured to a *brick*, attached to a cord; and **b)** charcoal packet inserted into the bottom of 3-m long, 2-inch PVC *pipe* with a perforated sweep-90° elbow (to keep sewer solids off the charcoal packet) inserted in the sewage stream (Figure 35).

About 110 minutes after eosine injection, the two dye receptors were removed from the sewer main. The *brick* sampler was determined to be positive for eosine (+), while the *pipe* sampler was very positive for eosine (++). Based on analyzed dye intensity, the pipe sampler recovered 43% more dye than the brick sampler. This test determined that the losing water from this reach of Weicher Creek was infiltrating the nearby sanitary sewer very quickly. This indicated that groundwater base flow from a sub-basin of about 1.7 $km^2$ was not contributing to Beargrass Creek (Figure 34). This systematic loss of base flow reduces dilution potential and negatively impacts water quality.

*Case 3: Brownsboro Road Groundwater Diversion to Sanitary Sewer*

**07-19**

*July 18, 2007:* During low flow conditions, 55 g of SRB were injected into **Drop-Box Spring** [N38.26017°/W85.70914°], 0.62 km east-southeast of CSO 154, where about 1.5 L/s of groundwater was entering the base of a storm drain drop box near Brownsboro Road (Figure 36). This spring flow exited the drop box by means of an underflow device to exclude floating debris. This test was designed to determine if this channelized groundwater was entirely engineered to the sewage treatment plant (as Louisville Metropolitan Sewer District [MSD] records indicate) or if flow leaked or discharged at CSO 154 along Melwood Ave., a sewage-bypass contaminated tributary of Beargrass Creek. In addition to CSO 154, the mouth of the channel fed by the CSO, called Edwards Pond Branch, was monitored for dye in order to detect any dye discharging between the two points.

The dye receptors were exchanged two days later and removed after five days. The results were negative, which supports the MSD records that the channelized groundwater is diverted to the sewage treatment plant. Because of this single diversion, Edwards Pond Branch below CSO 154, which is contaminated by frequent sewer bypasses, fails to receive at least 1.5 L/s (130 $m^3$/d) of flushing by groundwater discharge. Observations suggest that groundwater drainage from the entire 2.8 $km^2$ watershed at the west end of Brownsboro Road may be diverted into the sewer system, depriving the surface stream of ~440 $m^3$/d of base flow (not to mention overloading of the treatment system) (Ray, Blair, and Webb 2008). The map in Figure 37 shows the location of the drop box and groundwater diversion, along with the estimated groundwater basin for this area.

*Groundwater Contamination from Sanitary Sewer*

**Dye Test 07-24 CR (Charlie Roth)**

*December 15, 2007:* After a heavy rain, 15 g of eosine were injected by Charlie Roth of the DOW Louisville Regional Office into a **Sewer Manhole @ US 31-E and Wadsworth Ave** (N30.214972°/W85.673993°). The basement sump in Roth's home (N38.21544°/W85.671355°) was suspected to receive some sanitary sewer exfiltration during high water conditions. Because the sump is dry except during high flow conditions, no background dye receptor could be obtained. The dye receptor was recovered after three days and analyzed. It was determined to be very positive for eosine (++). This result confirmed that the sanitary sewer periodically discharged to the local groundwater system, somewhere within the 250 m distance between the two tested locations. Roth reported the test results to MSD and an investigation and repair was conducted.

**Dye Test 07-24 CR Rep**

*December 19, 2007:* During moderate flow conditions 15 g of eosine were injected with a few gallons of flush water into **Roth Basement Sump**. The purpose of this test was to determine the surface discharge points of the sanitary sewer exfiltration documented in test #07-24-CR. Within 4.5 hrs, a channelized flow beneath a drainage grate at Brighton and Lowell, about 75 m to the east-northeast of the basement sump, was very positive for eosine (++). The next day groundwater flow from a drainage culvert at Kipling Way, 130 m to the east of the basement sump, was likewise very positive for eosine (++). Because the local groundwater flow has been channelized through the storm drainage system, both monitored locations probably received the dye within minutes of the injection in the basement sump. Nearby Farmington Spring was not positive during this test.

**Dye Test 07-24-CR Rep II**

*February 6, 2008:* About 2 months later, the above sanitary sewer test was replicated with 15 g of SRB. During this test a dry background bug was deployed in the sump and exchanged prior to dye injection. One day after injection, the dye receptor was recovered and analyzed. The background and the test bugs were negative for SRB (-). This replication confirmed that the sanitary sewer had been successfully repaired by MSD. Due to the extremely short groundwater flow distance represented, no map for this tracer test has been prepared.

*Suspected Groundwater Contamination from Sanitary Sewer*

***Spring Station Spring* (2175)** is located along the north side of Trinity Road, approximately 550 m southeast of the intersection of Cannons Lane and Lexington Road (N38.24611°/W85.67139°) at an elevation of 156 m AMSL. The spring is not mapped on the Louisville East Topographic and Geological maps. Inventoried a few years prior to this study, the spring was originally called Jesse's Spring (after the owner), but was found to actually be named Spring Station Spring based on historical information. The spring issues from a stone trough, which feeds directly into a large, stone milk house. This spring is the headwaters of an unnamed tributary of the Middle Fork of Beargrass Creek. As mentioned in the water quality section of this report, Spring Station Spring had exceptionally high *E.* coli counts. Furthermore, background dye receptor analyses showed strong and persistent uranine recovery. Both of these factors can be indicative of groundwater contamination from leaking sewage systems. Although occasional sewage odors were present, no sewage solids or discoloration were observed or reported in this spring.

**Dye Test 08-02**

***January 4, 2008:*** During moderate flow conditions, 225 g of SRB were injected into the sanitary sewer at **Wiltshire and Wilmington** (N38.25247°/W85.65627°). This quick test was conducted to attempt the identification of a suspected sewer leak within the Spring Station Spring Basin. The water sample background at Spring Station Spring (N38.246614°/W85.671128°) was negative for SRB. However, an old charcoal receptor from the spring did contain a significant background of SRB. Three days later Spring Station Spring was inconclusive for SRB (?) and a replication was undertaken on 1/11/08.

**Dye Test 08-02 Rep**

***January 11, 2008:*** 170 g of eosine were injected at **Wiltshire and Wilmington** for a second test. Three days later Spring Station Spring was negative for eosine. This was the last attempt to identify the suspected sewer leak in the Spring Station Spring Basin.

## Tracer Tests Not Recovered

### Dye Test 06-18

*September 20, 2006:* During moderate flow conditions 170 g of eosine were injected at **Masonic Home Post Office Sinkhole**, 0.7 km northwest of the junction of Lexington Road (Alt US 60) and US 60 [N38.257696°/85.662859°]. The dye was flushed with water from a garden hose discharging about 0.1 L/s for 5 hours and 45 minutes, for a total of about 4030 L. This sinkhole is located within the hypothesized basin of Spring Station Spring. Four additional springs and streams were monitored until November 6, 2006; plus three sites were briefly monitored a few days after injection. However, the dye was not recovered. Information obtained later in the study suggested that this dye may have infiltrated the sanitary sewer network. This test was not replicated due to the relatively slow intake of flush water.

### Dye Test 06-24

*November 11, 2006:* In response to a reported sinkhole collapse in Plymouth Village of St. Matthews, 56 g of eosine were injected into **Purcell Sinkhole** [N38.241944°/W85.646631°], at the intersection of Plymouth Road and Breckinridge Lane. The soil collapse occurred around a horizontal storm drain pipe, which suggested a leak had triggered the collapse. The homeowner's garden hose was used to flush the dye with about 530 L of water. Charles Taylor of the USGS assisted in the dye injection. Three local sites were monitored for this test.

Floyds Station Spring, the hypothesized dye recovery point for this trace, was negative in three exchanges over two months. However, minor intermittent flow in the unnamed tributary above Floyds Station Spring was inconclusive for eosine (?) over two exchanges, suggesting that Purcell Sinkhole may drain southeast to the channel. Additionally, it cannot be ruled out that dye was stranded due the limited amount of flush water and/or may have infiltrated the sanitary sewer.

**Groundwater Sensitivity Verification**

The potential for extensive karst development in this area was recognized and reported by DOW nearly a decade before this project began (Ray and others, 1994). Figure 38 is the Jefferson County portion of this *Groundwater Sensitivity Regions of Kentucky* map. It clearly illustrates that high recharge porosity, rapid groundwater flow rates and widespread to extensive groundwater dispersion were anticipated. Therefore, a large portion of Jefferson County and almost the entire Beargrass Creek Watershed were given the highest ranking for groundwater sensitivity to contamination. This was based largely on the outcrops of soluble, carbonate rocks (Louisville and Sellersburg & Jeffersonville limestones) shown on the USGS 7.5-Minute Geological Quadrangle maps. However, when the groundwater sensitivity map was produced very little other karst data were known besides some spring locations.

This project showed that karst drainage in the study area is more developed than previously assumed and validated the groundwater sensitivity ranking made in 1994. High recharge porosity was evident in the large cover-collapse sinkholes and sinking/losing streams utilized throughout the watershed for tracer tests. Furthermore, tracer tests revealed rapid groundwater flow velocities in excess of 1.4 km/day. During the course of this study approximately 50 additional springs within the watershed were identified, inventoried and added to the database.

**Spring Descriptions with Summary of New Tracer Tests within the Sinking Creek Basin**

**Cutoff (2961)**

***Cutoff Spring*** is a meander cutoff spring (N37.81252°/W86.48616°) located where Hardins Creek waters return to the surface 685 m to the north of its losing reach, 4.3 km north-northwest of Hardinsburg. Cutoff Spring is unmapped on the Hardinsburg Topographic and Geologic Quadrangle sheets. The feature is a free-draining gravity spring emerging from two main orifices, about 1.5 m above the right bank of Hardins Creek (Figure 39). The spring discharges from the Reelsville Limestone at about 140 m AMSL (Amos, 1975). Low flow discharge of the spring was gaged at 6.8 L/s on 9/29/04, which was calculated to be 90% wastewater effluent discharged upstream from Hardinsburg's Wastewater Treatment Plant. During low flow conditions, a septic odor was apparent at the spring. High flow is estimated to be about 60-100 L/s. No dye trace was necessary to confirm this subterranean cutoff due to discharge observations showing that the intervening stream channel largely ran dry during low-flow conditions, water chemistry parameters and wastewater effluent odors observed (Figure 40).

### Shot Pouch (3360)

***Shot Pouch Bluehole*** is an 8-m wide rising spring (N37.88227°/W86.48333°) located on the left bank of Shot Pouch Creek, 1.35 km upstream of the confluence with Sinking Creek (Figure 41). This spring is unmapped on the Lodiburg Topographic and Geological Quadrangle sheets. The spring discharges from the Ste. Genevieve Limestone at about 117 m AMSL (Hose, Sable, and Hedlund, 1963). Low flow discharge was gaged at 6.5 L/s on 9/29/04, although, due to the size of the rise pool, high flow may be as great as 300-500 L/s.

#### Dye Test 04-07

*May 17, 2004:* During moderate flow conditions, 15 g of uranine were injected at **Overflow Spring @ Northwest Trib**, a pool of water within the base of an overflow spring (N37.87957°/W86.491616°). Shot Pouch Overflow Spring, 310 m to the east-northeast, and Shot Pouch Bluehole, 840 m to the east-northeast were monitored for this test. Two days later Shot Pouch Overflow Spring (N37.880842°/W86.488843°) was extremely positive for Uranine (+++) and Shot Pouch Bluehole (N37.88227°/ W86.48333°) was very positive for Uranine (++). Six weeks later Shot Pouch Bluehole was positive for Uranine (+).

#### Dye Test 04-08

*May 17, 2004:* During moderate flow conditions, 15 g of SRB were injected at **Caney Fork Swallet** (N37.87534°/W86.49439°). Shot Pouch Bluehole, 1.3 km to the northeast, and Shot Pouch Overflow Spring, 0.8 km to the north-northeast, were monitored. Two days later Shot Pouch Bluehole was positive for SRB (+), whereas Shot Pouch Overflow Spring was negative. However, six weeks later both the bluehole and overflow were negative, indicating that the dye passed quickly through the conduit system within the first two days.

**Dye Test 04-09**

***May 17, 2004:*** During moderate flow conditions, 15 g of eosine were injected at **Shot Pouch Creek Swallet** (N37.87305°/W86.48637°). Shot Pouch Bluehole, 1.06 km to the north-northeast, and Shot Pouch Overflow Spring, 0.9 km to the north-northwest, were monitored. Two days later Shot Pouch Bluehole was very positive for eosine (++), whereas Shot Pouch Overflow Spring was negative. However, at the next exchange six weeks later the bluehole was negative, indicating that the dye passed quickly through the conduit system within the first two days. These results are presented on the map in Figure 42.

## Bluehead (3554)

***Bluehead Spring*** is a 10-m wide rising spring located about 0.87 km east of the confluence of Blue Fork and Stony Fork (N37.769183°/W86.253077°), the primary headwaters of Sinking Fork. This spring primarily drains the surface watershed of Blue Fork and supplies the lower perennial reach of the stream. This spring has also been called Milburn Bluehole, and is unmapped on the Garfield Topographic and Geological Quadrangle sheets (Figure 43). The spring discharges from the Ste. Genevieve Limestone at about 171 m AMSL (Amos, 1976). Discharge was not gaged for Bluehead Spring, but the estimated range is 10-5000 L/s.

**Dye Test 07-01**

***February 20, 2007:*** During moderate flow conditions, 170 g of uranine were injected at **Kasey Cemetery Swallet** (N37.74695°/W86.18817°). Six springs and streams were monitored for this trace. Nine days later Bluehead Spring (N37.769183°/W86.253077°), 6.28 km to the northwest, was very positive for uranine (++). Also, dye was recovered at two down-gradient sites, Sinking Creek above Fiddle Spring (+) and Boiling Spring (?). Seven days later, Bluehead Spring was inconclusive for uranine (?) and all other sites were negative. This trace followed the main subsurface flow route for Blue Fork, a predominantly dry stream karst watershed recharging Bluehead Spring (Figure 44).

### Fiddle (1027)

***Fiddle Spring*** is a 5 x 20-m wide rising spring located at the base of a steep bluff at the head of a 200-m long pocket valley (N37.813122°/W86.291253°). It discharges from a large channel on the right bank of Sinking Creek, about 1 km south-southeast of Dents Bridge (Figure 45). The spring is not mapped on the Garfield Topographic and Geological Quadrangle sheets, although the pocket valley is clearly visible. This spring discharges at about 160 m AMSL, from the Ste. Genevieve Limestone (Amos, 1976). Low flow discharge was previously gaged at 26.1 L/s on 9/27/95, and judging from the large spring morphology, high flow may range up to 5 $m^3$/s.

**Dye Test 07-02**

*March 3, 2007:* During moderate flow conditions, 225 g of SRB were injected at **Pilot Ridge @ Billy Johnson** (N37.82404°/W86.27132). Three springs and streams were monitored for this trace. Seven days later Fiddle Spring (N37.813122°/ W86.291253°), 2.1 km to the southwest, was positive for SRB (+) (Figure 46). By 3/20 Fiddle Spring was negative for SRB, indicating an efficient flow system. Considering the dye used and the injection location, the positive trace was accepted, even with a single dye recovery. The basin for Fiddle Spring probably extends much further to the northeast, possibly associated with the Locust Hill Fault or parallel lineaments. However, karst features with active inflow could not be located in the area. Both Bluehead and Fiddle springs are sub-basins of the Boiling Spring karst basin and their positions in the larger system are illustrated on Figure 47 (Ray and others, 2009).

### Dowell #2 (3561)

***Dowell #2 Spring*** is a minor gravity spring (N37.83783°/W86.42008°), with a former pump house below a steep bluff. It is located about 0.47 km north-northwest of Horsley Chapel. The spring is unmapped on the Hardinsburg Topographic and Geologic Quadrangle sheets. It discharges from the Haney Limestone at about 216 m AMSL (Amos, 1975). Winter low flow discharge was estimated at 0.85 L/s on 3/28/07.

**Dye Test 07-03**

*March 28, 2007:* During moderate flow conditions, 30 g of eosine were injected at **Horsley Chapel Swallet** (N37.83504°/W86.41856°). This site is located in the Haney Limestone atop a plateau. A swallet with minor inflow below a waterfall was utilized and about 10 L of additional flush water was carried from a nearby pond in a plastic trash bag. Five local springs were monitored for this trace. Within six days Dowell Spring #2 (N37.83783°/W86.42008°), 340 m to the north-northwest, was extremely positive for eosine, while the other four monitoring locations were negative. Dowell Spring #2 was either very positive (++) or positive (+) for eosine on five additional exchanges until 5/31 (Figure 48).

### Dowell (3555)

***Dowell Spring*** is a minor gravity spring (N37.83799°/W86.42093°) with an active pump house below a steep bluff. It is located about 0.5 km north-northwest of Horsley Chapel. The spring is not mapped on the Hardinsburg Topographic and Geologic Quadrangle sheets. It discharges from the Haney Limestone at about 216 m AMSL (Amos, 1975). Winter moderate-flow discharge was estimated at 0.6 L/s on 3/26/06.

#### Dye Test 07-10

*April 25, 2007:* During moderate flow conditions, 15 g of uranine were injected at **Billy McCubbins Sinkhole** (N37.83569°/W86.41995°) with 375 L of hauled flush water. Three local springs were monitored for this test. Within seven days Dowell Spring (N37.83799°/W86.42093°), 280 m to the north-northwest, was extremely positive for uranine (+++) and Dowell #2 Spring, 270 m to the north, was very positive for uranine (++). Dowell Spring was very positive (++) over three exchanges until 5/30, whereas Dowell #2 Spring was inconclusive by the second exchange on 5/17(Figure 48).

### O’Reilly (2962)

***O’Reilly Spring*** (N37.834816°/W86.425774°) is a minor gravity spring developed as a local domestic and livestock water supply (Figure 49). Located about 0.58 km west-northwest of Horsley Chapel, it discharges at about 210 m AMSL from the Haney Limestone (Amos, 1975). The spring is unmapped on the Hardinsburg Topographic and Geologic Quadrangle sheets. Winter low flow discharge was estimated at 1.1 L/s on 4/15/04, and high flow may increase about ten times.

**Dye Test 07-11**

*April 25, 2007:* During moderate flow conditions, 28 g of SRB were injected at Roadside Sinkhole (N37.83495°/W86.42075°), using 375 L of hauled flush water. Three local springs were monitored for this test. Within seven days Dowell Spring (N37.83799°/W86.42093°), 350 m to the north, was extremely positive for SRB (+++), while O'Reilly Spring (N37.834816°/W86.425774°), 440 m to the west was very positive for SRB (++). Dowell #2 Spring was inconclusive (?) on this exchange and negative thereafter. Dowell Spring remained either very positive (++) or positive (+) over the next three exchanges, until 5/31. O'Reilly Spring was positive (+) on the second exchange on 5/17, inconclusive (?) on the third exchange on 5/24 and negative on the last two exchanges. Figure 48 is a map of the results.

## Thornhill (3563)

***Thornhill Spring*** is a minor gravity spring (N37.83775°/W86.43798°) located about 1.63 km west-northwest of Horsley Chapel. It discharges from the Haney Limestone at about 207 m AMSL (Amos, 1975). The spring is unmapped on either the Hardinsburg Topographic or Geologic Quadrangle sheets. Summer low flow discharge was estimated at about 0.3 L/s on 6/6/07.

**Dye Test 07-17**

*May 24, 2007:* During low flow conditions 28 g of uranine were injected at **Thornhill Sinkhole** (N37.83775°/W86.43798°) using 375 L of hauled flush water. Robbins Spring (N37.84013°/W86.43902°), 330 m to the north-northwest, was monitored for this test (Robbins Spring (#3562) had been identified by Bob Dowell, who was curious about its source). However, seven days and thirteen days later Robbins Spring was negative and it was apparent that the relevant spring had not been monitored. On 6/6 a reconnaissance of two ravines to the south was conducted and Thornhill Spring (N37.83540°/W86.43798°) was discovered, 250 m to the south (Figure 50) of Thornhill Sinkhole. A water sample was taken and determined to be very positive for Uranine (++). The spring was not visited again. However, considering the proximal location and very positive water sample taken 13 days after the sinkhole dye injection, the trace was considered valid.

**Dye Test 07-18**

*May 24, 2007:* During low flow conditions, 0.1 L of Rhodamine WT was injected at **Horsley Chapel Sinkhole** (N37.83396°/W86.41932°), using 375 L of hauled flush water. Three local springs were monitored for this test. Seven days later O'Reilly Spring, 570 m to the west-northwest, was extremely positive for Rhodamine WT (+++), including a visual observation of pink water at the spring. On the last exchange, thirteen days later on 6/6, O'Reilly Spring remained extremely positive for Rhodamine WT (+++). Dowell Spring and Dowell #2 Spring were negative on 5/31. The results for these tests are shown on the map in Figure 48.

**Appendix I** is a summary of the 48 tracer tests conducted for this study. Inferred groundwater flow routes are illustrated as minimum straight-line to curvilinear distances (km), which are less than actual conduit pathways. Groundwater flow velocities are ratios of the straight-line flow path to the recovery-time interval. This interval is usually the time elapsed until the first dye-receptor exchange. Consequently, actual velocities are typically 2-3 times greater than shown.

## CONCLUSIONS

Groundwater in both the Beargrass Creek and Sinking Creek watersheds has been impacted by nonpoint source pollution. The most pervasive pollutants are nutrients, in the form of nitrate (as N), orthophosphate and total phosphorus. Although all of these nutrients can occur naturally, their consistently high levels - over the groundwater quality index values - confirm contribution from anthropogenic sources as well. Within the Beargrass Creek Watershed, elevated nutrients are mainly attributed to residential and commercial application of lawn fertilizers. In the Sinking Creek Watershed, elevated nutrients would mainly be derived from fertilizers applied to agricultural areas. Secondary sources of excess nutrients could also be leaking sewers, failing septic systems and improper management of animal waste. Elevated nutrient levels have a negative impact on surface water quality.

Although none of the pesticides detected exceeded their respective standards, their presence in groundwater was fairly widespread in the Beargrass Creek Watershed. The numerous detections of pesticides at 14 of the Beargrass Creek springs are indicative of nonpoint source pollution impacts to groundwater. However, it does not seem that any of these constitute groundwater failing to meet the standards in 401 KAR 10:031. Pesticide detections in springs in the Beargrass Creek Watershed were much more prevalent than those in the Sinking Creek watershed. The numerous pesticide detections in Beargrass Creek Watershed are attributed to residential and commercial applications of lawn chemicals and treatment around buildings.

Impacts on groundwater from total dissolved solids and total suspended solids seem plausible within the Beargrass Creek Watershed. Although the requisite biological indicators were not analyzed, six of the springs had TDS values that were consistently at or above 500 mg/L and TSS values did occasionally spike over 100 mg/L. Increases in both are attributable to overland runoff entering the karst system rapidly with little or no attenuation.

Only the springs in the Beargrass Creek Watershed were analyzed for *E. coli*. Definite groundwater quality impacts are evident, with 17 of the 18 springs assessed failing to meet the standard. Elevated *E. coli* levels are mainly attributed to leaking sewers and sewer overflows into the karst system. Minor *E. coli* input may also come from surface runoff carrying pet and wildlife waste as it infiltrates the subsurface at sinkholes and stream swallets.

Land use seems to be closely tied to the apparent impacts on groundwater quality. The urban and residential areas of Beargrass Creek Watershed have a stronger negative influence than the agricultural areas drained by springs in the Sinking Creek Watershed. Groundwater quality assessment checklists for each spring evaluated can be found in Appendix II. These spring assessment checklists are grouped by watershed and monitoring site location maps are included for reference.

The 48 tracer tests conducted for this study greatly expanded our knowledge of groundwater flow in both of the study area watersheds. Groundwater tracing and field reconnaissance in Beargrass Creek Watershed revealed significant karst development and verified the high groundwater sensitivity rating assigned by DOW in 1994 by Ray and others. In addition, confirmed loss of groundwater to the sanitary sewer illustrates the need for repairs to aging infrastructure – not only in Jefferson County, but also in urbanized areas throughout Kentucky's karst regions.

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# Appendix I. Tracer Test Summary Tables

## Beargrass Creek Watershed and Vicinity (Jefferson County)

## Tracer Tests Summary Table

| Dye Injection Number (Date m/d/y) | Dye Injection Site | Coordinates (Decimal Degrees) | Dye Recovery Site(s) | Coordinates | Interpreted GW-Flow Path (km) | GW-Flow Velocity (km/day) |
|---|---|---|---|---|---|---|
| 04-01 (4/14/04) | Bullitt Estate Swallet | N38.229553°/ W085.597083° | not recovered | - | - | - |
| 04-01 rep (2/14/08) | Bullitt Estate Swallet | N38.229553°/ W085.597083° | Hole 10 Spring | N38.22862°/ W085.602467° | 0.5 | >0.125 |
| 04-02 (4/14/04) | Sayback Ditch | N38.23748°/ W085.60196° | Oxmoor Spring<br>Upper Oxmoor Spring | N38.23962°/ W085.60834°<br>N38.24166°/ W085.60590° | 0.6<br>0.6 | >0.6<br>>0.6 |
| 04-03 (4/14/04) | Perma Drive Class V | N38.19704°/ W085.64584° | Buechel Spring | N38.18851°/ W85.65575° | 1.32 | >1.4 |
| 04-04 (4/15/04) | Buechel Park North Swallet | N38.19400°/ W85.63498° | Culvert Spring<br>Confluence Spring | N38.18808°/ W85.64254°<br>N38.18832°/ W85.64183° | 0.94<br>0.85 | >0.24<br>>0.21 |
| 04-05 (4/22/04) | Woodhaven County Club Trib | N38.17028°/ W85.63989° | not recovered | - | - | - |
| 04-05 rep (5/4/04) | Woodhaven County Club Trib | N38.17028°/ W85.63989° | Culvert Spring @ Genfab | N38.15386°/ W85.64984° | 2.0 | >1.0 |
| 04-06 (4/22/04) | Taylor Spring | N38.274791°/ W85.638285° | Windy Hills Springs<br>(Newstadt Spring) | N38.273197°/ W85.637755°<br>N38.273096°/ W85.638117° | 0.175<br>0.175 | >0.044<br>>0.044 |
| 04-10 (6/15/04) | Swallet @ St. Matthews Park | N38.255553°/ W85.624340° | Bowling Blvd. Spring | N38.24583°/ W85.62848° | 1.14 | >0.38 |
| 04-11 (6/29/04) | U of L/US 60 Sinkhole | N38.24710°/ W85.58122° | Steinrock Spring | N38.25695°/ W85.58991° | 1.32 | >0.66 |
| 04-12 (6/29/04) | Losing Stream @ Hurstbourne | N38.243567°/ W85.595966° | not recovered | - | - | - |
| 04-17 (10/8/04) | Weicher Creek Swallet | N38.23040°/ W85.61611° | not recovered | - | - | - |
| 04-18 (10/8/04) | Losing Stream (Bedrock Slot) @ Hurstbourne | N38.242126°/ W85.593385° | not recovered | - | - | - |
| 04-19 (11/17/04) | Fenley Development Sink | N38.270285°/ W85.575960° | A.B. Sawyer Gate<br>Sawyer Karst Window | N38.261793°/ W85.582976°<br>N38.263502°/ W85.580822° | 1.18<br>0.74 | >0.63<br>>0.4 |
| 06-18 (9/20/06) | Masonic Home Post Office Sinkhole | N38.257696°/ 85.662859° | not recovered | - | - | - |
| 06-19 (9/20/06) | Crescent Hill Golf Course Swallet | N38.259278°/ W85.67533° | Mockingbird Valley Spring | N38.269408°/ W85.681913° | 1.2 | >0.133 possibly >0.240 |
| 06-20 (10/2/06) | CarMax Sinkhole Collapse | N38.22016°/ W85.58054° | Nunnlea Spring<br>Zehnderhouse Spring | N38.218455°/ W85.585427°<br>N38.216145°/ W85.589230° | 0.518<br>0.91 | >0.296<br>>0.227 |
| 06-21 (10/17/06) | St. Matthews Elementary School Swallet | N38.246111°/ W85.638910° | not recovered | - | - | - |

| Dye Injection Number (Date m/d/y) | Dye Injection Site | Coordinates (Decimal Degrees) | Dye Recovery Site(s) | Coordinates | Interpreted GW-Flow Path (km) | GW-Flow Velocity (km/day) |
|---|---|---|---|---|---|---|
| 06-21 rep (2/5/08) | St. Matthews Elementary School Swallet | N38.246111°/ W85.638910° | Cypress Pointe Sp. #3? (inconclusive) | N38.241991°/ W85.632750° | - | - |
| 06-21 rep II (2/22/08) (moderate flow conditions) | St. Matthews Elementary School Swallet | N38.246111°/ W85.638910° | Cypress Pointe Sp. #1 (quaternary; overflow?)<br>Cypress Pointe Sp. #2 (primary dye recovery)<br>Cypress Pointe Sp. #3 (secondary)<br>Cypress Pointe Sp. #4 (tertiary; overflow?) | N38.242544°/ W85.631940°<br>N38.242494°/ W85.632281°<br>N38.241991°/ W85.632750°<br>N38.241857°/ W85.633005° | 0.69<br>0.68<br>0.67<br>0.67 | >0.230<br>>0.227<br>>0.223<br>>0.223 |
| 06-22 (10/20/06) | Taylor Karst Window | N38.21763°/ W85.61720° | Ray Spring | N38.212246°/ W85.624122° | 0.86 | >0.215 |
| 06-23 (10/24/06) | Forum 3 Pool | N38.25193°/ W85.57577° | Steinrock Spring | N38.25695°/ W85.58991° | 1.4 | >0.495 |
| 06-24 (11/11/06) | Purcell Sinkhole | N38.241944°/ W85.646631° | Unnamed tributary above Floyds Station Sp. (inconclusive) | N38.238502°/ W85.645104° | - | - |
| 06-26 (11/27/06) | Losing Stream @ Hurstbourne | N38.242126°/ W85.593385° | not recovered | - | - | - |
| 06-26 rep (12/15/06) | Losing Stream @ Hurstbourne | N38.242126°/ W85.593385° | not recovered | - | - | - |
| 06-26 rep II (1/23/07) | Losing Stream @ Hurstbourne | N38.242126°/ W85.593385° | not recovered | - | - | - |
| 07-04 (4/3/07) | Losing Stream @ Hurstbourne | N38.242126°/ W85.593385° | Oxmoor Woods Sanitary Sewer @ Manhole<br>Camden Oxmoor Sanitary Sewer @ Manhole | N38.242324°/ W85.603981°<br>N38.240462°/ W85.618625° | 0.9<br>2.2 | >2.7 sewer flow<br>>6.2 sewer flow |
| 07-19 (7/18/07) | Drop-box Spring | N38.26017°/ W85.70914° | Channelized to STP | - | - | - |
| 07-20 (7/18/07) | Dannywood Swallet | N38.22976°/ W85.61562° | not recovered | - | - | - |
| 07-20 rep (1/25/08) | Dannywood Swallet | N38.22976°/ W85.61562° | Dannywood Sewer | N38.230247°/ W85.615683° | 0.07 | >0.918 sewer flow |
| 07-24-CR (Charlie Roth) (12/15/07) | Sewer Manhole @ US 31-E and Wadsworth Ave. | N30.214972°/ W85.673993° | Roth Basement Sump Discharge (via sewer exfiltration) | N38.21544°/ W85.671355° | 0.245 | >0.082 partially sewer flow |
| 07-24-CR rep (2/6/08) | Sewer Manhole @ US 31-E and Wadsworth Ave. | N30.214972°/ W85.673993° | not recovered in Roth Basement Sump Discharge** | N38.21544°/ W85.671355° | 0.245 | **sewer exfiltration repaired by MSD |
| 07-24 (12/19/07) | Roth Basement Sump | N38.21544°/ W85.671355° | Channelized Flow @ Brighton & Lowell<br>Kipling Way Culvert Spring | N38.215574°/ W85.670717°<br>N38.215288°/ W85.669888° | 0.075<br>0.13 | >0.4<br>>0.126 |
| 07-25 (12/19/07) | Interchange Sinkhole | N38.23953°/ W85.62223° | not recovered | - | - | - |
| 07-25 rep (12/26/07) | Interchange Sinkhole | N38.23953°/ W85.62223° | Culvert Spring above Watterson [Expressway] | N38.24380°/ W85.62099° | 0.49 | >0.245 |
| 08-01 (1/4/08) | Bonner Ave. Collapse | N38.25340°/ W85.63839° | Cypress Pointe Sp. #1<br>Cypress Pointe Sp. #2 (monitored 1/11/08) | N38.242544°/ W85.631940°<br>N38.242494°/ W85.632281° | 1.352<br>equivalent? | >0.450<br>equivalent? |

| Dye Injection Number (Date m/d/y) | Dye Injection Site | Coordinates (Decimal Degrees) | Dye Recovery Site(s) | Coordinates | Interpreted GW-Flow Path (km) | GW-Flow Velocity (km/day) |
|---|---|---|---|---|---|---|
| 08-02 (1/4/08) | Wiltshire-Wilmington Sewer | N38.25247°/ W85.65627° | Spring Station Spring? (inconclusive with SRB; actual backgr.) | N38.246614°/ W85.671128° | - | - |
| 08-02 rep (1/11/08) | Wiltshire-Wilmington Sewer | N38.25247°/ W85.65627° | not recovered (negative with eosine) | - | - | - |
| 08-03 (1/11/08) | Bag Job @ 1-64 I-264 Interchange | N38.23658°/ W85.62469° | Weicher Creek Diversion Spring<br><br>Brown Cemetery Culvert Spring<br><br>Low Dutch Station Spring | N38.23564°/ W85.63550°<br>N38.23569°/ W85.63596°<br>N38.23667°/ W85.63469° | 0.94<br><br>0.94<br><br>0.87 | >0.313<br><br>>0.313<br><br>>0.29 |
| 08-04 (1/14/08) | Watterson Sinkhole #3 | N38.23513°/ W85.62545° | Weicher Creek Diversion Spring<br><br>Brown Cemetery Culvert Spring<br><br>Low Dutch Station Spring | N38.23564°/ W85.63550°<br>N38.23569°/ W85.63596°<br>N38.23667°/ W85.63469° | 0.655<br><br>0.655<br><br>0.62 | >0.328<br><br>>0.328<br><br>>0.310 |
| 09-01 (2/4/09) | Darbyshire Swallet | N38.262893° W85.599834° | A'Sturgus Station Spring | N38.24556°/ W85.61639° | 2.6 | >0.325 |

Summary of groundwater tracer tests (4/14/2004-2/04/2009). *Dye non-recovery emphasized in yellow, including most likely destination of drainage (?).* **Tests interpreted to be positive at less than the standard criterion of 4X background, or two sequential positives.*

## Sinking Creek Watershed (Breckinridge County)

## Tracer Tests Summary Table

| Dye Injection Number (Date m/d/y) | Dye Injection Site | Coordinates (Decimal Degrees) | Dye Recovery Site(s) | Coordinates | Interpreted GW-Flow Path (km) | GW-Flow Velocity (km/day) |
|---|---|---|---|---|---|---|
| Dye-trace of cutoff route not required. | Hardins Creek Losing Reach | N37.806343°/ W86.486247° | Cutoff Spring *Determined by gaged stream loss and similar water chemistries. | N37.81252°/ W86.48616° | 0.685 | - |
| 04-07 (5/17/04) | Overflow Sp. @ NW Trib | N37.87957°/ W86.491616° | Shot Pouch Bluehole<br>Shot Pouch Overflow Sp. | N37.88227°/ W86.48333°<br>N37.880842°/ W86.488843° | 0.84<br>0.31 | >0.42<br>>0.155 |
| 04-08 (5/17/04) | Caney Fork Swallet | N37.87534°/ W86.49439° | Shot Pouch Bluehole | N37.88227°/ W86.48333° | 1.3 | >0.65 |
| 04-09 (5/17/04) | Shot Pouch Cr. Swallet | N37.87305°/ W86.48637° | Shot Pouch Bluehole | N37.88227°/ W86.48333° | 1.06 | >0.53 |
| 07-01 (2/20/07) | Kasey Cemetery Swallet | N37.74695°/ W86.18817° | Bluehead Spring | N37.769183°/ W86.253077° | 6.28 | >0.7 |
| 07-02 (3/1/07) | Pilot Ridge @ Billy Johnson | N37.82404°/ W86.27132 | Fiddle Spring | N37.813122°/ W86.291253° | 2.11 | >0.3 |
| 07-03 (3/28/07) | Horsley Chapel Swallet | N37.83504°/ W86.41856° | Dowell Sp. #2 | N37.83783°/ W86.42008° | 0.34 | >0.056 |
| 07-10 (4/25/07) | Billy McCubbins Sinkhole | N37.83569°/ W86.41995° | Dowell Spring<br>Dowell Sp. #2 | N37.83799°/ W86.42093°<br>N37.83783°/ W86.42008° | 0.28<br>0.27 | >0.04<br>>0.038 |
| 07-11 (4/25/07) | Roadside Sinkhole | N37.83495°/ W86.42075° | Dowell Spring<br>O'Reilly Spring | N37.83799°/ W86.42093°<br>N37.834816°/ W86.425774° | 0.35<br>0.44 | >0.05<br>>0.063 |
| 07-17 (5/24/07) | Thornhill Sinkhole | N37.83775°/ W86.43798° | Thornhill Spring | N37.83540°/ W86.43798° | 0.25 | >0.019 |
| 07-18 (5/24/07) | Horsley Chapel Sinkhole | N37.83396°/ W86.41932° | O'Reilly Spring | N37.834816°/ W86.425774° | 0.57 | >0.081 |

Summary of groundwater tracer tests (4/14/2004-2/04/2009).

## Appendix III. Financial and Administrative Closeout

Workplan Outputs

The [former] Groundwater Branch has committed to the following outputs:

- Identification of suitable groundwater monitoring sites in the Salt River basin
- Collection of samples from 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 priority watersheds
- 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 $138,412
- Budget has been expended in personnel costs approximately equivalent to 2.03 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 code used for this project was:

ACT MOAM/MODA

PROJECT NPS0303Z

**Project Budget:**

**The total project budget is $138,412. The budget will be expended in personnel costs reflecting a total equivalent of approximately 2.03 person years. The [former] Groundwater Branch personnel will manage the project, research background data, conduct on-site inspections and groundwater sampling, transport samples, interpret sample results, prepare maps and reports, and present the summary information to stakeholders and other interested parties. The Environmental Services Branch (ESB) lab personnel will conduct chemical analysis. A time code will be established to track personnel time spent on the project. Match for this grant will be provided by DOW and ESB personnel costs, including fringe and overhead.**

Budget Summary:

| Budget Categories | BMP Implementation | Project Management | Public Education | Monitoring | Technical Assistance | Other | Total |
|---|---|---|---|---|---|---|---|
| Personnel | $ | $ | $ | $96,930 | $ | $ | $96,930 |
| Supplies | | | | | | | |
| Equipment | | | | | | | |
| Travel | | | | | | | |
| Contractual | | | | | | | |
| Operating Costs | | | | $41,482 | | | $41,482 |
| Other | | | | | | | |
| **TOTAL** | **$** | **$** | **$** | **$138,412** | **$** | **$** | **$138,412** |

## Detailed Budget

| Budget Categories | Section 319(h) | Non-Federal Match | Total |
|---|---|---|---|
| Personnel | $58,158 | $38,772 | $96,930 |
| Supplies | $ | $ | $ |
| Equipment | $ | $ | $ |
| Travel | $ | $ | $ |
| Contractual | $ | $ | $ |
| Operating Costs | $24,889 | $16,593 | $41,482 |
| Other | $ | $ | $ |
| **TOTAL** | $**83,047** | **$55,365** | **$138,412** |

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 IV.  Quality Assurance / Quality Control for Water Monitoring

QA/QC Plan for Nonpoint Source Pollution Impacts and Spring Basin Delineations within Sub-watersheds of the Salt River Basin:  Beargrass Creek and Sinking Creek (BMU2, Round 2)

Prepared by

Peter T. Goodmann, Manager, Groundwater Branch
James S. Webb, Supervisor, Groundwater Branch
Joseph A. Ray, Geologist-Registered, Groundwater Branch

Kentucky Division of Water

# 1. Title Section

## A. Project Name

Integrated Surface Water and Groundwater Assessment of Large Springs in the Green River Basin (Basin Management Unit 4).

## B. QA/QC Plan Preparers

Peter T. Goodmann, Manager, [former] Groundwater Branch
James S. Webb, Supervisor, [former] Groundwater Branch
Joseph A. Ray, Geologist-Registered, [former] Groundwater Branch
Kentucky Division of Water
200 Fair Oaks Lane
Frankfort, Kentucky 40601
(502) 564-3410

## C. Date

January 31, 2004

## D. Project Description

The project is part of the Salt and Licking Rivers Strategic Watershed Monitoring Plan. The Kentucky Division of Water currently conducts quarterly nonpoint source groundwater monitoring at approximately 70 sites across the state. This project will expand that monitoring effort in priority watersheds in the Salt River Basin 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 Beargrass and Sinking Creeks Watersheds. 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

The Technical Services Section of the [former] Groundwater Branch will coordinate this project in cooperation with Data Management Section staff of the [former] Groundwater Branch, Kentucky Division of Water.

The [former] Groundwater Branch, Kentucky Division of Water, will scout and select suitable sampling locations. Staff of the [former] Groundwater Branch will perform 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 Department for Environmental Protection's Consolidated Groundwater Database and will be forwarded to the Kentucky Geological Survey's Groundwater Data Repository.

Robert J. Blair, P.G., will be the Project Officer, QA Officer, and Field Sampling Officer. Address: 200 Fair Oaks Lane, Frankfort, KY 40601. Phone (502)-564-3410.

**B. Laboratory**

Environmental Services Branch
100 Sower Boulevard
Frankfort, Kentucky 40601
(502) 564-6120

**C. Participating Agencies**

The [former] Groundwater Branch, Division of Water currently conducts statewide ground water monitoring for the Ambient Groundwater Monitoring Program.

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

## 3. Watershed Information

**A. Stream Names**

Beargrass Creek, Sinking Creek and tributaries.

**B. Major River Basins**

Salt River Basin.

**USGS Hydrologic Unit Number (HUC)**

| | |
|---|---|
| Salt River Basin: | 051401 |
| Beargrass Creek: | 0514010105 |
| Sinking Creek: | 0514010425 |

**C. Stream Order**

This project encompasses basins of the Salt River.

### D. Counties in the Study Area

Beargrass Creek Watershed: Jefferson.

Sinking Creek Watershed: Breckinridge, Meade and Hardin.

## 4. Monitoring Objectives

- Determine impacts of nonpoint source pollution on groundwater resources in Beargrass and Sinking creeks watersheds.
- Integrate surface water assessment protocols into groundwater monitoring programs.
- 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 and the Agriculture Water Quality Authority.
- Provide additional data useful for the long-term management of the resource.

## 5. Study Area Description

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 basin, the Ohio River Alluvium is also an important aquifer and is sometimes considered as a unique physiographic region.

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

The Beargrass Creek watershed is located in west-central Jefferson County, Kentucky and covers an area of 157 $km^2$. The highest elevation of 750 feet (229 m) occurs on the northeastern tip of the watershed boundary. The elevation of the creek's confluence with the Ohio River is approximately 430 feet (131 m). The watershed is in the Outer Bluegrass Physiographic Region (Lobeck, 1930). This area is underlain by limestone, dolostone and shale of Ordovician, Silurian, Devonian and Mississippian ages. The majority of the Outer Bluegrass Region has only moderate to minor karst development. However, rock units within the Beargrass Creek watershed are very soluble and have well developed karst drainage. The creek has three main tributaries: Muddy Fork, Middle Fork and South Fork. The Muddy Fork is the northern-most tributary and rises in the Windy Hills area, northeast of St. Matthews. It flows generally westward to the confluence with the main stem of the creek, which is just east of the intersection of Interstates 64 and 71. The Middle Fork rises just west of Anchorage and flows westward to its confluence with the South Fork, just north of Cave Hill Cemetery. Weicher Creek is a minor tributary of the Middle Fork, originating near Hurstbourne Acres and flowing west to the confluence near the interchange of Interstates 64 and 264. The South Fork rises to the south of Hurstbourne Acres and flows west and northwest to the confluence with the Middle Fork. Other minor, unnamed tributaries are shown on the USGS topographic maps. Beargrass Creek discharges to the Ohio River just upstream of the Municipal Harbor and Towhead Island.

The Sinking Creek watershed is located mainly in Breckinridge County, Kentucky with headwaters extending slightly into western Meade County and northern Hardin County. The creek rises on the southern fringes of Breckinridge County and flows west-northwest to its confluence with the Ohio River. Numerous short-segment sinking streams occur on the eastern fringe of the watershed, which have been shown through tracer tests to drain mainly to springs in the lower part of the watershed. However, some of these sinking streams have been traced to springs in adjacent watersheds. The watershed covers 620 $km^2$, all of which is within the Mississippian Plateau Physiographic Region, on the eastern edge of the Western Coal Field (Lobeck, 1930). The watershed is underlain primarily by Mississippian-aged limestone with minor sandstone units. Well-developed karst drainage is prevalent throughout the watershed. The highest elevation of 984 ft (300 m) occurs on the eastern divide at Bee Knob Hill, near Flaherty, Kentucky in Meade County. The elevation at the mouth of Sinking Creek, where it meets the Ohio River, is 383 ft (117 m). Main tributaries to Sinking Creek include Sugar Tree Run on the north side and Shot Pouch Creek, Hardins Creek and Dorridge Creek flowing from the south. All of these tributaries are located in the lower portion of the watershed. Tributaries in the upper portion of the watershed are typically short, unnamed sinking streams, many of which have been dye traced (Ray and others, 2009).

## 6. Monitoring Program/Technical Design

### A. Monitoring Approaches

Monitoring of approximately 30 sites will begin in April 2004. Specific sample sites will be selected after the Division of Water’s groundwater database has been reviewed for candidate sites and field inspection has confirmed that the candidate sites are suitable for monitoring. For all selected sites, either a Kentucky Water Well Record or a Kentucky Spring Inventory Form (examples attached as Appendix 1) will be placed on record with the Division of Water. 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 final site selection 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 2004 and samples will be collected quarterly through March 2005.

### D. Sample Parameters, Containerization, Preservation, and Handling

Consistent with other monitoring efforts, samples will be collected at each spring or well and 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 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, 1995) and current guidance from the Division of Environmental Services. Parameters to be measured, volume required for analysis, container type, preservative (if any), holding times (if any), and analytical methods are shown on the attached Chain-of-Custody Form.

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 fabric swatches may be used to detect optical brighteners, the whitening agents used in laundry products and commonly found in sewage (Quinlan, 1987). 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.

All samples will be analyzed by Environmental Services Branch laboratory according to the appropriate EPA 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 ESB laboratory, for each sample. The ESB 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 [former] 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 directly into a new clean sampling container and will be transferred to the appropriate new clean sample container during the filtration process container. New disposable single use filters and tubing will be used in the filtration process. 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, 1995) and current guidance from the Division of Environmental Services. 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 until conductivity readings stabilize prior to sampling, in order to ensure that groundwater, rather than water that has been standing in the well bore, is being sampled. Spring 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. According to Division of Environmental Services accepted procedures, duplicate analyses will be accepted if they are within 20 % rsd. If unacceptable results are found, samples will be re-analyzed and field records will be examined to determine the cause.

### 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.

## 9. References

Kentucky Division of Water, 1995, Standard operating procedures for nonpoint source surface water quality monitoring projects: Kentucky Natural Resources and Environmental Protection Cabinet, Frankfort, KY, 138 p.

McDowell, Robert C., Grabowski, Gilbert J, Moore, Samuel L., 1988, Geologic Map of Kentucky, Sesquicentennial Edition of the Kentucky Geological Survey, by U.S. Geological Survey, Daniel Peck, Director, and in cooperation with the Kentucky Geological Survey, Donald C. Haney, State Geologist and Director. Compiled by Martin C. Noger, Kentucky Geological Survey.

Quinlan, J. F., ed., 1987, Qualitative water-tracing with dyes in karst terrains – Practical karst hydrogeology, with emphasis on groundwater monitoring, National Water Well Association 26 p.

Ray, Joseph, Webb, James, S., and O'dell, Phillip W., 1994, Groundwater Sensitivity Regions of Kentucky, Kentucky Department for Environmental Protection, Division of Water, Groundwater Branch, map.

**CHAIN OF CUSTODY RECORD**
**ENERGY and ENVIRONMENT CABINET**
**DIVISION OF WATER - WATERSHED MANAGEMENT BRANCH - GROUNDWATER – WPC0603Z**

| **Site Identification** | **Collection Date/Time** | **Field Measurements** |
|---|---|---|
| □ – Complaint/1x Sample Site<br>Location:<br><br>County:<br><br>AKGWA #: | Date: ____________<br><br>Time: ____________ | pH: _______ Conductivity: _________ μmhos<br><br>Temp: ______ °C Spring flow: _____________ |

Sampler ID: ___________________________

| **Division for Environmental Services Samples** | | | |
|---|---|---|---|
| **Analysis Requested** | **Container Size, Type** | **Preservation Method** | **Parameters** |
| | 1000 ml<br>Plastic<br>Boston Round | Cool to 4°C | **Bulk Parameters**<br>Chloride,<br>Conductivity, Fluoride,<br>Nitrate-N, Nitrite-N, pH,<br>Sulfate, TSS, TDS, Ortho-P |
| | 1000 ml<br>Plastic<br>Boston Round | $H_2SO_4$<br>Cool to 4°C | **Nutrients**<br>$NH_3$ / TKN / TOC/Total Phosphorous |
| | 1000 ml<br>Plastic<br>Boston Round | Filtered<br>$HNO_3$<br>Cool to 4°C | **Dissolved Metals by ICP**<br>Plus: Arsenic, Lead,<br>Mercury, Selenium |
| | 1000 ml<br>Plastic<br>Boston Round | $HNO_3$<br>Cool to 4°C | **Total Metals by ICP**<br>plus Arsenic, Lead,<br>Mercury, Selenium |
| | 1000 ml<br>Amber Glass | Cool to 4°C | **NP Pesticides**<br>**Pesticides/PCBs**<br>Methods 507/508 |
| | 1000 ml<br>Amber Glass | 5ml HCl<br>Cool to 4°C | **Herbicides/Caffeine** |
| | 250 ml HDPE<br>Wide Mouth | Cool to 4°C<br>NO HEAD SPACE | **Alkalinity** |
| | Three 40ml<br>Amber Glass | 50% HCl<br>Cool to 4°C | **VOCs**<br>(Trip Blank Required) |
| | 125ml Amber Glass | Cool to 4º C | **Glyphosate** |
| | Two - 1000 ml<br>Amber Glass | 5ml HCl<br>Cool to 4°C | **Duplicate**<br>(only collect if requested) |
| | | | |

**Signatures:**

Relinquished by: ____________________________________
Date: ___________ Time: _________
Received by: ________________________________________

Relinquished by: ____________________________________
Date: ___________ Time: _________
Received by: ________________________________________

Relinquished by: ____________________________________
Date: ___________ Time: _________
Received by: ________________________________________

Sample #: __________________ Report #: __________________
**DISCARD SAMPLES UPON COMPLETION**

Comments:

$H_2SO_4$ ________________ (Expiration Date)

$HNO_3$ ________________ (Expiration Date)

HCl (1:1) ______________(Expiration Date)

# Beckmar Laboratory

**3251 Ruckriegle Parkway, Louisville, KY  40299**

**Phone (502) 266-6533 (Paul Barker)**

| Field Conditions | | | | | MPN Analysis Requested | | Lab Receipt | | | | Results (per 100 mL sample_ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Time | ID/Description | Discharge Est. | Temperature (optional) | Total Coliform | E. Coli | Date | Time | Temperature | Lab Number | Total Coliform | E. Coli |
| | | | | | X | X | | | | | | |
| | | | | | X | X | | | | | | |
| | | | | | X | X | | | | | | |
| | | | | | X | X | | | | | | |
| | | | | | X | X | | | | | | |
| | | | | | X | X | | | | | | |
| | | | | | X | X | | | | | | |
| | | | | | X | X | | | | | | |
| | | | | | X | X | | | | | | |
| | | | | | X | X | | | | | | |

Relinquished By: ____________________ Date/Time: ____________

Received By: ____________________ Date/Time: ____________

Analysis Results Reported By: ____________________ Date/Time: ____________

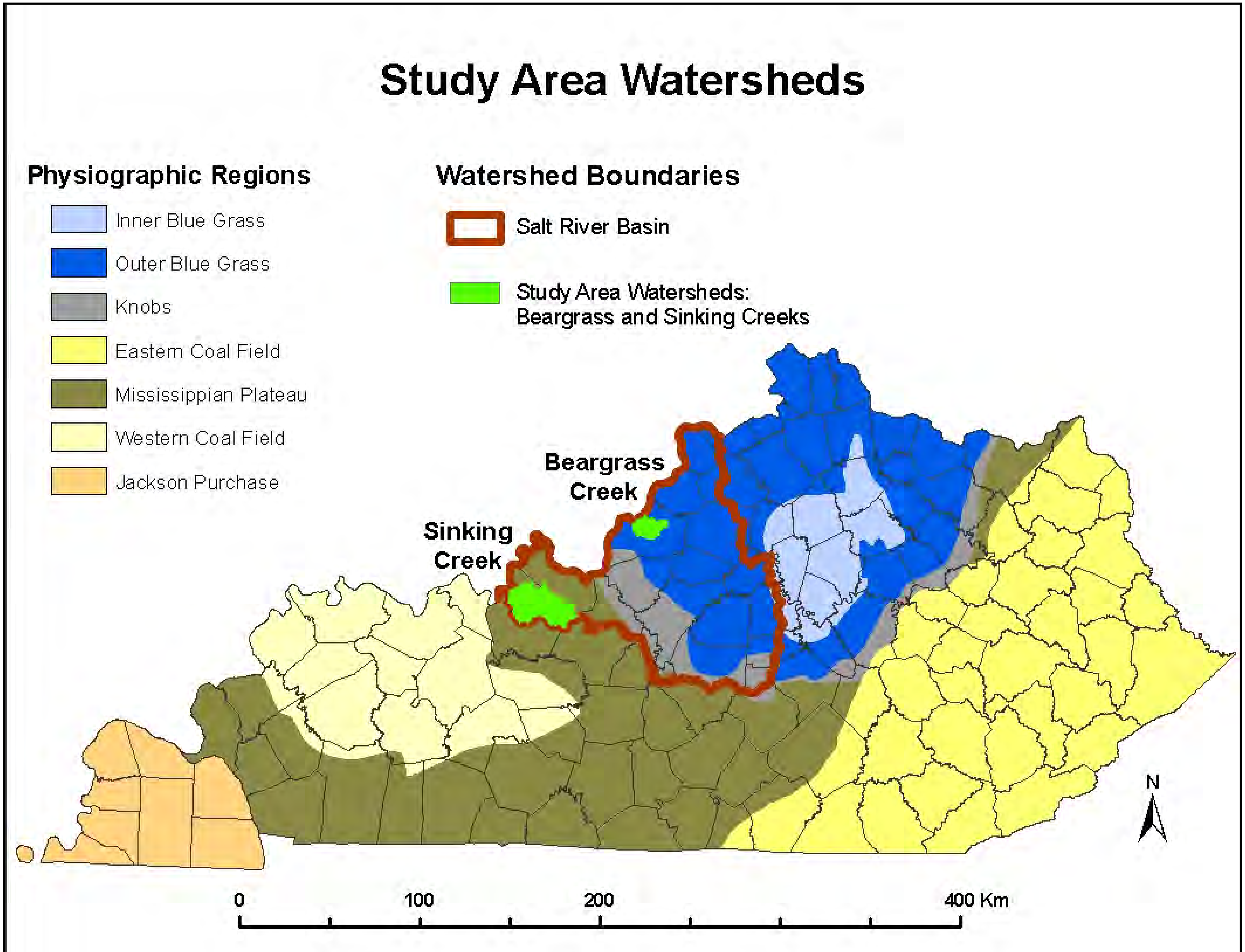



Figure 1a. Study Area Watershed Locations

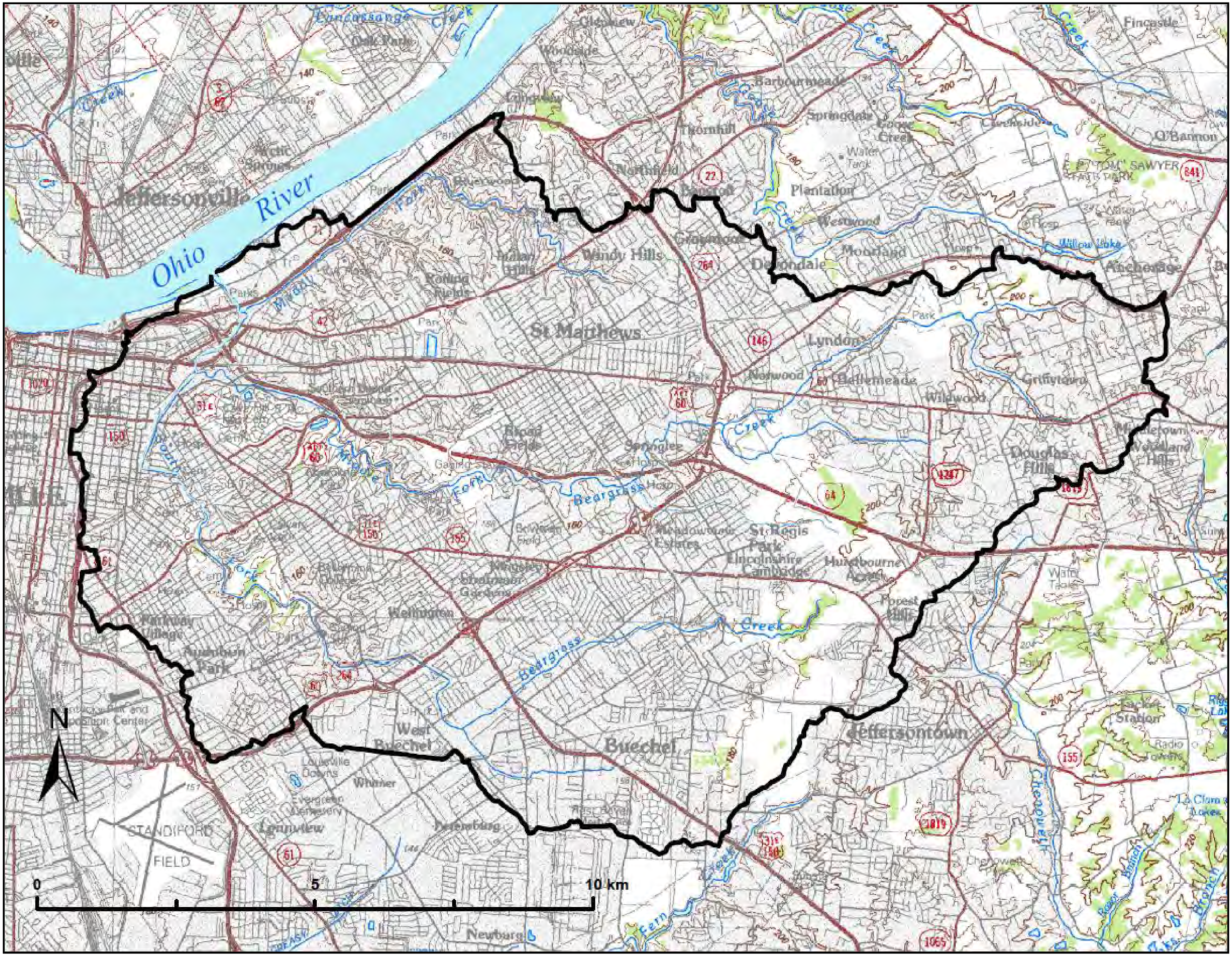



Figure 1b. Beargrass Creek Watershed

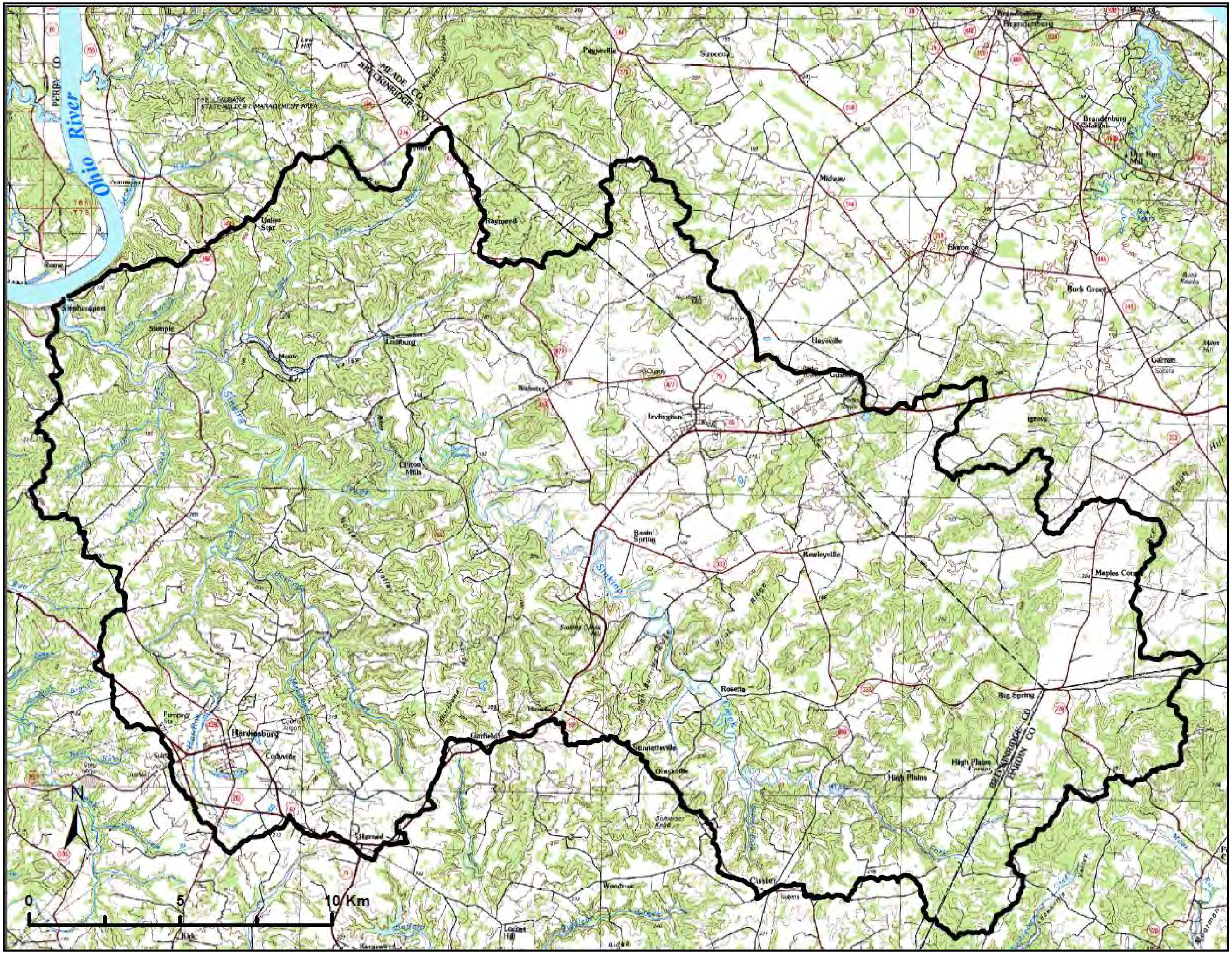



Figure 1c. Sinking Creek Watershed

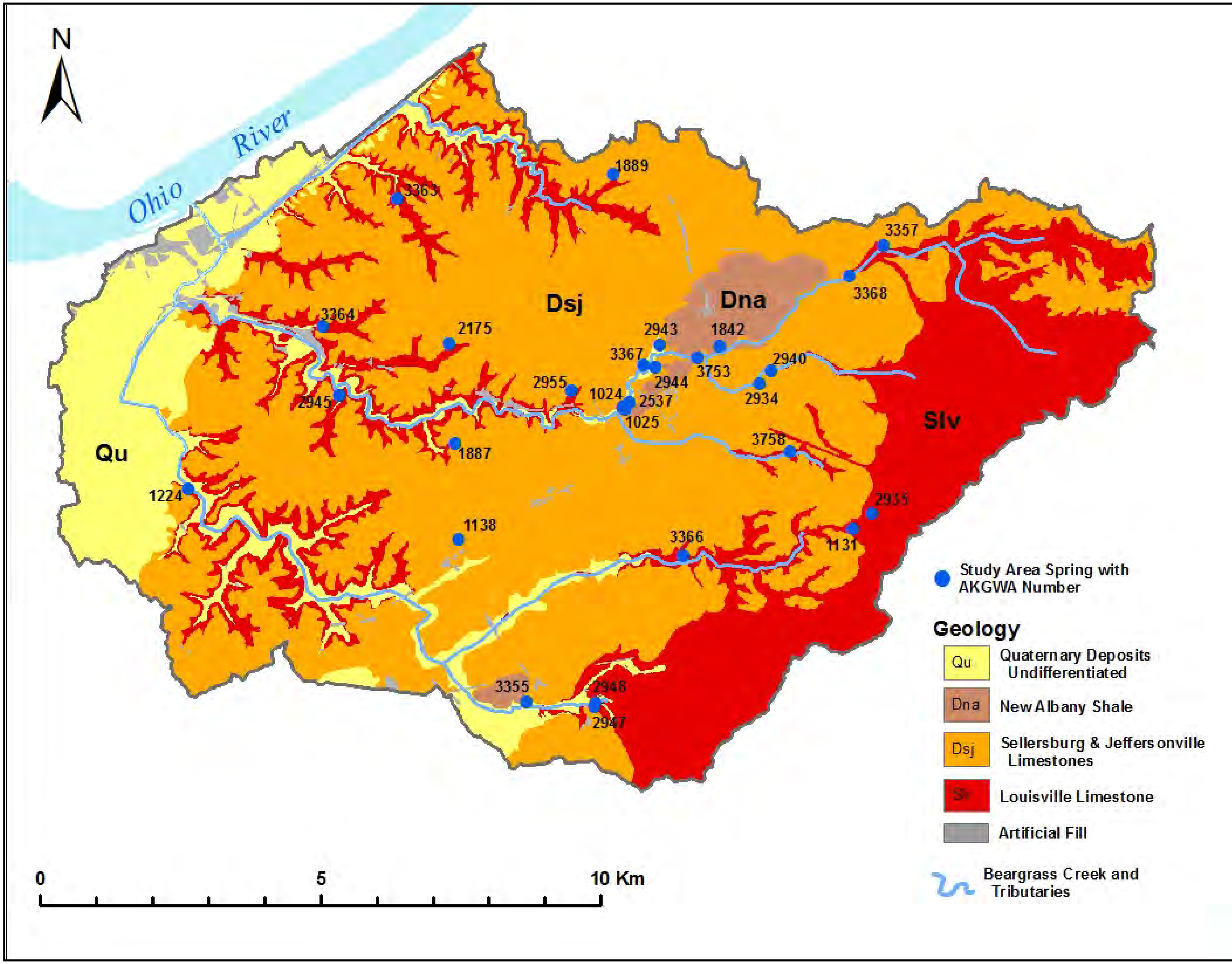



Figure 2. Beargrass Creek Watershed Geological Map with Monitored Spring Locations

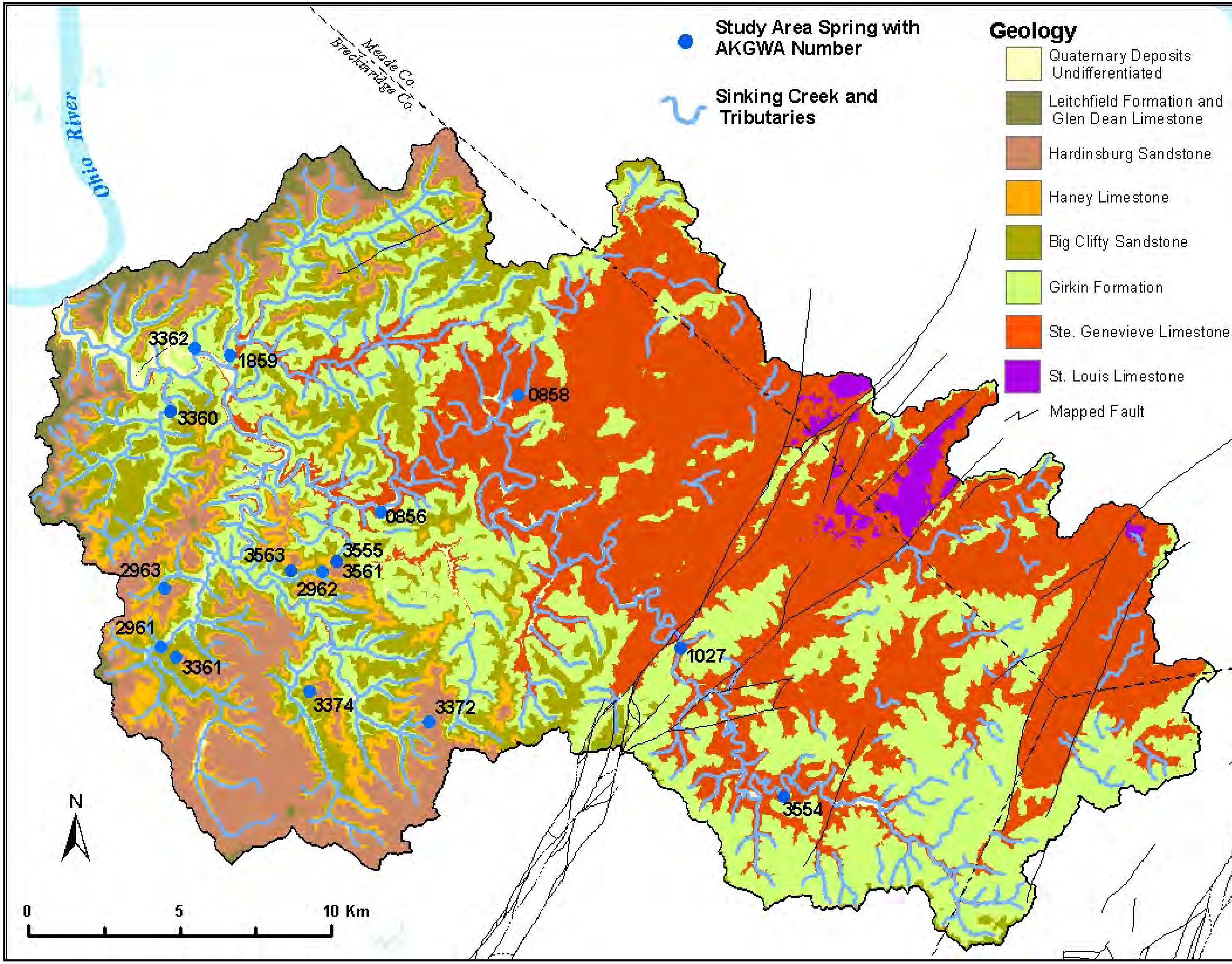



Figure 3. Sinking Creek Watershed Geological Map with Monitored Spring Locations

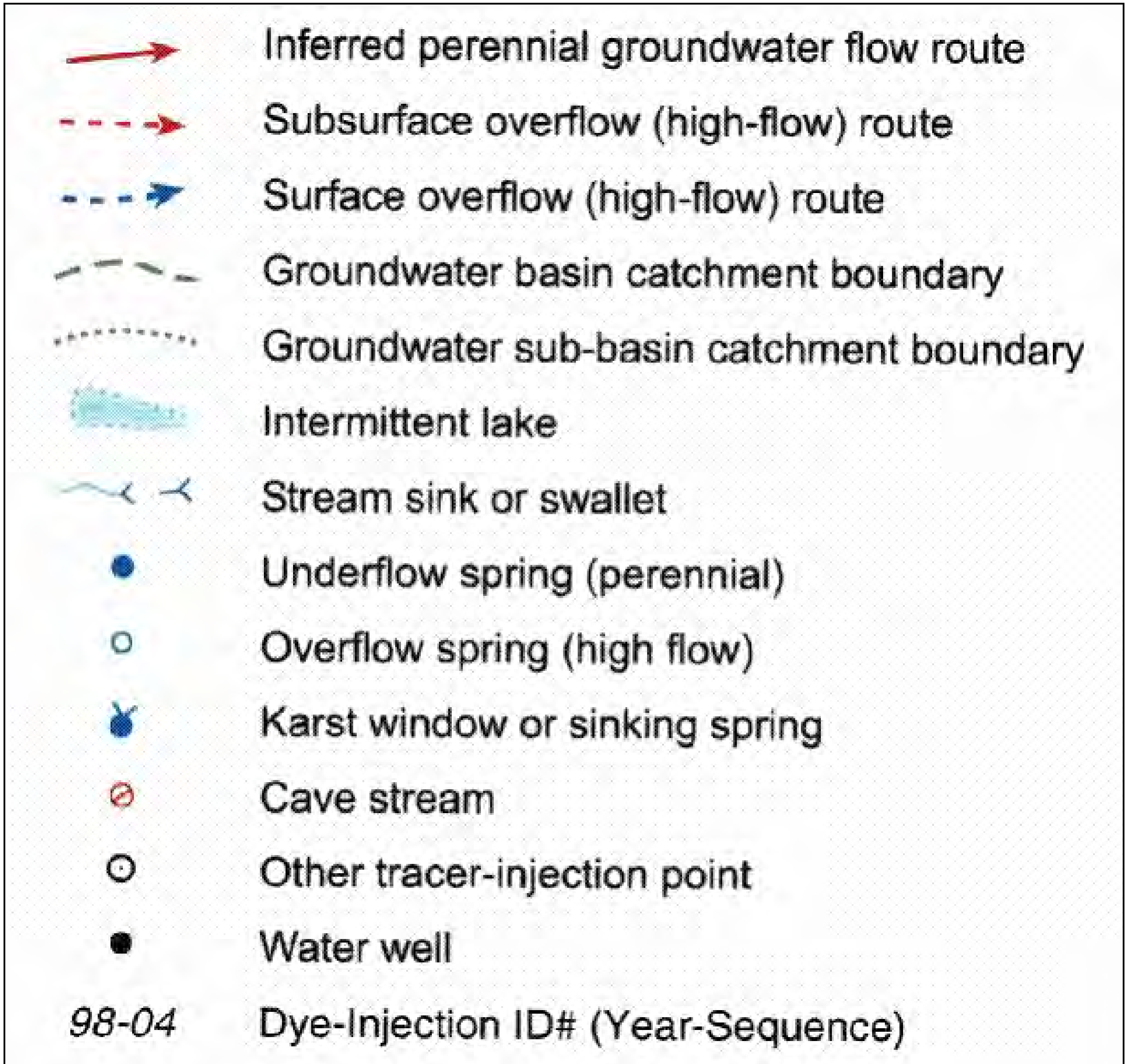



Figure 4. Karst Atlas Map Legend

Figure 5. Activated charcoal packet attached by trot-line clip to “Quinlan Gumdrop”or brick fitted with #10 copper wire.  Devices secured to retrieval point with nylon cord.

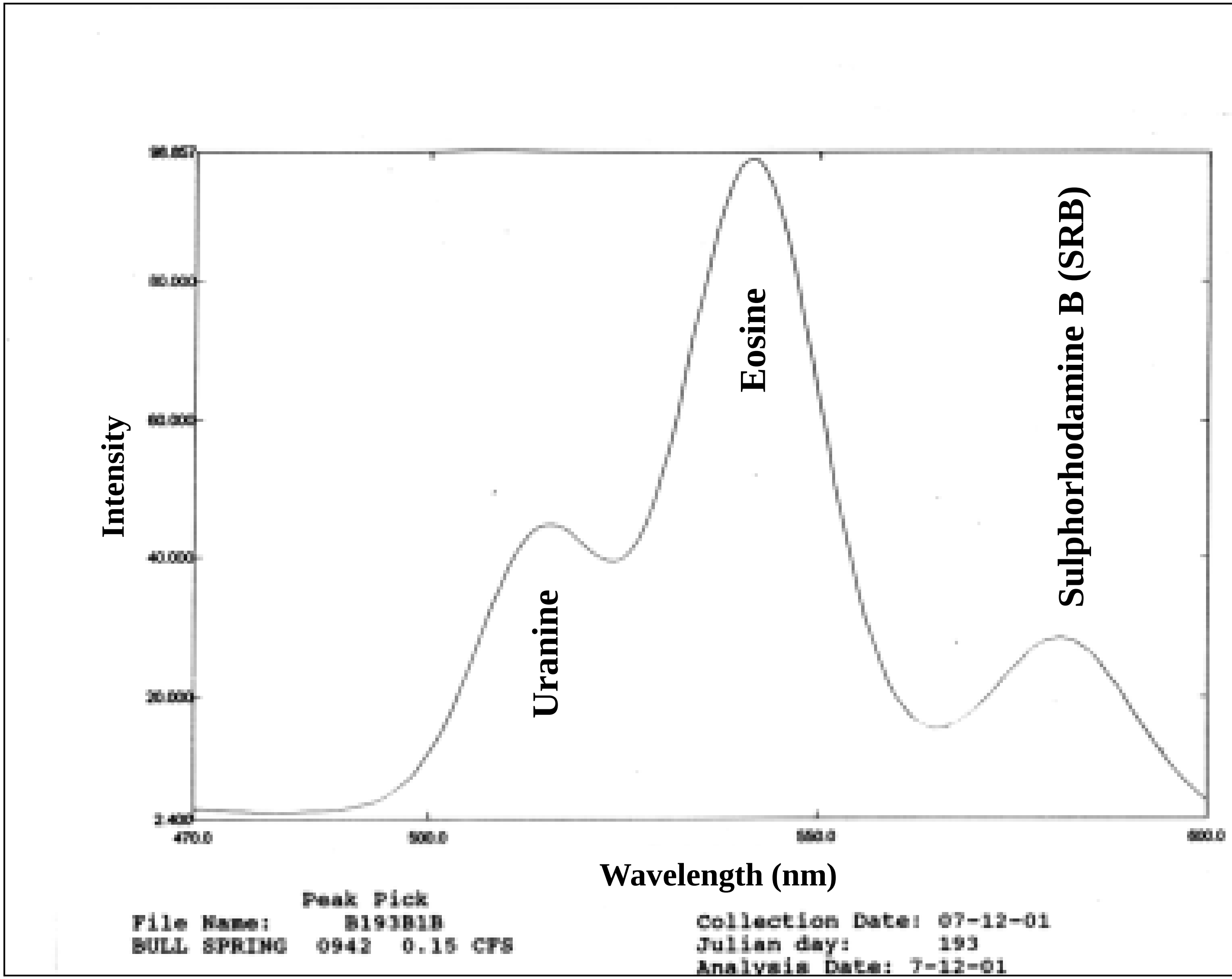



Figure 6. Typical Dye Curve on Spectrofluorophotometer

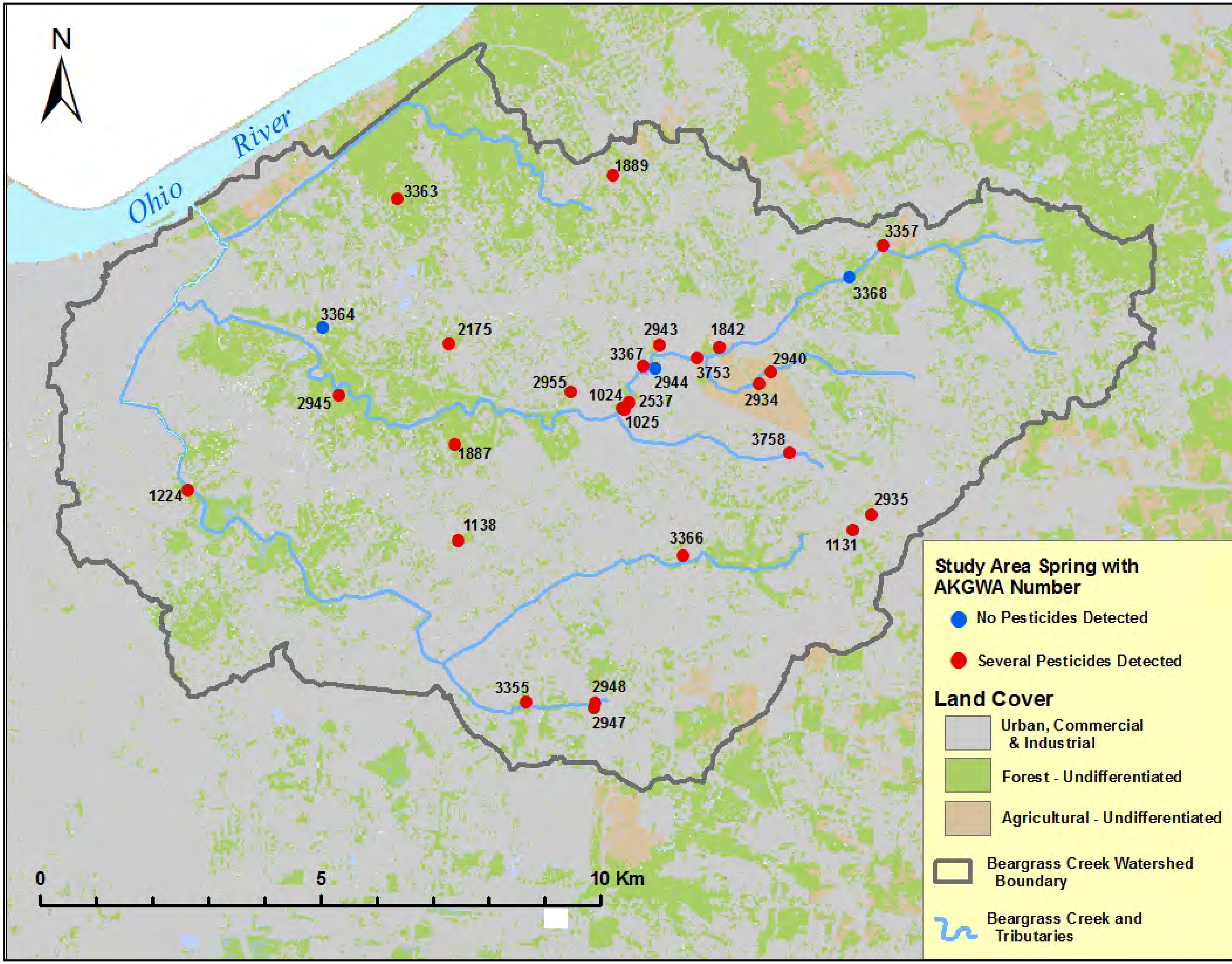



Figure 7. Pesticides Occurrences at Springs Monitored in Beargrass Creek Watershed

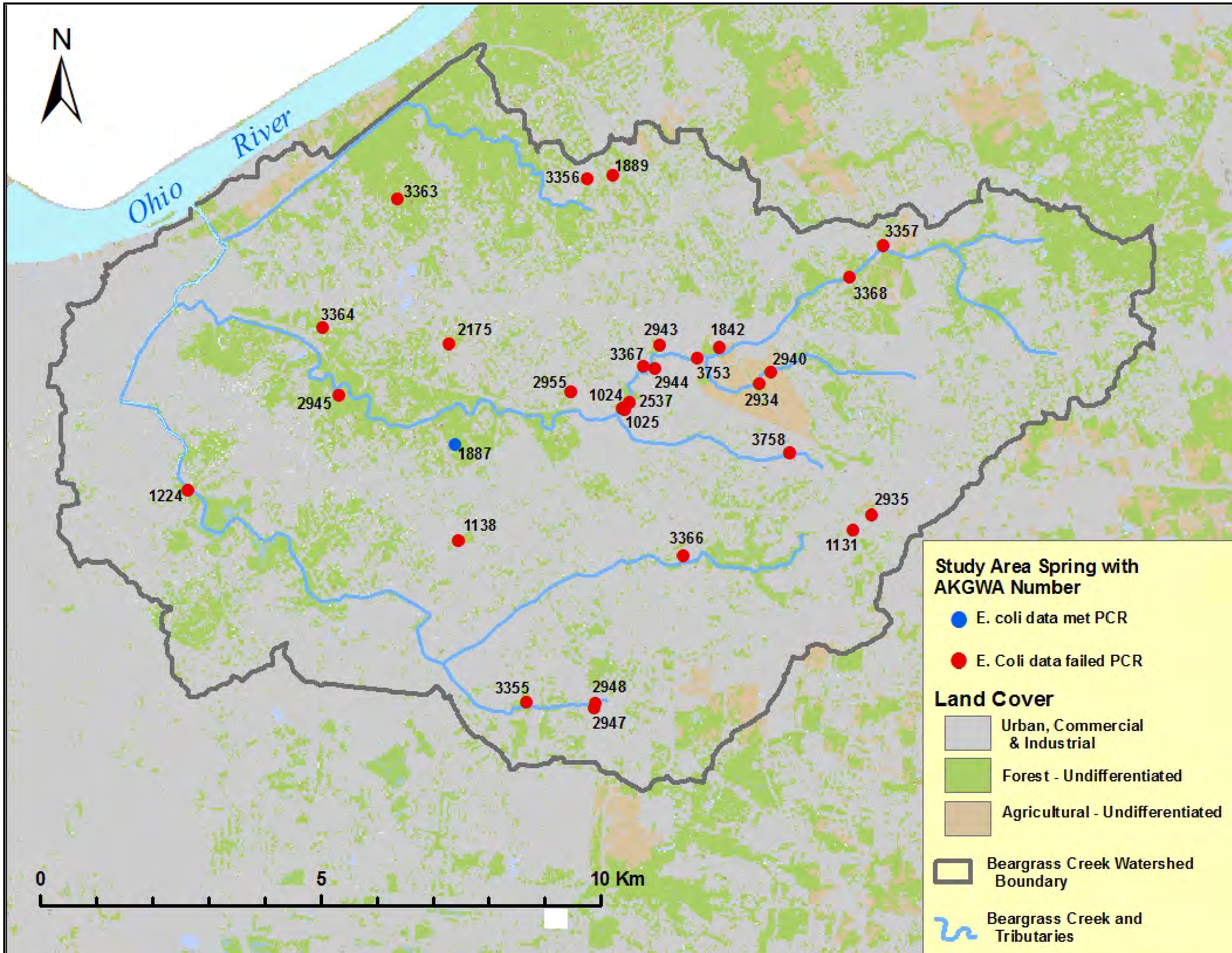



Figure 8. *E. coli* Occurrence at Springs Monitored in Beargrass Creek Watershed

Figure 9.  A’Sturgus Station Spring Photograph

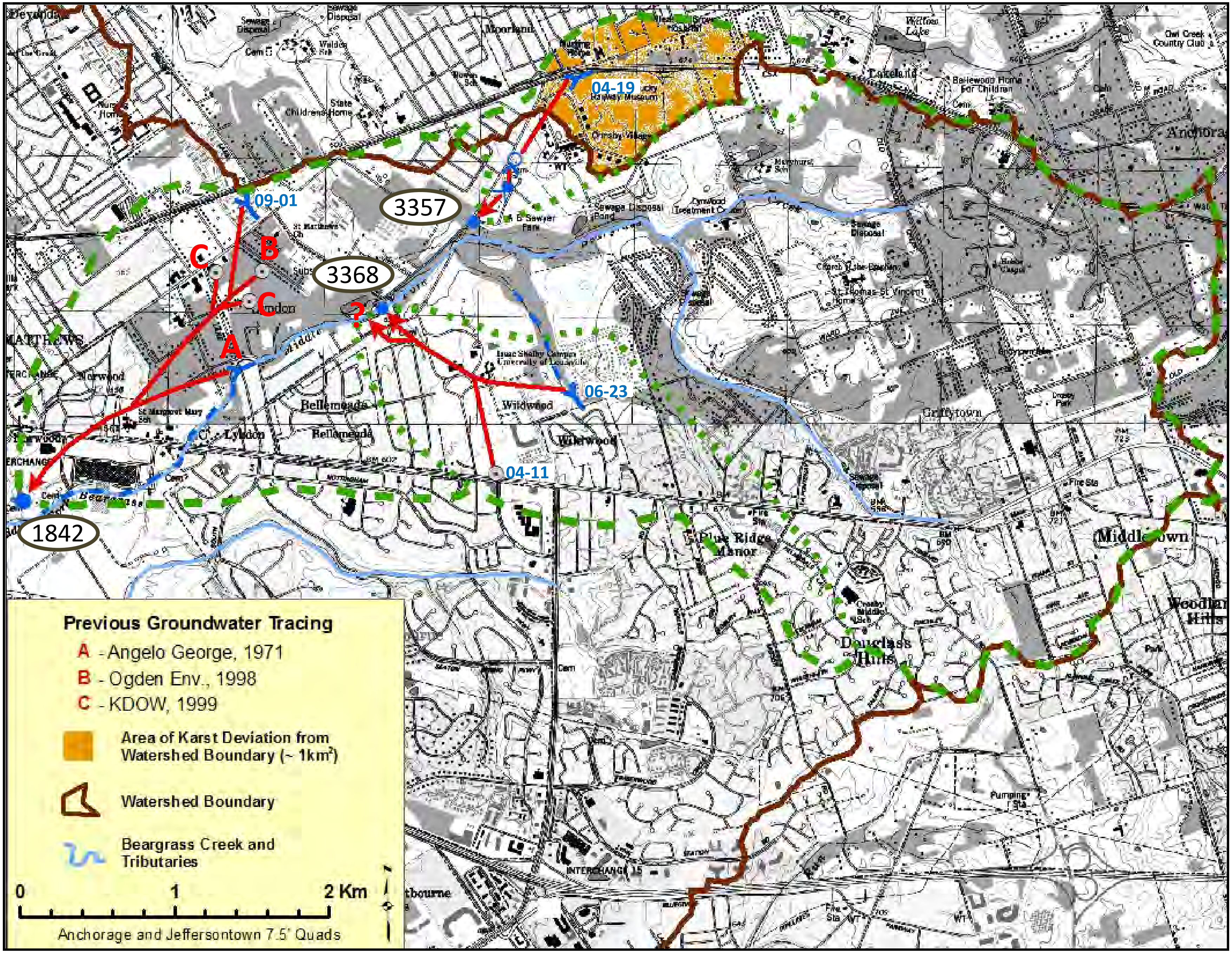



Figure 10. Tracer Data for A'Sturgus Station Sp (1842), Steinrock Sp (3368) and A.B. Sawyer Gate Sp (3357)


Figure 11.  Steinrock Spring Photograph

Figure 12.  A.B. Sawyer Gate Spring Photograph


Figure 13. Bowling Blvd Spring Photograph

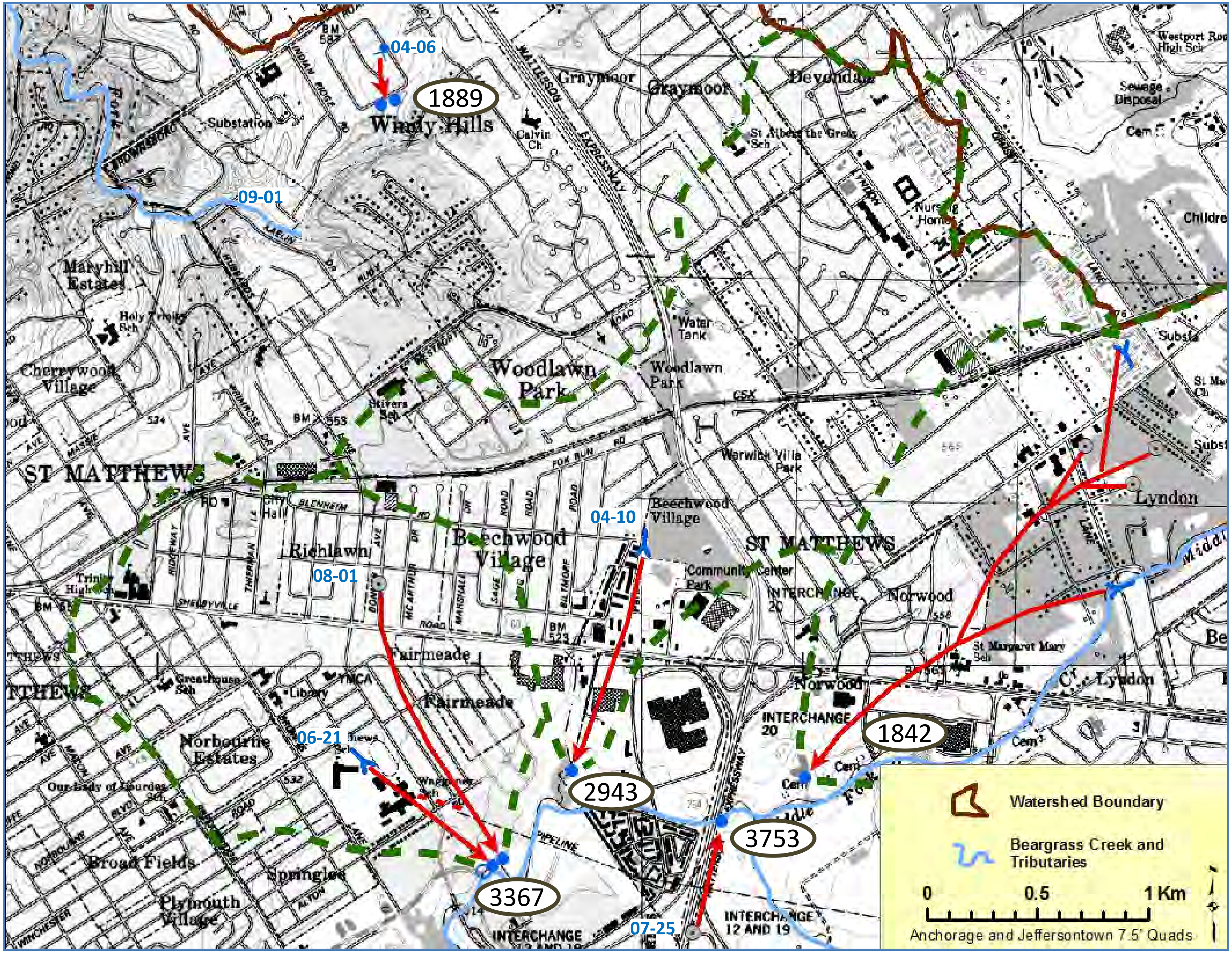



Figure 14. Tracer Data for Bowling Blvd Sp (2943), Cypress Pointe Sp (3367), Windy Hills Sp (1889) and Culvert Sp above Watterson (3753)


Cypress Pointe Springs #1 (3367)


Cypress Pointe Springs #2 (3760)

Cypress Pointe Springs #3 (3761)

Cypress Pointe Springs #4 (3762)

Figure 15. Cypress Pointe Springs Photographs


Figure 16.  Mockingbird Valley Spring Photograph

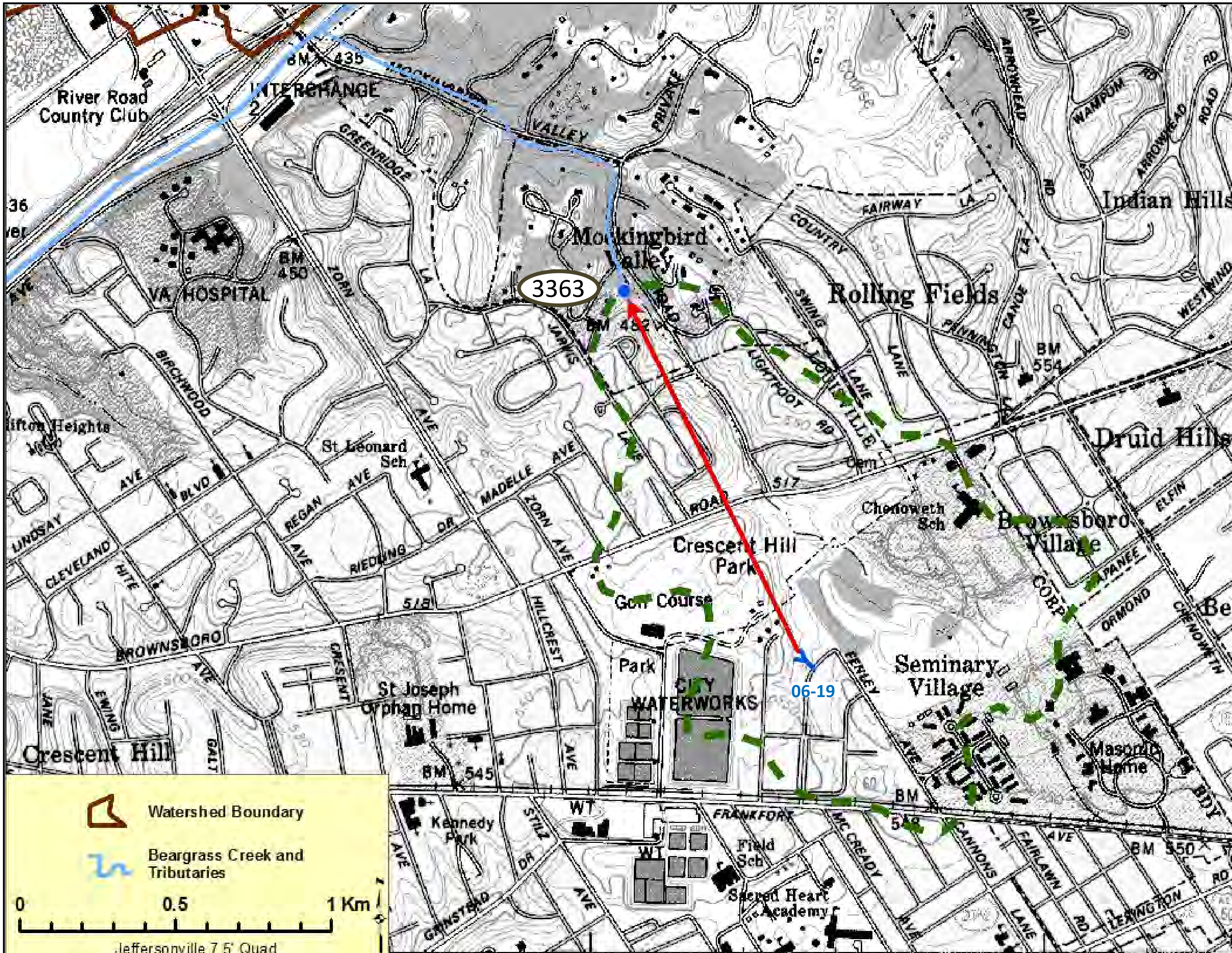



Figure 17. Tracer Data for Mockingbird Valley Sp (3363)

Figure 18.  Oxmoor Spring Photograph

Figure 19.  Upper Oxmoor Spring Photograph

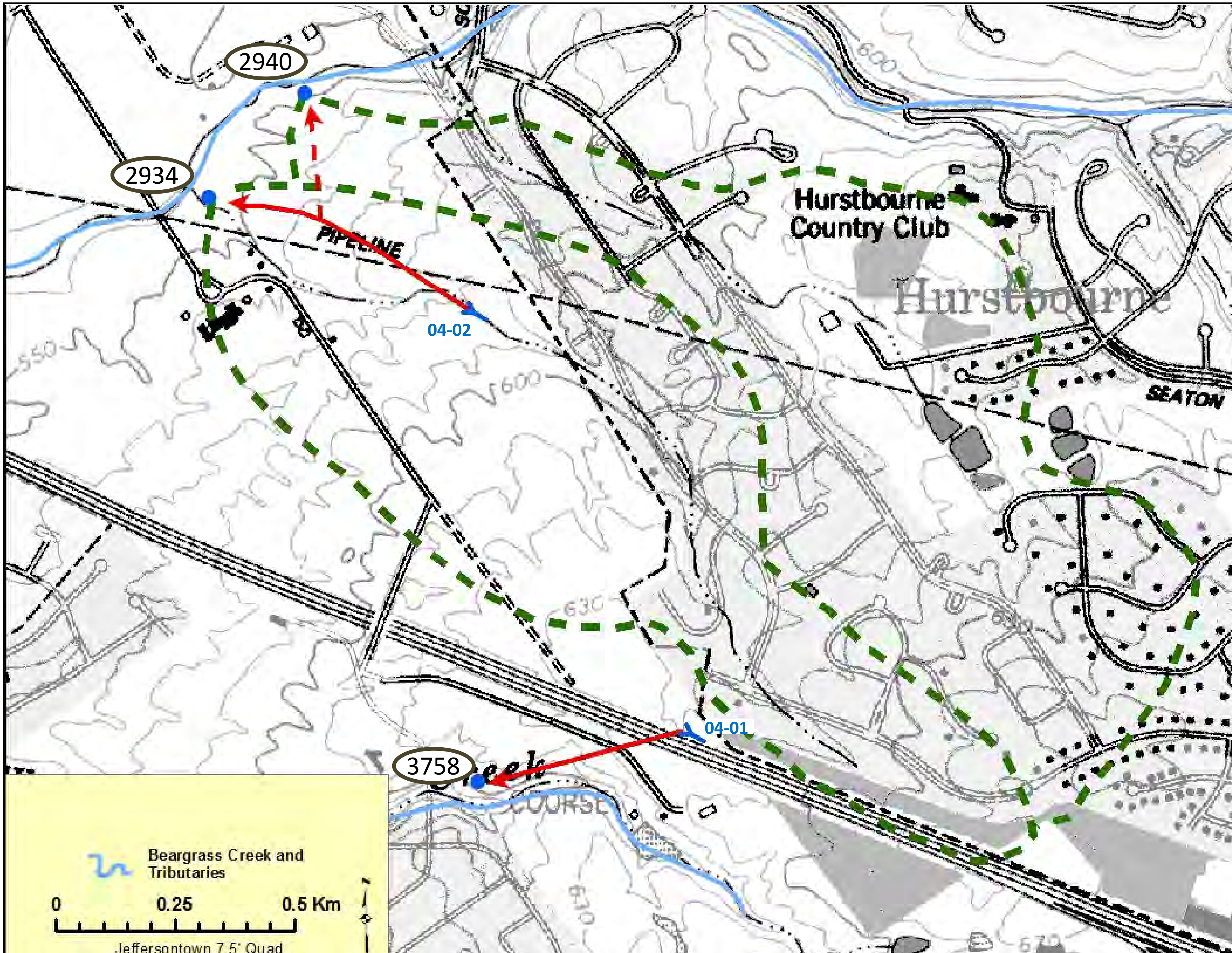



Figure 20. Tracer Data for Oxmoor Sp (2934), Upper Oxmoor Sp (2940) and Hole 10 Sp (3758)


Figure 21. Brown Cemetery & Weicher Creek Diversion Culvert Springs Photograph


Figure 22. Low Dutch Station Spring Photograph

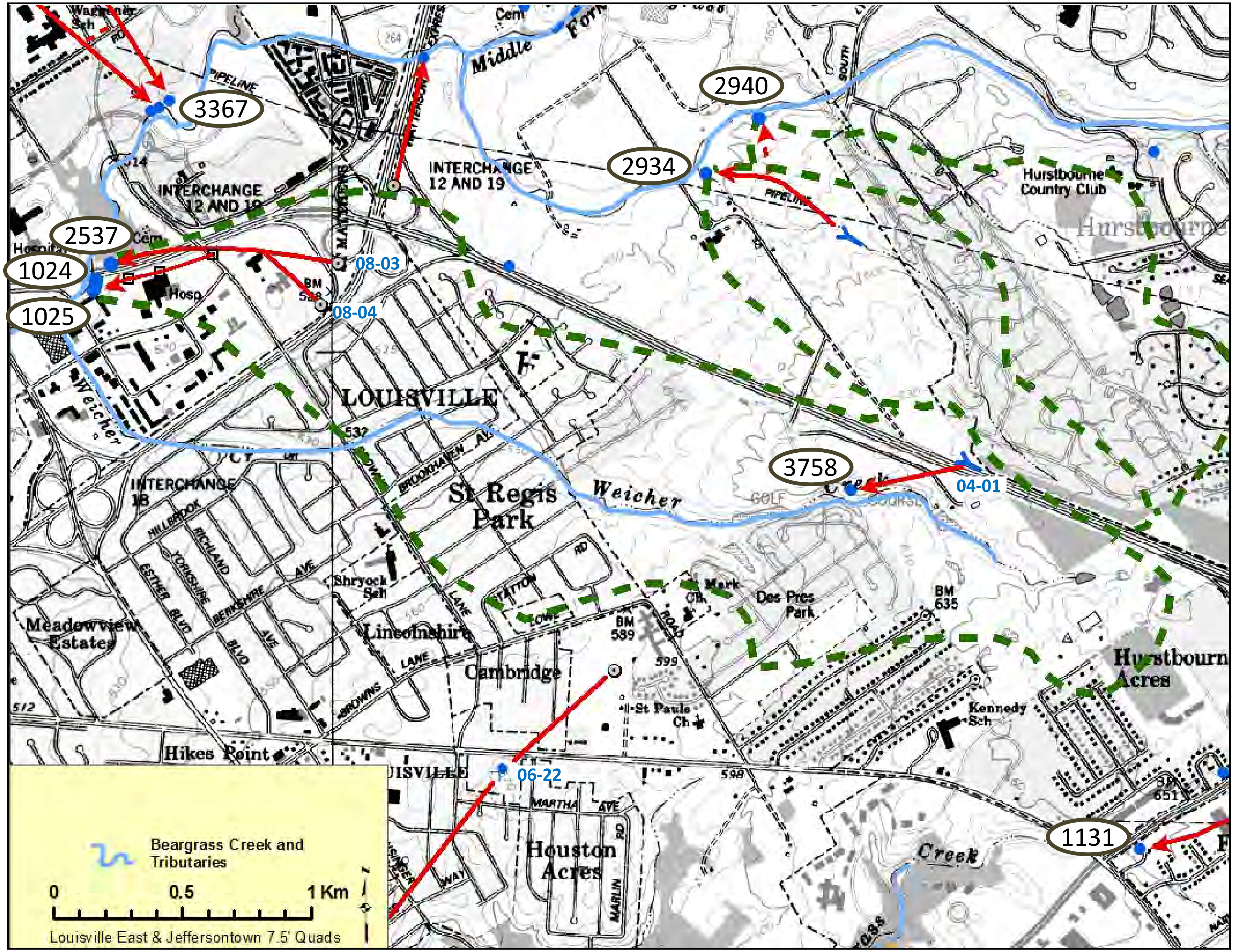



Figure 23. Tracer Data for Low Dutch Station Sp (2537), Brown Cem. Culvert Sp (1024) and Weicher Cr. Diversion Culvert Sp (1025)


Figure 24.  Hole 10 Spring Photograph

Nunnlea Spring

Zenderhouse Spring

Figure 25a. Nunnlea & Zenderhouse Springs Photographs


Figure 25b. CarMax Sinkhole Collapse Photograph

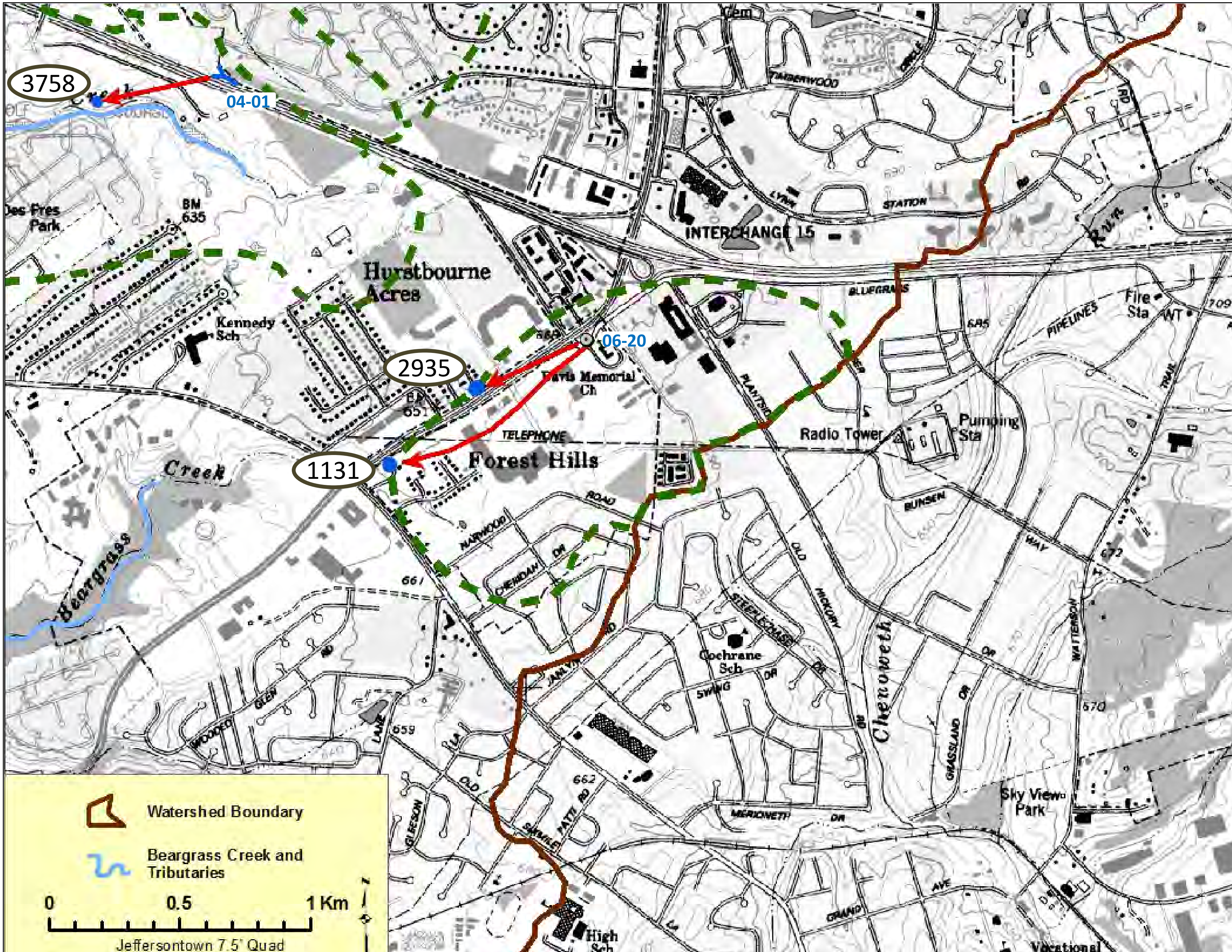



Figure 26. Tracer Data for Nunnlea Sp (2935) and Zenderhouse Sp (1131)

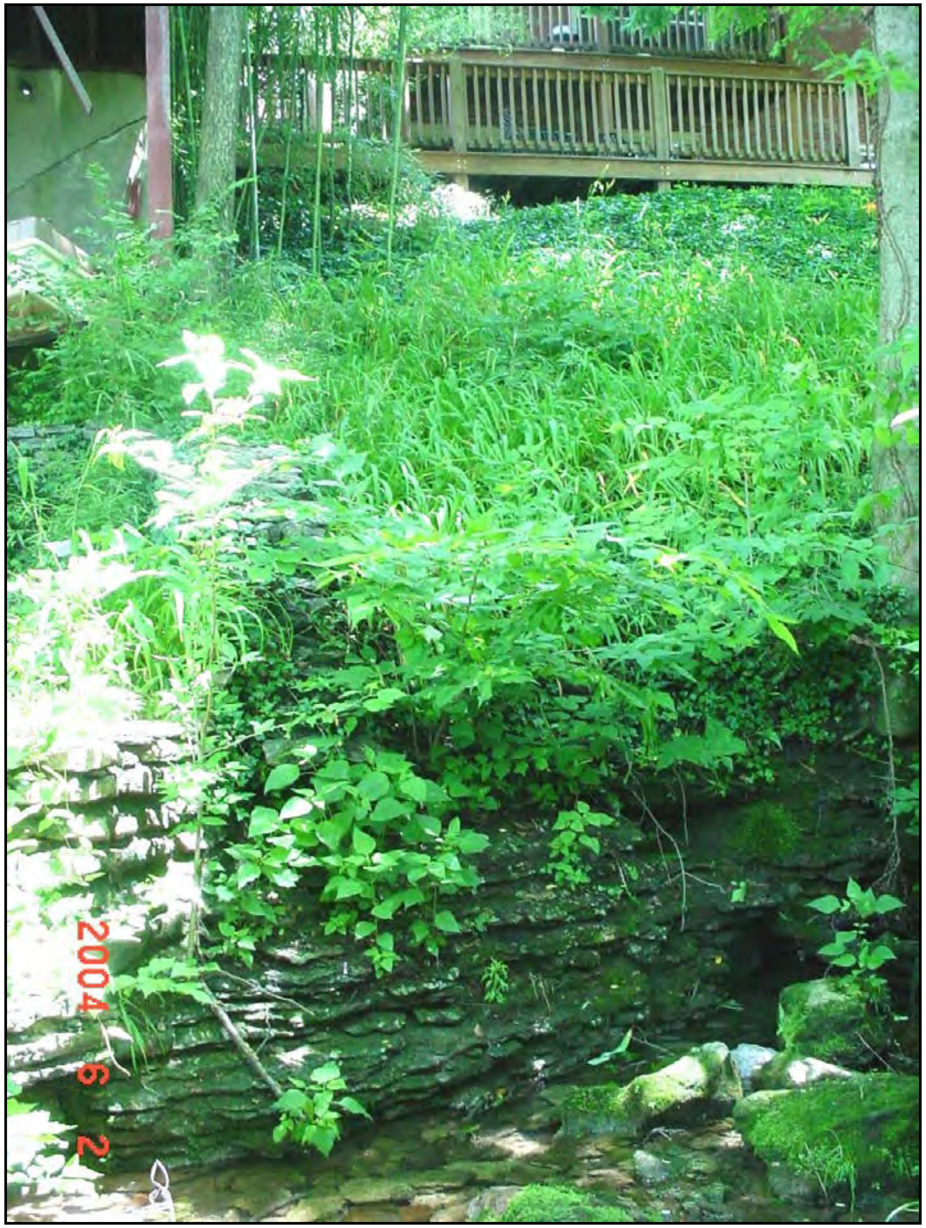


Figure 27.  Ray Spring Photograph

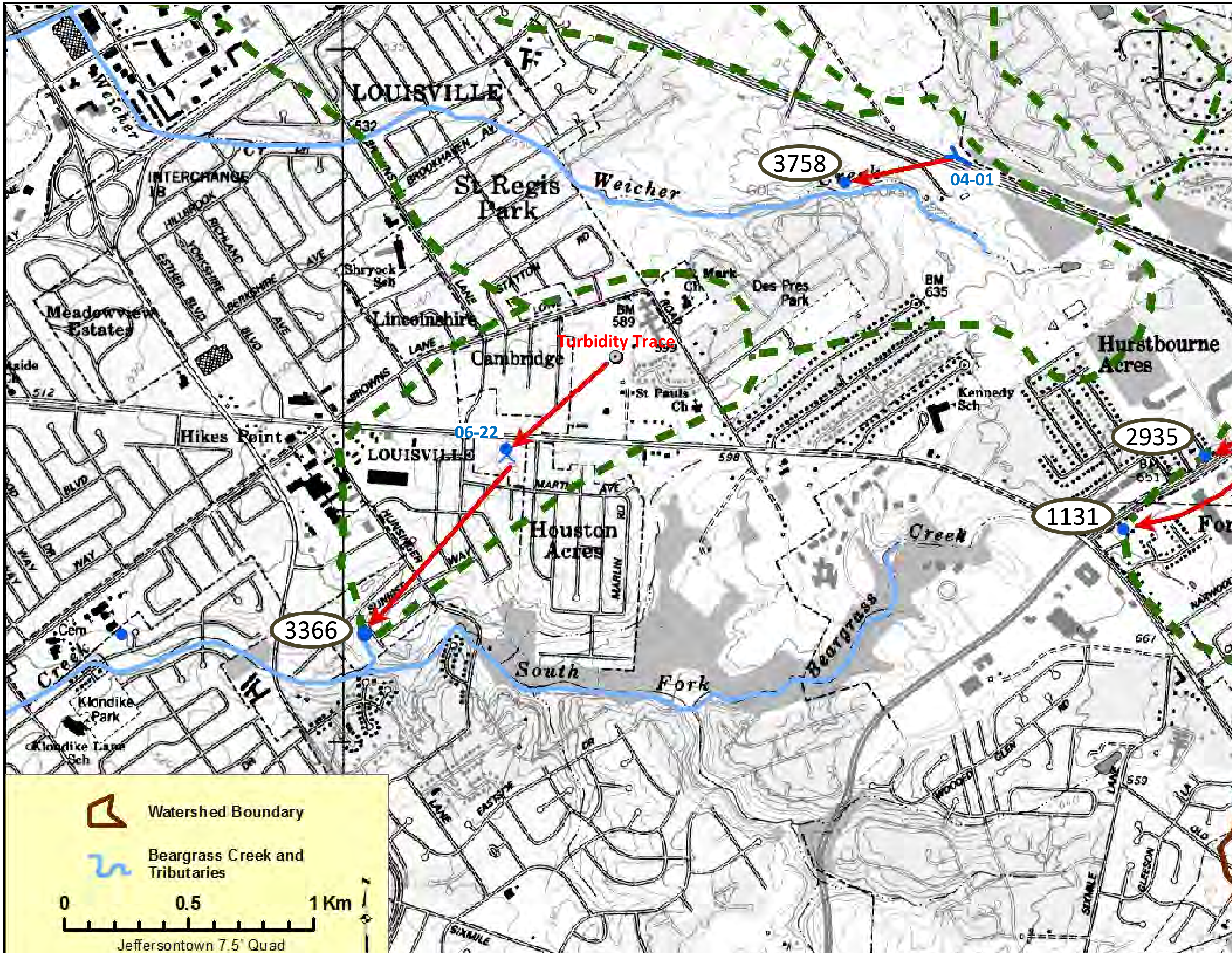



Figure 28. Tracer Data for Ray Sp (3366)

Figure 29.  Culvert Spring Photograph

Figure 30.  Confluence Spring Photograph

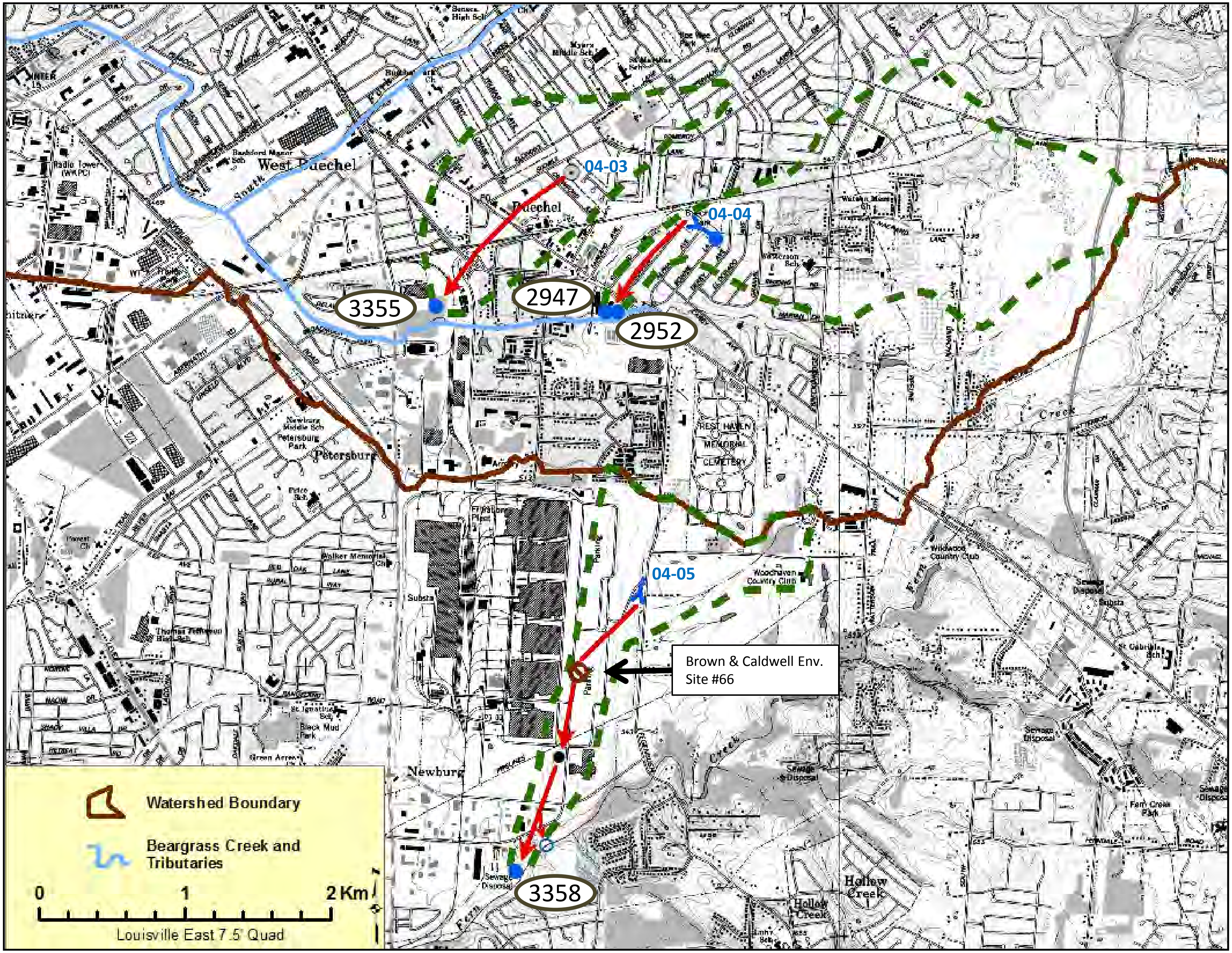



Figure 31. Tracer Data for Buechel Sp (3355), Culvert/Confluence Springs (2947/2952) and Culvert Sp @ Genfab (3358)


View looking downstream from above rise pool

View looking upstream from below rise pool


Figure 32. Buechel Spring Photographs

Figure 33. Culvert Spring @ Genfab Photograph

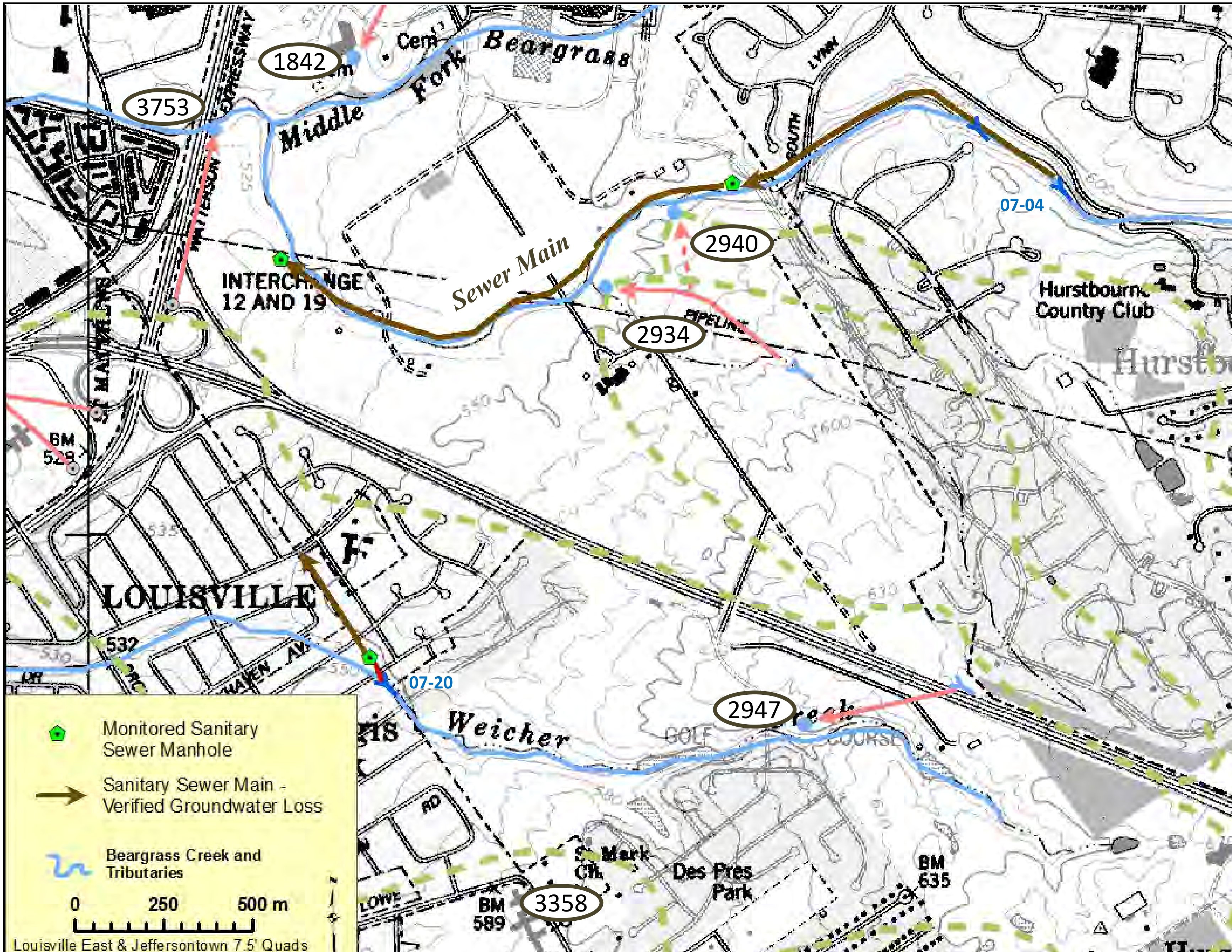



Figure 34. Tracer Data for Injections Recovered in Sanitary Sewers from Hurstbourne Trib and Dannywood Dr

Figure 35a. Inconsistent Dye Monitoring in Sanitary Sewer with Dye-Receptor Submerged on Brick Anchor following 1 hour of deployment and covered with sewer solids

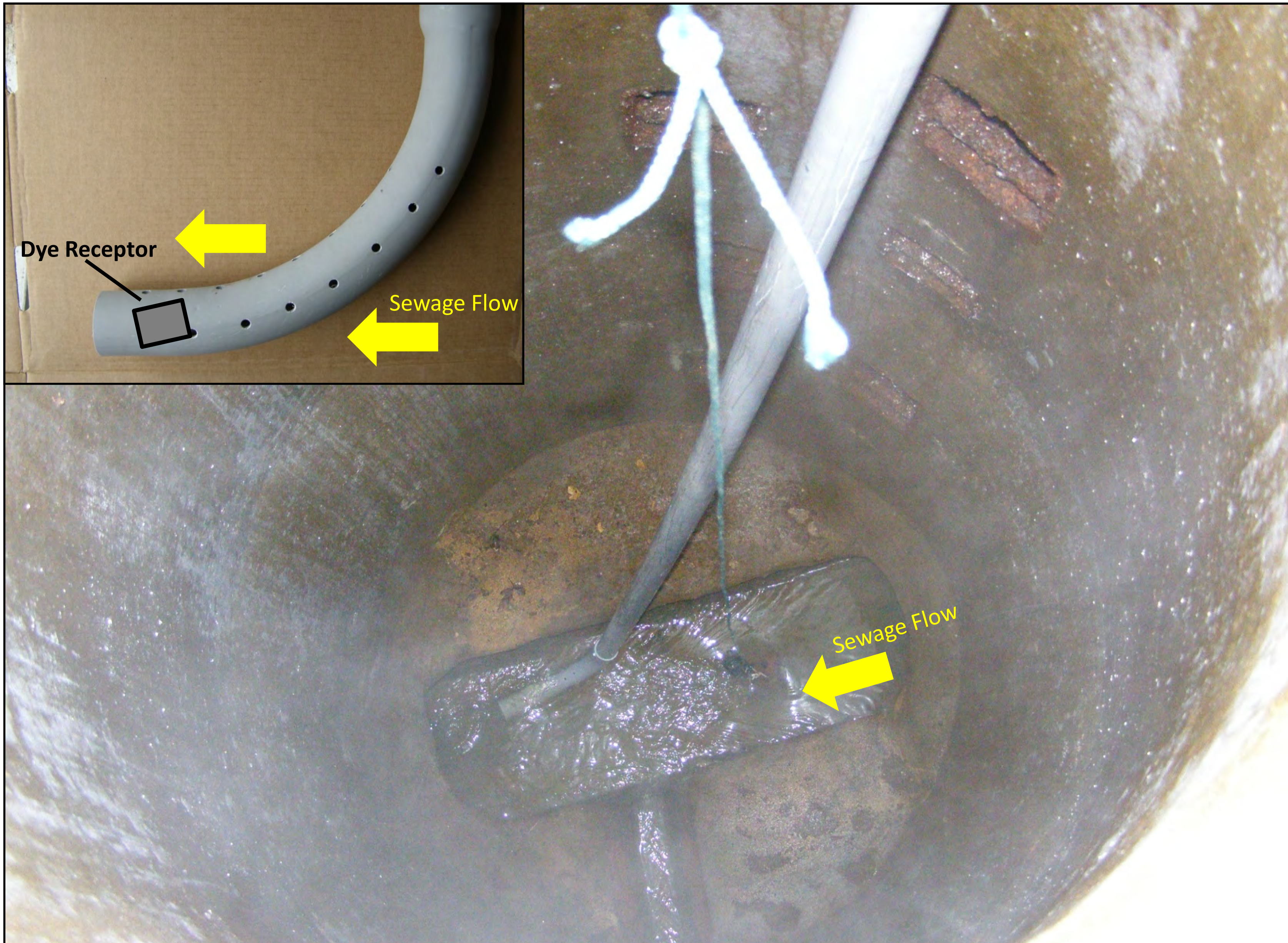



Figure 35b. Dye Monitoring in Sanitary Sewer Main along Weicher Creek with perforated sweep-90° PVC allowed for more consistent tracer recovery by shielding dye receptor from sewer solids


Figure 36.  Drop-Box Spring Photograph

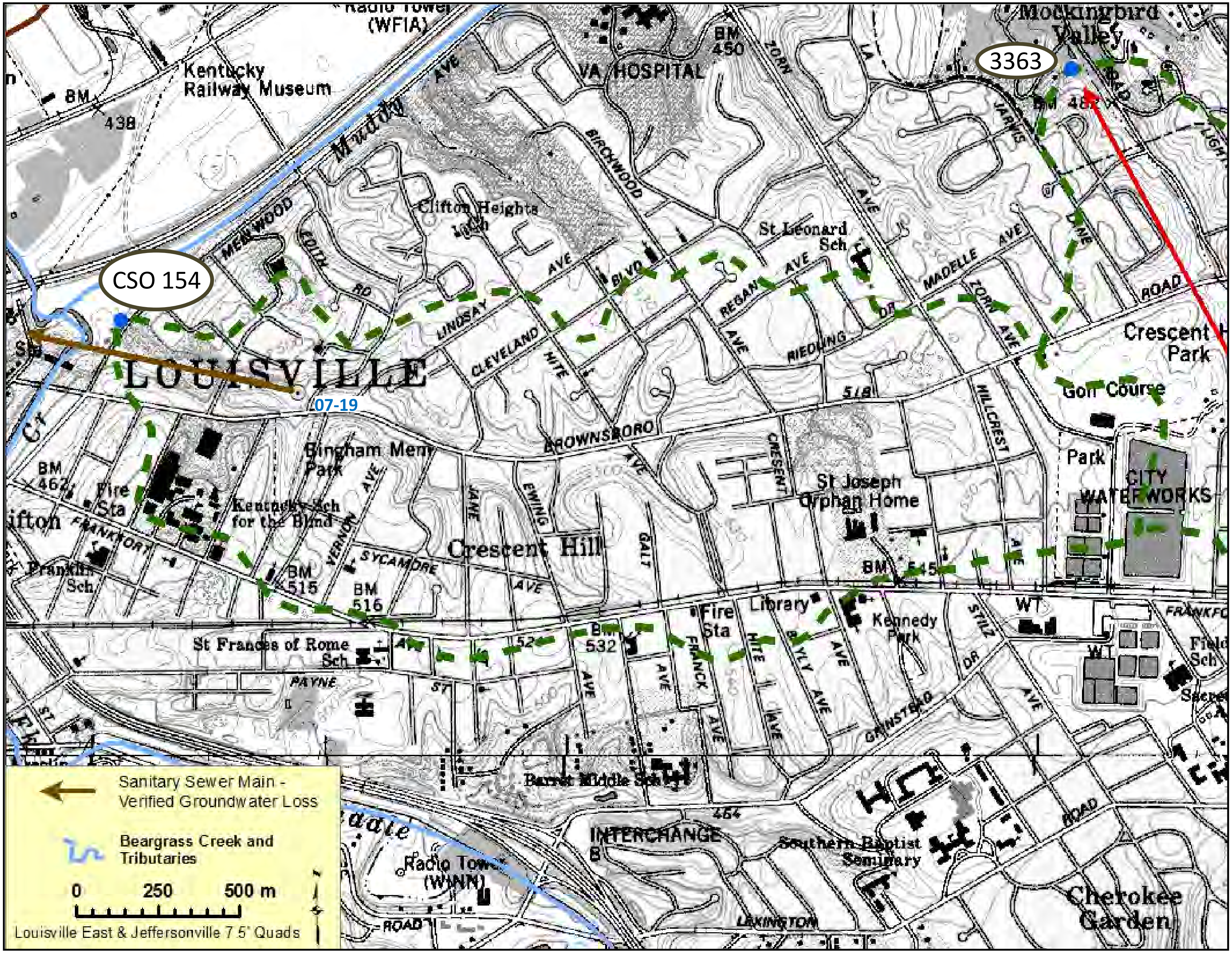



Figure 37. Tracer Data for Groundwater Diversion to Sanitary Sewer at Brownsboro Rd (Drop Box Sp)

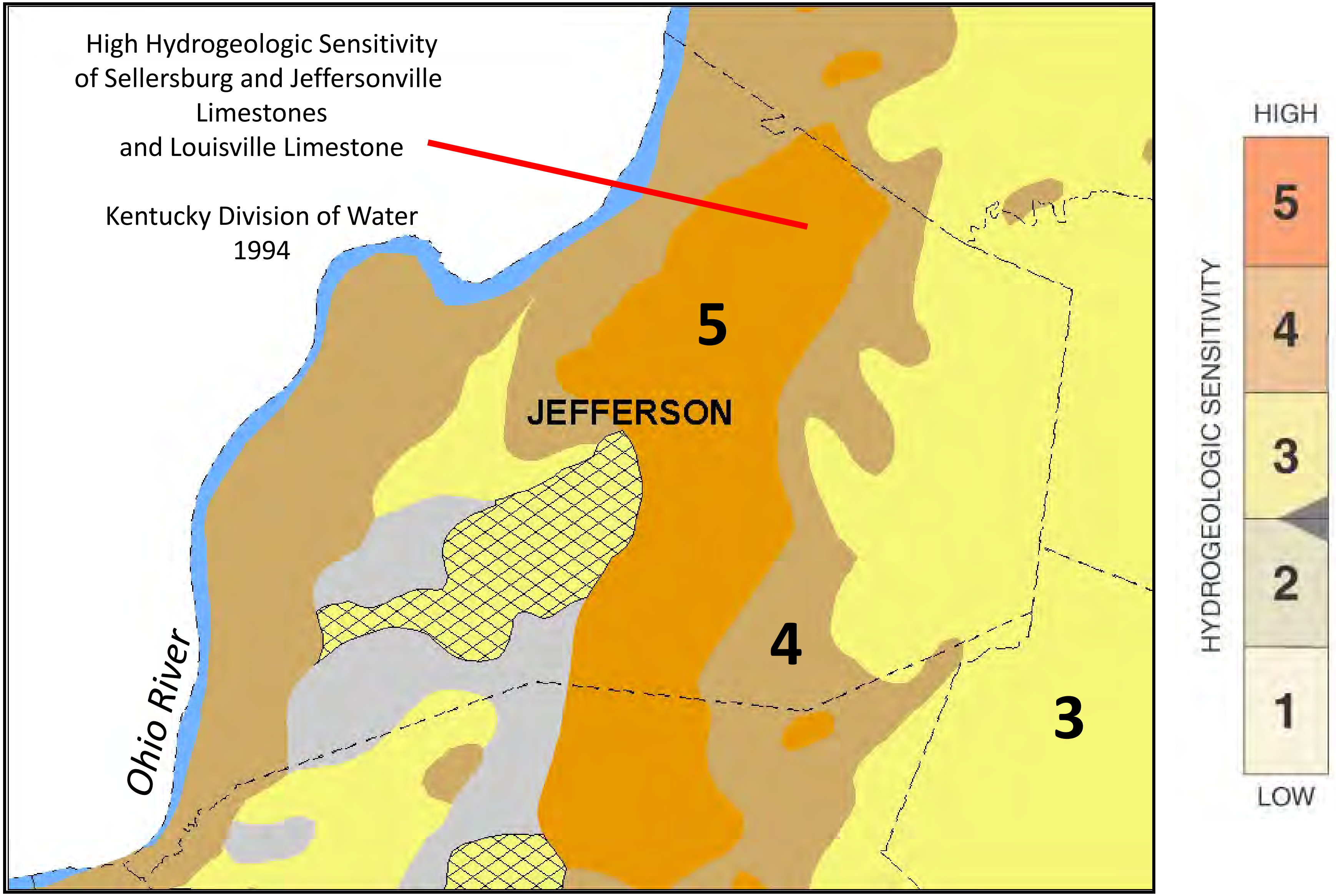



Figure 38. Groundwater Sensitivity Map of Jefferson County


Figure 39.  Cutoff Spring Photograph

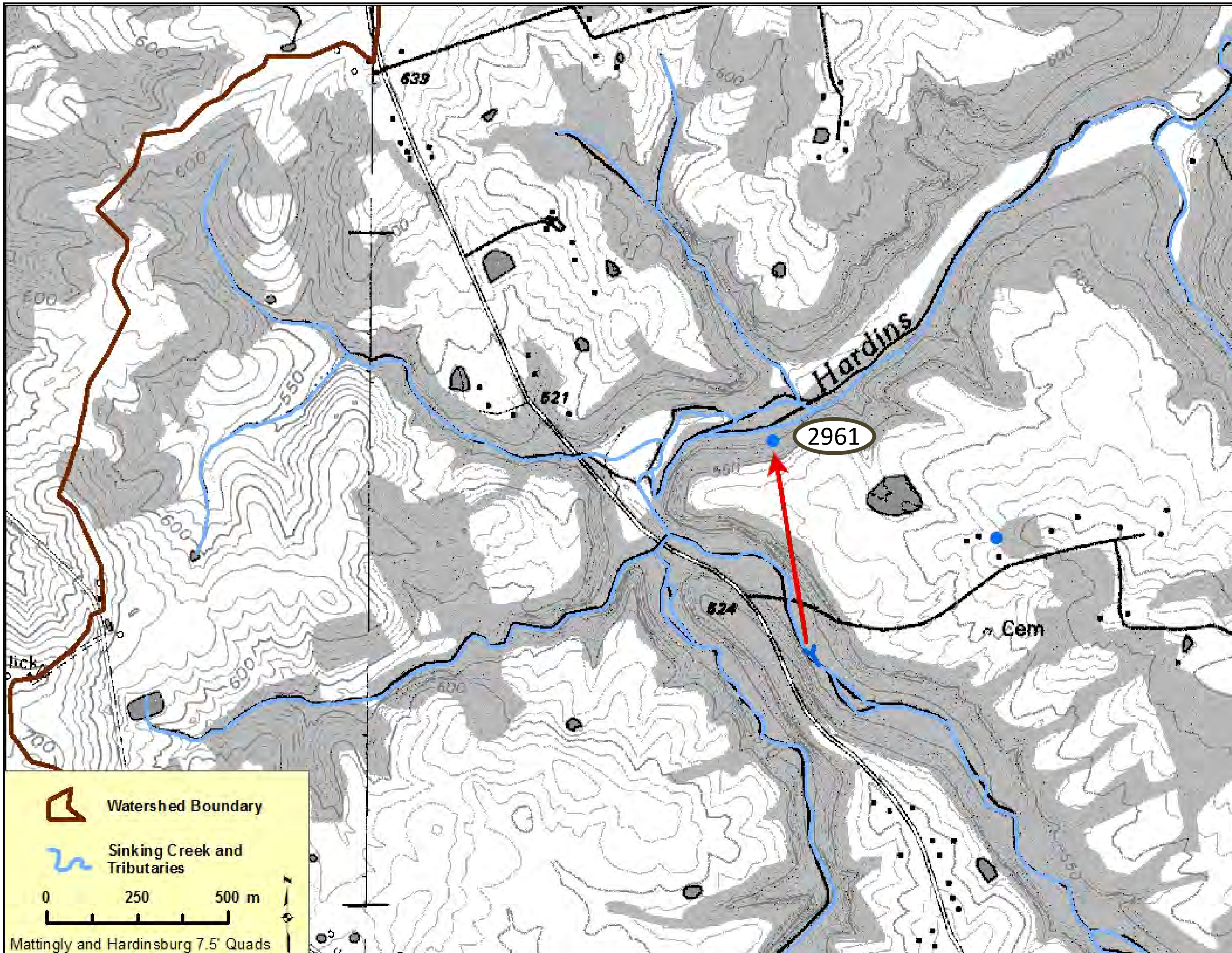



Figure 40. Flow Route for Cutoff Sp (2961)


Figure 41. Shotpouch Spring Photograph

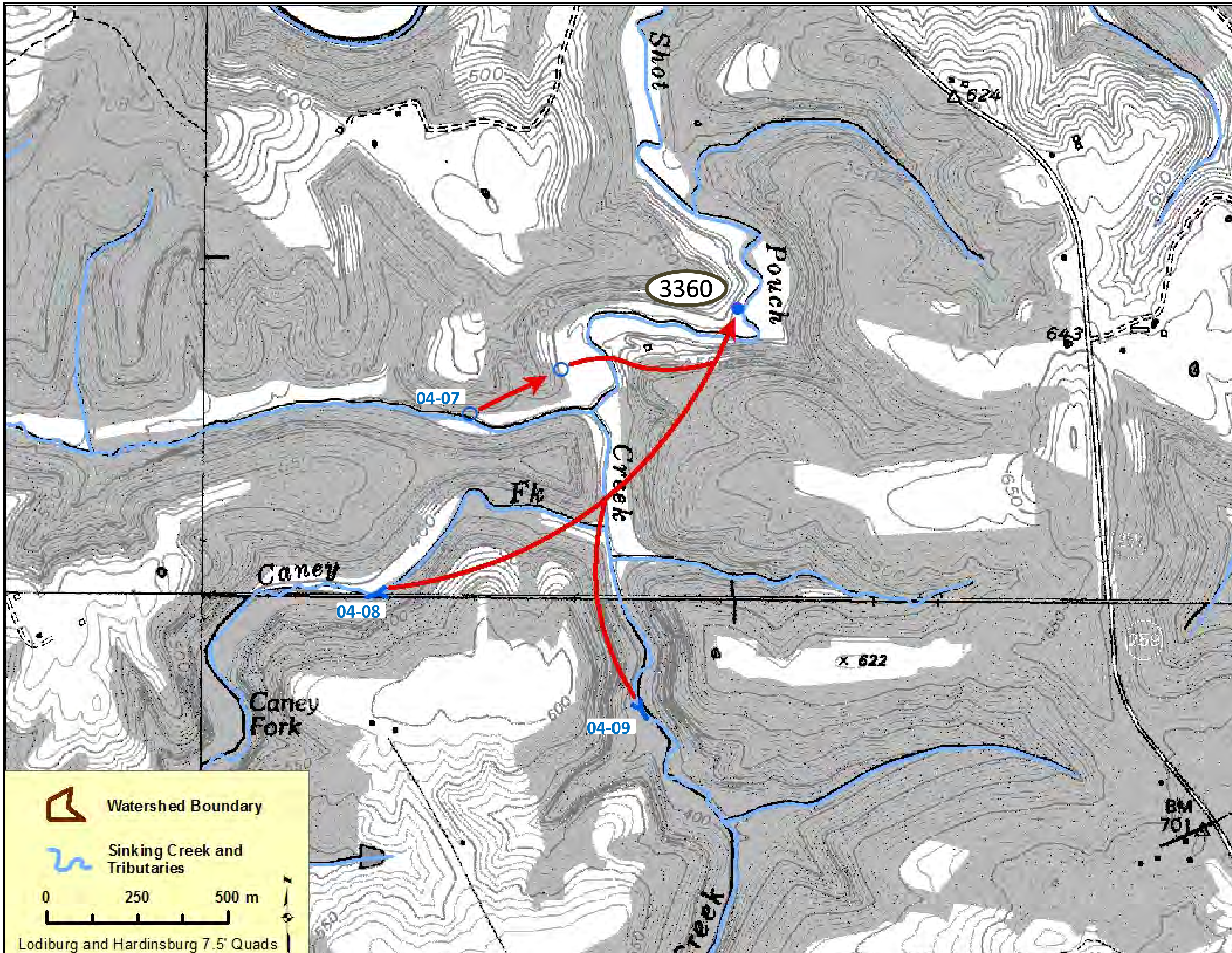



Figure 42. Tracer Data for Shotpouch Sp (3360)

Figure 43.  Bluehead Spring Photograph

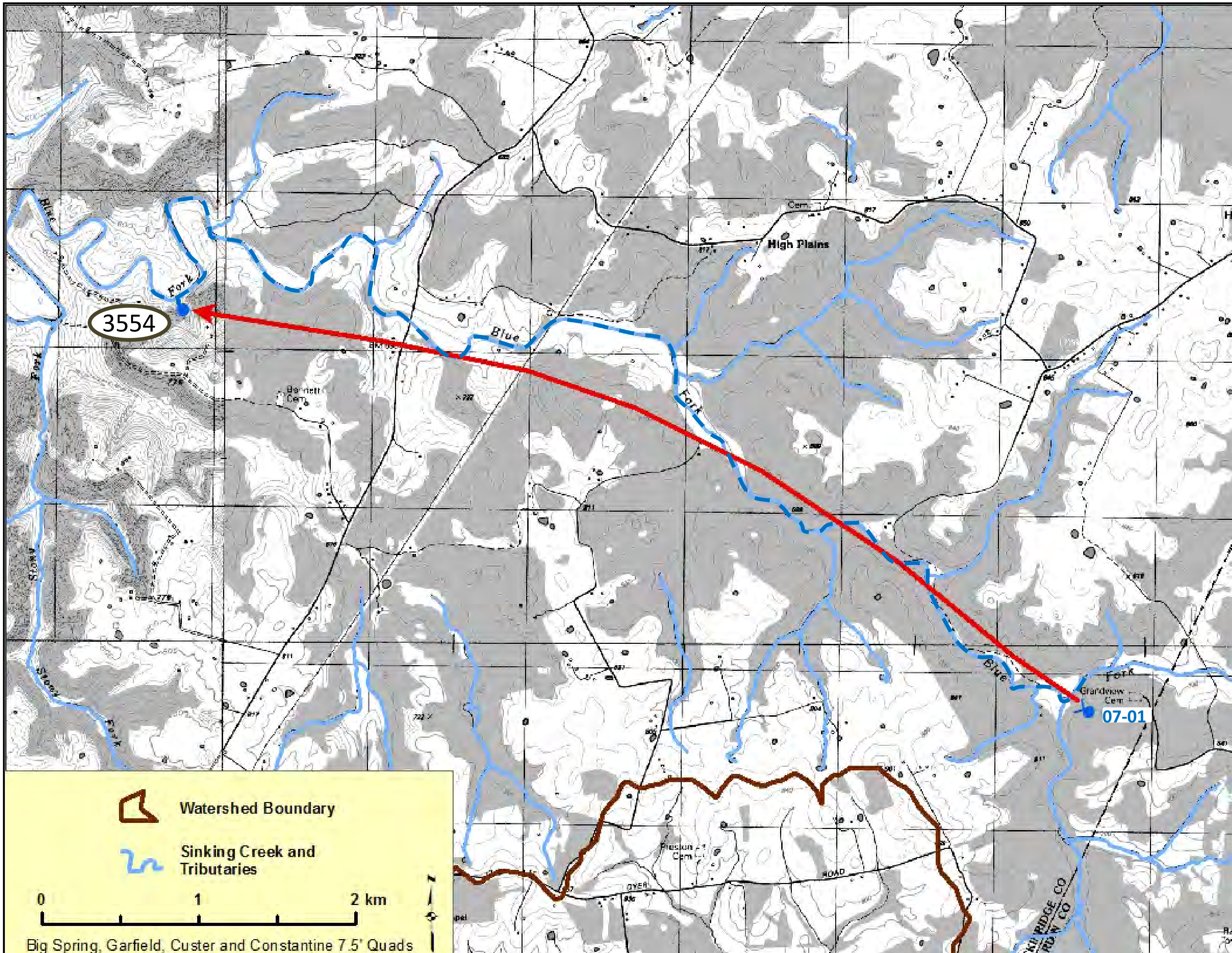



Figure 44. Tracer Data for Bluehead Sp (3554)

Figure 45. Fiddle Spring Photograph. View from head of spring looking downstream (note figure at top left for scale).

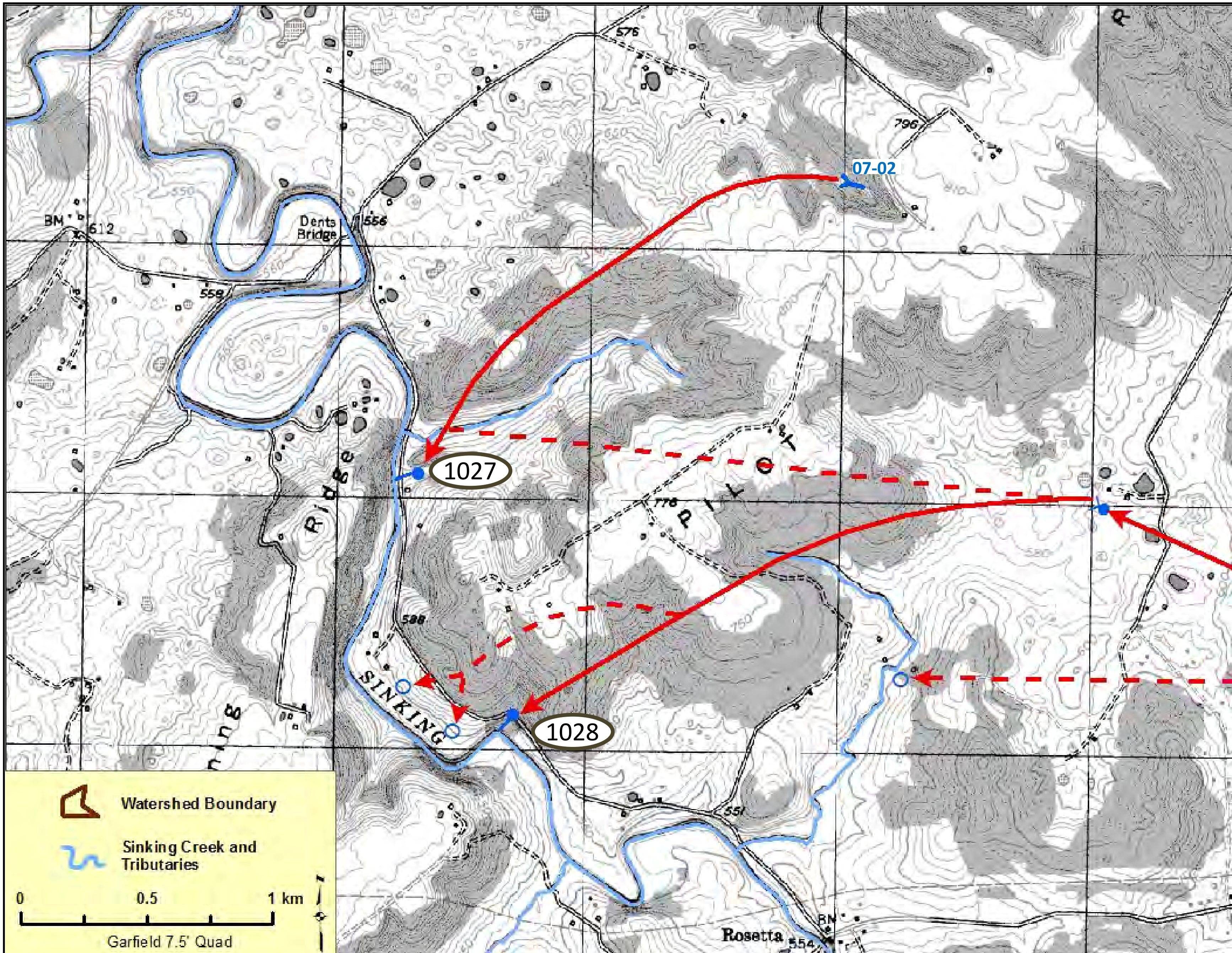



Figure 46. Tracer Data for Fiddle Sp (1027) with part of Flat Rock Sp (1028) groundwater basin

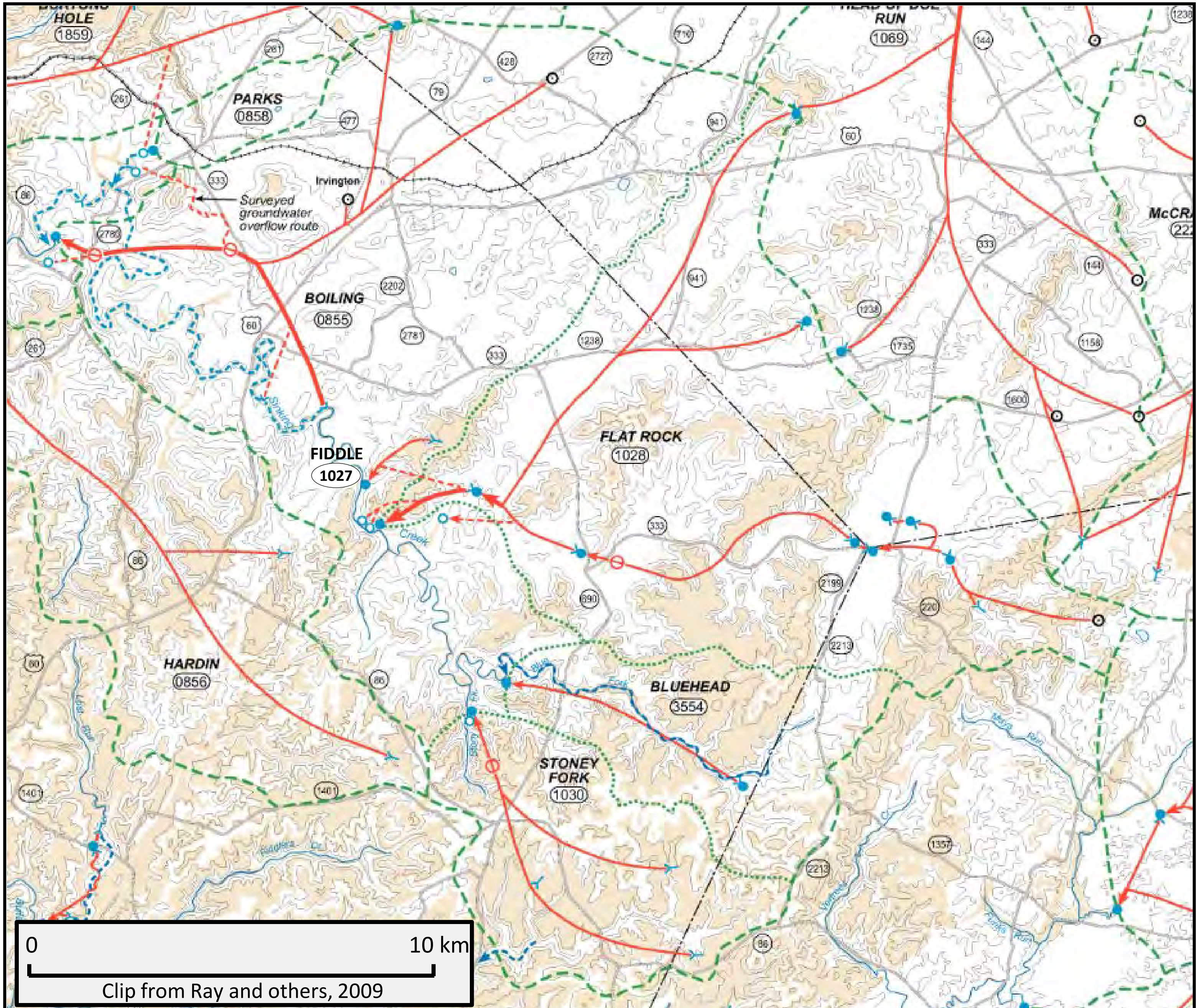



Figure 47. Boiling Spring Karst Basin showing Fiddle (1027) and Bluehead (3554) springs traces

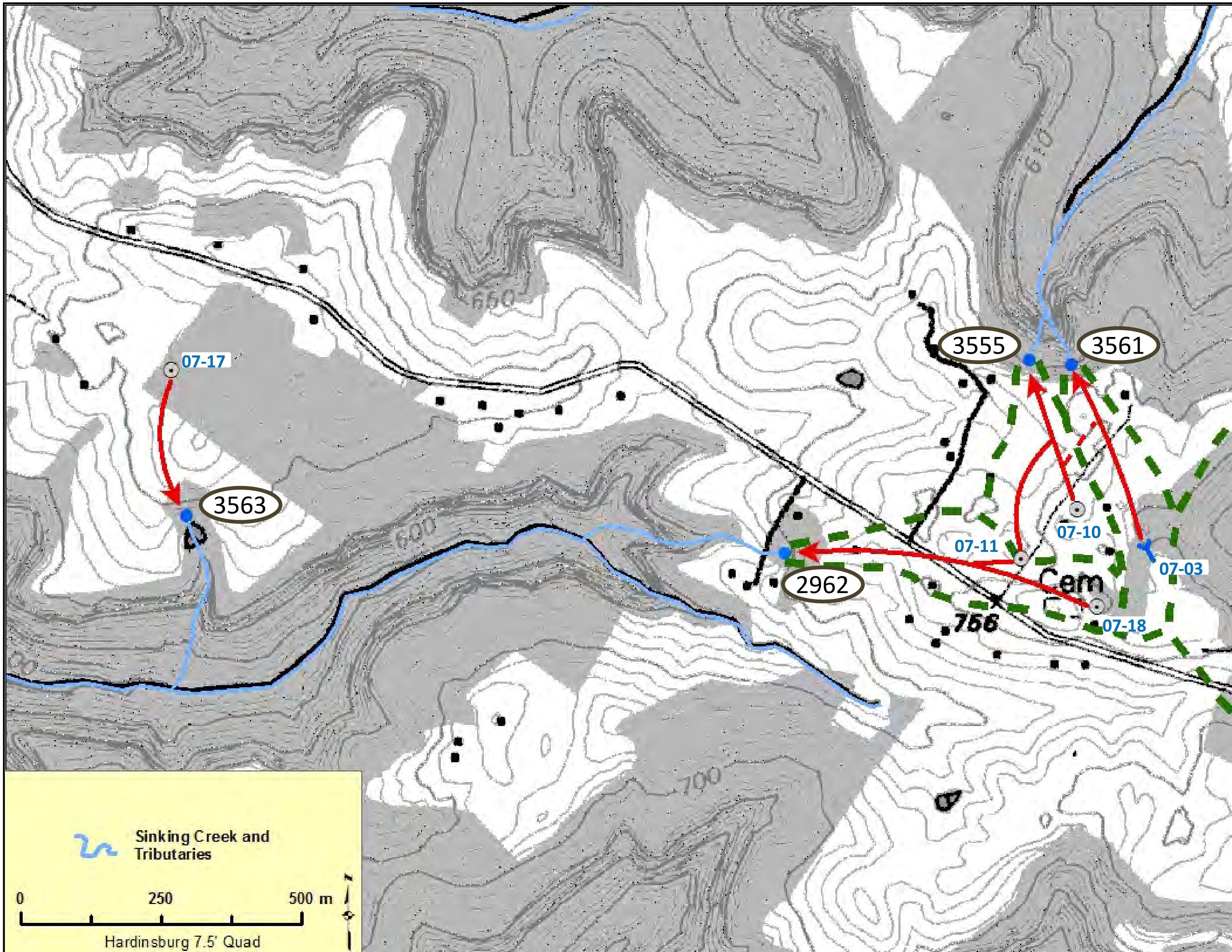
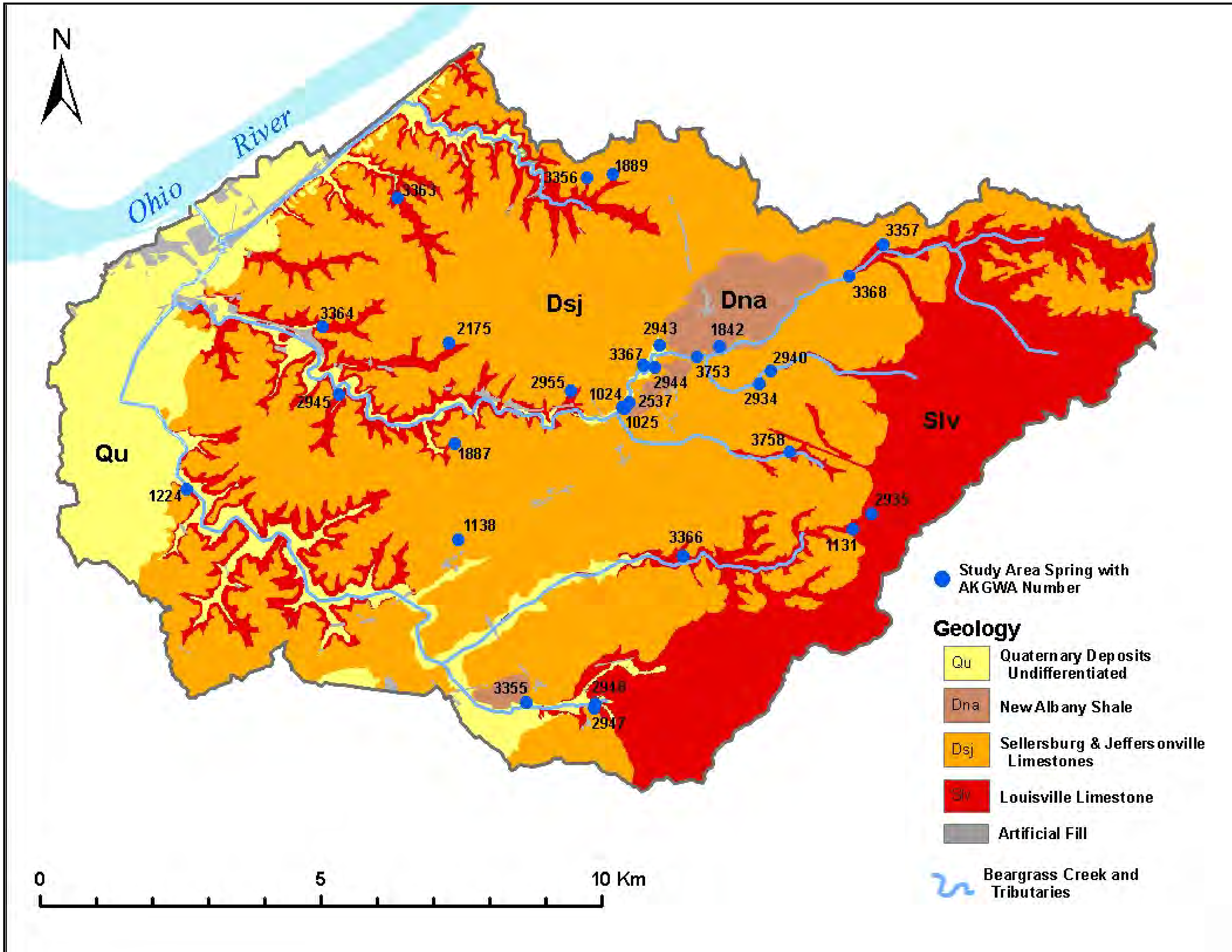



Figure 48. Tracer Data for Dowell Sp (3555), Dowell Sp #2 (3561), O'Reilly Sp (2962) and Thornhill Sp (3563)

Figure 49.  O’Reilly Spring Photograph

Figure 50.  Thornhill Spring Photograph

# Appendix II.  Groundwater Quality Assessment Checklists from 401 KAR 10:031




Sites Monitored in Beargrass Creek Watershed. Groundwater Quality Assessment Checklists for Springs are below.

Farmington Sp - 1138

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria µg/L[2]** | | | | |
| | | Human Health: | | **Warm Water Aquatic Habitat[3]:** | | |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | Not Impaired |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | Not Impaired |
| Arsenic | 7440382 | 10 | | 340 | 150 | 7 detects; all < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | All < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | All < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | 2 detects; all < Chronic |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | Partial - 3 detects > Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All < Chronic |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | All < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | 1 detect < Chronic |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | All in range |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 9 detects; all < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Seem OK |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | All < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | IMPAIRED |

Eleven Jones Sp-1224 (2 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria µg/L[2]** | | | | |
| | | Human Health: | | **Warm Water Aquatic Habitat[3]:** | | |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | Both Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | No issue |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | Both Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | Both Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | Both Non-detect |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | Both Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | Both Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | Both < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | Both Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | Both < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | Both < Chronic |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | Both Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | Both Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | Both Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | Both Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | Both < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | Both Non-detect |
| Malathion | 121755 | | | | 0.1 | Both Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | Both Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | Both Non-detect |
| Mirex | 2385855 | | | | 0.001 | Both Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | Both < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | Both Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | One detect < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | One detect < Acute |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | TDS<SDWR |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | Both Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | Both < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | Both Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 2/7 > 240 IMPAIRED |

A'Sturgus Sta Sp - 1842 (6 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Pollutant | CAS[1] Number | Water Quality Criteria μg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | 1/5 @ Acute Partial? |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 3 detects < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | All < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | All < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | All < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | All < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | 1 Detect-very low |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | ?? |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 3 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Seem OK |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 2 Detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 4/7 > 240 IMPAIRED |

Breckinridge Sp-1887 (2 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Pollutant | CAS[1] Number | Water Quality Criteria µg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | OK |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | One detect < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 2 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 2 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | All Non-detect |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | One detect < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | One detect < Chronic |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | All Non-detect |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | One detect < Chronic |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | OK |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | < SDWR |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | All Non-detect |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | Fully Supporting |

Spring Sta-2175 (7 samples)

| Pollutant | CAS[1] Number | Water Quality Criteria μg/L[2] Human Health: DWS[4] | Fish[5] | Warm Water Aquatic Habitat[3]: Acute | Chronic | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detects |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | OK |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detects |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | ?? Need field parameters |
| Arsenic | 7440382 | 10 | | 340 | 150 | 2 detects < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detects |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detects |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 6 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detects |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 6 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | 2 detects < Chronic |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detects |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detects |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detects |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detects |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 6 detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detects |
| Malathion | 121755 | | | | 0.1 | All Non-detects |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detects |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detects |
| Mirex | 2385855 | | | | 0.001 | All Non-detects |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 6 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | All Non-detects |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detects |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detects |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 2 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detects |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Seem OK |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detects |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 2 detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detects |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 7/7 > 240 IMPAIRED |

| Nunnlea Sp-2935 (4 samples) | | | | | | |
|---|---|---|---|---|---|---|
| **401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants** | | | | | | **Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired** |
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria µg/L[2]** | | | | |
| | | Human Health: | | **Warm Water Aquatic Habitat[3]:** | | |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | 1/4 Partial |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | All Non-detect |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 4 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 3 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | All Non-detect |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 2 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | 1 detect-very low |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 3 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | 1/4 TDS>SDWR ?? |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 2 detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 2/7 > 240 IMPAIRED |

Bowling Blvd Sp-2943 (7Samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | |
|---|---|---|---|---|---|---|
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria µg/L[2]** | | | | **Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired** |
| | | Human Health: | | **Warm Water Aquatic Habitat[3]:** | | |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | 2/7 Partial |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | 1 detect Y=0.0003 |
| Arsenic | 7440382 | 10 | | 340 | 150 | 3 detects < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 7 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 6 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | 5 detects < Chronic |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 3 detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | 1 detect < Chronic |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 7 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 6 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | 2 ~ SDWR |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 6 detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | One detect > Chronic |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 4/7 > 240 IMPAIRED |

Beargrass Preserve Park Sp-2944 (2samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Pollutant | CAS[1] Number | Water Quality Criteria μg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | OK |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | All Non-detect |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | Both < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 1 detect < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | All Non-detect |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | Both < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | Both < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | TDS Very High-Partial?? |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 1 detect < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | NO DATA |

CSO 206 Sp-2945 (2 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Pollutant | CAS[1] Number | Water Quality Criteria µg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | IMPAIRED |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | Insufficient Data |
| Arsenic | 7440382 | 10 | | 340 | 150 | 1 detect < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | Both < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | Both < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | 1 detect < Chronic |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | Both < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | 1 detect < Chronic |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 1 detect < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | Insufficient Data |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 1 detect < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Seem OK |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | Both < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 7/7 > 240 IMPAIRED |

Collins Sp-2948 (6 samples)

| Pollutant | CAS[1] Number | Water Quality Criteria µg/L[2] Human Health: DWS[4] | Fish[5] | Warm Water Aquatic Habitat[3]: Acute | Chronic | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | OK |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 1 detect < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 6 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 5 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 5 detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 4 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | 2 detects < Chronic |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 3 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Seem OK |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 3 detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 3/7 > 240 IMPAIRED |

Floyds Sta Sp-2955 (3 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria μg/L[2]** | | | | |
| | | Human Health: | | **Warm Water Aquatic Habitat[3]:** | | |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | OK |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | All Non-detect |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 3 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 2 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | 2 detects < Chronic |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 1 detect < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 3 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 3 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | 1 detect < Acute |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | TDS a little high |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 1 detect < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 3/7 > 240 IMPAIRED |

Buechel Sp-3355 (24 samples/5yrs)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | |
|---|---|---|---|---|---|---|
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria μg/L[2]** Human Health: | | **Warm Water Aquatic Habitat[3]:** | | **Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired** |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | IMPAIRED |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | Several; Y < 0.05 |
| Arsenic | 7440382 | 10 | | 340 | 150 | Several < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 24 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | 1 detect < Chronic |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 24 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | 15 detects < Chronic |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | 2 detects > Chronic |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | Several < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | 7 detects < Chronic |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 24 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | 1 detect < Chronic |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | Several < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Seem OK |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 24 detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 3/7 > 240 IMPAIRED |

| AB Sawyer Sp-3357 (12 samples/3yrs) | | | | | | |
|---|---|---|---|---|---|---|
| **401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants** | | | | | | **Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired** |
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria µg/L[2]** | | | | |
| | | Human Health: | | **Warm Water Aquatic Habitat[3]:** | | |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | 2/12 Partial |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | 3 Detects; Y < 0.05 |
| Arsenic | 7440382 | 10 | | 340 | 150 | 9 Detects < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 12 Detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 12 Detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 2/12 Partial |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | 7 Detects < Chronic |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | 1 detect < Chronic |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 9 Detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | 1 detect < Chronic |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 8 Detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | 1/12 > SDWR |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 9 Detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | 1 detect > Chronic (NOT) |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 4/7 > 240 IMPAIRED |

Mockingbird Valley Sp-3363 (3 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria μg/L[2]** | | | | |
| | | Human Health: | | **Warm Water Aquatic Habitat[3]:** | | |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | 1/3 > 25% Reduction |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 3 detects < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 3/3 < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 3/3 < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | 1 detect < Chronic |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 2 detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | 2 detects < Chronic |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 3 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | 1 detect < Chronic |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 3 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | 1/3 a bit high |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 3 detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 7/7 > 240 IMPAIRED |

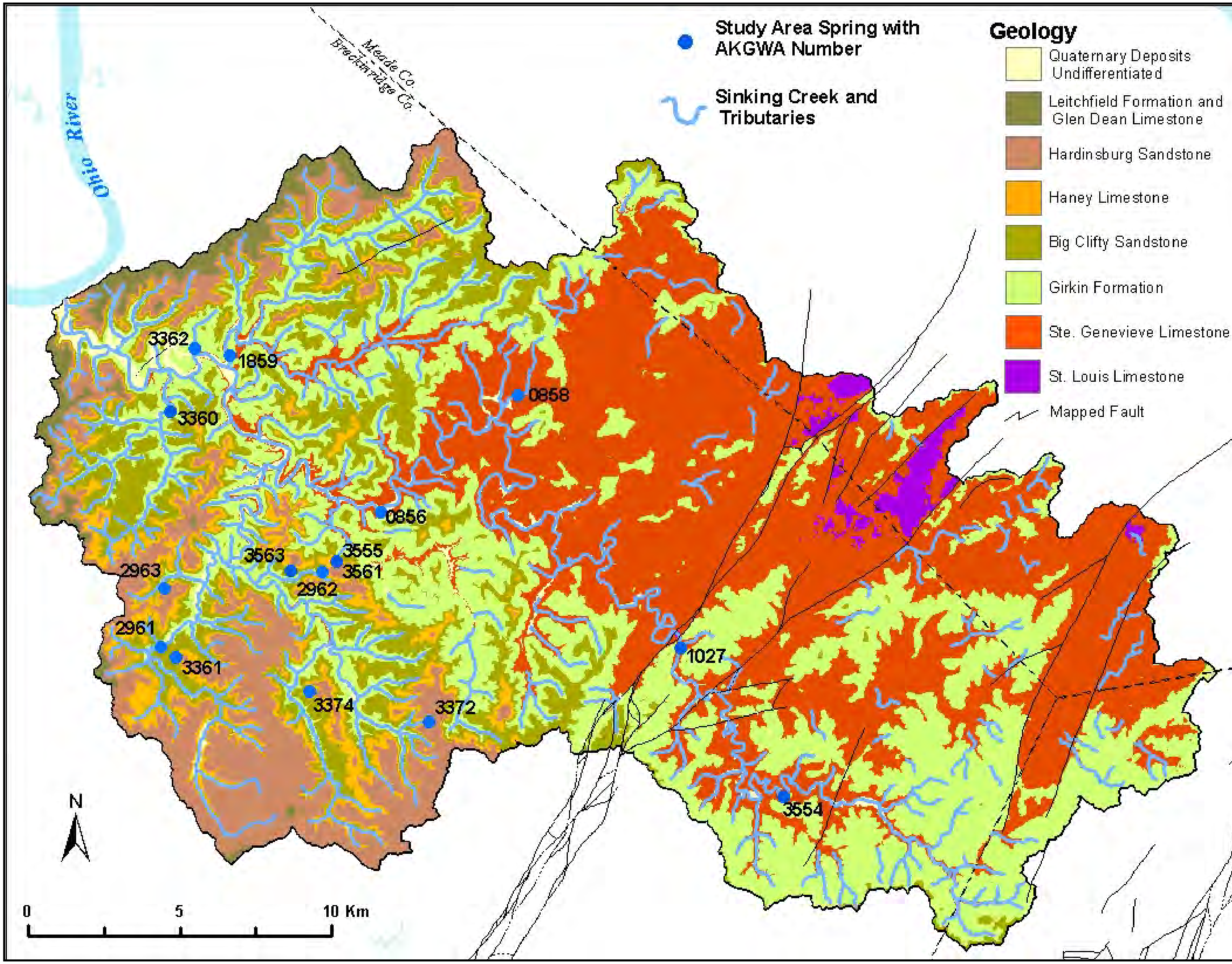
Barret Sp-3364 (2 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Pollutant | CAS[1] Number | Water Quality Criteria µg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | ok |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 1 detect < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 2 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 2 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 2 detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 2 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | ok |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 2 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | 1 detect < Chronic |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | TDS a little high |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 2 detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 5/7 > 240 IMPAIRED |

Cypress Pointe Sp-3367 (6 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Pollutant | CAS[1] Number | Water Quality Criteria μg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | 1/5 Partial |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 2 detects < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 6 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 6 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | 6 detects < Chronic |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | 1 detect > Chronic |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | All Non-detect |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | 1 detect < Chronic |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 6 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 6 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Seem OK |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | All Non-detect |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | 1 detect < Chronic |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 4/7 > 240 IMPAIRED |

| Steinrock Sp-3368 (2 samples) | | | | | | |
|---|---|---|---|---|---|---|
| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
| Pollutant | CAS[1] Number | Water Quality Criteria μg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | OK |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | All Non-detect |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 2 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 2 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 1 detect < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 1 detect < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 1 detect < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Seem OK |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 2 detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | 1/4 > 240 IMPAIRED?? |




Sites Monitored in Sinking Creek Watershed. Groundwater Quality Assessment Checklists for Springs are below.

| Hardin Sps-0856 (7 samples) | | | | | | |
|---|---|---|---|---|---|---|
| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
| Pollutant | CAS[1] Number | Water Quality Criteria µg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | OK |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 3 detects < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 7 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 6 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 7 detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | 1 detect < Chronic |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 3 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | OK |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 1 detect < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | 1/7 TDS a little high |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 2 detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | NO DATA |

Parks Sp-0858 (2 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Pollutant | CAS[1] Number | Water Quality Criteria μg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | ok |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | All Non-detect |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 2 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 1 detect < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 2 detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | All Non-detect |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | ok |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 1 detect < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | 1 detect < Chronic |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | ok |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | All Non-detect |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | NO DATA |

Burtons Hole Sp-1859 (7 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Pollutant | CAS[1] Number | Water Quality Criteria µg/L[2] Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | 2/7 > 25% Partial |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | All Non-detect |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 8 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 6 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 7 detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 2 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | ok |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 2 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | 1 detect < Chronic |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | ok |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | All Non-detect |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | NO DATA |

| Cutoff Sp-2961 (8 samples) | | | | | | |
|---|---|---|---|---|---|---|
| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria μg/L[2]** | | | | |
| | | Human Health: | | **Warm Water Aquatic Habitat[3]:** | | |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | Ok |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 6 Detects < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 8 Detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 8 Detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 7 Detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 6 Detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | Ok |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 1 Detect < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | 2 Detects < Chronic |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Ok |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 8 Detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | NO DATA |

O'Reilly Sp-2962 (4 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria µg/L[2]** | | | | |
| | | Human Health: | | **Warm Water Aquatic Habitat[3]:** | | |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | Ok |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 1 detect < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 4 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 2 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 1 detect < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | All Non-detect |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 1 detect < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Ok |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | All Non-detect |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | NO DATA |

Jarboe Sp-2963 (3 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Pollutant | CAS[1] Number | Water Quality Criteria μg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | Ok |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | All Non-detect |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 3 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 3 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | All Non-detect |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 1 detect < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 1 detect < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Ok |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 1 detect < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | NO DATA |

Finley Sp-3361 (5 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Pollutant | CAS[1] Number | Water Quality Criteria μg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | Ok |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 1 detect < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | 1 detect < Chronic |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 5 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 4 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | All Non-detect |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 2 detects < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | 1 detect - Insufficient Data |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 2 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Ok |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 1 detect < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | NO DATA |

Adkins Sp-3362 (3 samples)

**401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants**

| Pollutant | CAS[1] Number | Water Quality Criteria µg/L[2] Human Health: DWS[4] | Fish[5] | Warm Water Aquatic Habitat[3]: Acute | Chronic | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | Ok |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 2 detects < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 3 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | 1 detect < Chronic |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 3 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | 1 detect < Acute |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 3 detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | All Non-detect |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | 1 detect < Chronic |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | Ok |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 1 detect < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | 1 detect < Acute |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Ok |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | All Non-detect |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | NO DATA |

Blackburn Sp-3372 (3 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | |
|---|---|---|---|---|---|---|
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria µg/L[2]** | | | | **Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired** |
| | | Human Health: | | **Warm Water Aquatic Habitat[3]:** | | |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | 1/3 > 25% |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC)) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 1 detect < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 3 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 3 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 2 detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | All Non-detect |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 2 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Ok |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | All Non-detect |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | NO DATA |

Fentress Sp-3374 (3 samples)

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| **Pollutant** | **CAS[1] Number** | **Water Quality Criteria µg/L[2]** | | | | |
| | | Human Health: | | **Warm Water Aquatic Habitat[3]:** | | |
| | | DWS[4] | Fish[5] | **Acute** | **Chronic** | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | All Non-detect |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | Ok |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | All Non-detect |
| Arsenic | 7440382 | 10 | | 340 | 150 | 1 detect < Chronic |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | All Non-detect |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | All Non-detect |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | 3 detects < Chronic |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | All Non-detect |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | 2 detects < Chronic |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | All Non-detect |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | All Non-detect |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | All Non-detect |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | All Non-detect |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | All Non-detect |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | 3 detects < Chronic |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | All Non-detect |
| Malathion | 121755 | | | | 0.1 | All Non-detect |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | All Non-detect |
| Methoxychlor | 72435 | 40 | | | 0.03 | All Non-detect |
| Mirex | 2385855 | | | | 0.001 | All Non-detect |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | 1 detect < Chronic |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | All Non-detect |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | Ok |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | All Non-detect |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | 2 detects < Chronic |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | All Non-detect |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | Ok |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | All Non-detect |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | 2 detects < Chronic |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | All Non-detect |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | NO DATA |

| 401 KAR 10:031. Section 4, Section 6 & Section 7-Allowable instream concentrations of pollutants | | | | | | Impairment Level ?10%=Not 11-25%=Partial >25%=Impaired |
|---|---|---|---|---|---|---|
| Pollutant | CAS[1] Number | Water Quality Criteria µg/L[2] | | | | |
| | | Human Health: | | Warm Water Aquatic Habitat[3]: | | |
| | | DWS[4] | Fish[5] | Acute | Chronic | |
| Aldrin | 309002 | 0.000049 | 0.00005 | 3 | | |
| Alkalinity (as $CaCO_3$) | | | | Reduction >25% | | |
| alpha-Endosulfan | 959988 | 62 | 89 | 0.22 | 0.056 | |
| Ammonia, un-ionized (mg/L) Y < 0.05 mg/L | | | | Y=1.2(Ammonia-N)/(1+10pKa-pH) | pKa=0.0902+(2730/273.2+TC) ) | |
| Arsenic | 7440382 | 10 | | 340 | 150 | |
| Beta-Endosulfan | 33213659 | 62 | 89 | 0.22 | 0.056 | |
| Cadmium | 7440439 | 5 | | e(1.0166 (ln Hard*)-3.924) | e(0.7409 (ln Hard*)-4.719) | |
| Chlordane | 57749 | 0.0008 | 0.00081 | 2.4 | 0.0043 | NO DATA |
| Chloride | 16887006 | 250,000 | | 1,200,000 | 600,000 | |
| Chloropyrifos | 2921882 | | | 0.083 | 0.041 | |
| Chromium (III) | 16065831 | | | e(0.8190 (ln Hard*)+3.7256) | e(0.8190 (ln Hard*)+0.6848) | NO DATA |
| Chromium (VI) | 18540299 | | | 16 | 11 | NO DATA |
| Copper | 7440508 | 1,300 | | e(0.9422 (ln Hard*)-1.7) | e(0.8545 (ln Hard*)-1.702) | |
| Cyanide, Free | 57125 | 700 | 220,000 | 22 | 5.2 | NO DATA |
| Demeton | 8065483 | | | | 0.1 | NO DATA |
| Dieldrin | 60571 | 0.000052 | 0.000054 | 0.24 | 0.056 | |
| Endrin | 72208 | 0.76 | 0.81 | 0.086 | 0.036 | |
| gamma-BHC (Lindane) | 58899 | 0.019 | 0.063 | 0.95 | | |
| Guthion | 86500 | | | | 0.01 | NO DATA |
| Heptachlor | 76448 | 0.000079 | 0.000079 | 0.52 | 0.0038 | |
| Heptachlor epoxide | 1024573 | 0.000039 | 0.000039 | 0.52 | 0.0038 | |
| Iron[6] | 7439896 | | | 4,000 | 1,000 | |
| Lead | 7439921 | 15 | | e(1.273 (ln Hard*)-1.46) | e(1.273 (ln Hard*)-4.705) | |
| Malathion | 121755 | | | | 0.1 | |
| Mercury | 7439976 | 2 | 0.051 | 1.7 | 0.91 | |
| Methoxychlor | 72435 | 40 | | | 0.03 | |
| Mirex | 2385855 | | | | 0.001 | |
| Nickel | 7440020 | 610 | 4,600 | e(0.8460 (ln Hard*)+ 2.255) | e(0.8460 (ln Hard*)+ 0.0584) | |
| Parathion | 56382 | | | 0.065 | 0.013 | NO DATA |
| Pentachlorophenol | 87865 | 0.27 | 3 | e(1.005(pH)-4.869) | e(1.005(pH)-5.134) | |
| pH | | 6.5-8.5 | | 6.0 - 9.0 | | |
| Phthalate esters | N/A | | | | 3 | NO DATA |
| Phenol | 108952 | 21,000 | 1,700,000 | | | NO DATA |
| PolychlorinatedBiphenyls (PCBs) | N/A | 0.000064 | 0.000064 | | 0.0014 | |
| Selenium | 7782492 | 170 | 4,200 | 20 | 5 | |
| Silver | 7440224 | | | e(1.72 (ln Hard*)-6.59) | | |
| Hydrogen Sulfide, Undissociated | 7783064 | | | | 2 | NO DATA |
| Temperature | | | | See Temp-Month Table | | |
| TDS and TSS | N/A | 750,000 | | No adverse effects on aquatic life | | |
| Toxaphene | 8001352 | 0.00028 | 0.00028 | 0.73 | 0.0002 | |
| Zinc | 7440666 | 7,400 | 26,000 | e(0.8473 (ln Hard*)+0.884) | e(0.8473 (ln Hard*)+0.884) | |
| 4,4'-DDT | 50293 | 0.00022 | 0.00022 | 1.1 | 0.001 | |
| E. Coli (Sec7-Primary Contact) | | < 1 | | 240 CFU (20% of samples) | | |

Table 1. Water Quality Standards 401 KAR 10:031