Project Title: Identification and Prioritization of Karst Groundwater Basins in Kentucky for Targeting Resources for Nonpoint Source Pollution Prevention and Abatement

Joseph A. Ray, Phillip W. O'dell, and Jack R. Moody
Technical Services Section

Jolene M. Blanset and Robert J. Blair
Data Management and Support

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

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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)	640.0	acres
mi^2	2.590	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	2.20	lb
hectare	2.471	acre

Miscellaneous abbreviations:

BMP - Best Management Practice
DOW - Division of Water
EPA – U. S. Environmental Protection Agency
ft^3/s - Cubic Feet per Second
GQ - Geological Quadrangle
GIS - Geographic Information System
HA - Hydrologic Investigation Atlas
HAL - Health Advisory Level
KGS - Kentucky Geological Survey
L/s - Liters per Second
MCL - Maximum Contaminant Level
MDL - Minimum Detection Level
mg/L - milligrams per liter (parts per million)
NE - Northeast Study Area
NPS - Nonpoint Source
ppm - parts per million
QA/QC - quality assurance/quality control
SMCL - Secondary Maximum Contaminant Level
SW - Southwest Study Area
TMDL - Total Mean Daily Loading
UBF - Unit Base Flow (base flow per unit area)
USGS - United States Geological Survey

EXECUTIVE SUMMARY

This project investigated the water quality of twelve large karst springs, their drainage basins, and several neighboring basins in the Pennyroyal Plateau over a four-year period. The purpose was to identify and evaluate impacts from nonpoint source (NPS) pollution in sensitive karst watersheds of north-central and western Kentucky. Ninety-six quarterly water-quality samples were collected at these large springs from January, 1999, through May, 2001. Key parameters that reflect NPS pollution include nutrients and herbicides, applied mainly to row crops. Nitrate-N and atrazine were of special concern because of moderate to elevated levels measured in the spring waters. Nitrate-N levels fluctuated somewhat throughout the study period with medians ranging from about 1-6 mg/L [compared to the Maximum Contaminant Level (MCL) allowed in public drinking water of 10 mg/L]. Atrazine detections peaked in the spring application season, sometimes well above the MCL of 0.003 mg/L.

Karst terrane is well known for complex groundwater drainage systems, which are sensitive to pollution. In order to correctly attribute NPS impacts observed at springs to the appropriate watersheds, groundwater-tracing studies were conducted from 1997-2000 to more accurately identify basin boundaries. Two major areas were investigated in this project: the northeastern (NE) portion of the Pennyroyal Plateau, primarily in Meade and Breckinridge counties, and the southwestern (SW) portion of the Pennyroyal Plateau, largely in Christian and Trigg counties.

Forty-two groundwater tracer tests were completed and 261 km (162 mi) of subsurface flow routes within nineteen groundwater basins were mapped for the first time or replicated. These basins represent total land areas of 670 km^2 (258 mi^2) and base-flow water supply of 850 L/s (30 ft^3/s). This improved mapping of complex karst watersheds can be used to more accurately develop Total Mean Daily Loading (TMDL) assessments of regional streams. The Kentucky Geological Survey in cooperation with the Kentucky Division of Water will also publish subterranean flow-route and groundwater basin-boundary data in the karst-atlas mapping project. The study areas are located on the Tell City (NE) and Hopkinsville (SW), 1:100,000 quadrangles.

An additional assessment of watershed area and aquifer yield (base flow per unit area or UBF) was achieved by measuring spring discharges during dry-season base-flow conditions. Thirty-two springs were gaged in combined study areas, from 1997-2001, resulting in the following conclusions:

(a) A direct relationship exists between base-flow discharge and basin area, within uniform hydrogeologic setting. However, UBF in the SW study area is 25-30% greater than in comparable areas of the NE. This is likely due to slightly higher rainfall and increased groundwater storage within thicker soils of the SW study area.

(b) Within the NE study area, basins typified by sinkhole-plain topography yielded twice the UBF as did basins draining dissected sandstone caprock. This is a consequence of greater sustained groundwater storage in soil-mantled limestone than in sandstone-capped plateaus.

After spring-basin boundaries were delineated, digital land-cover data were evaluated to quantify the variety and concentration of agricultural activities. Based on average percentage of row crops and pasture & hay, the SW study area, which is more level and arable, contains about twice the number of acres in agriculture versus the NE study area. Conversely, the more rugged NE study area is covered by four times more deciduous forest than in the SW. These fundamental differences result in better overall water quality in the NE than in the SW.

Based on water quality and land-use, the impacts of NPS pollution of these karst springs and basins were ranked and prioritized. As expected, the more intensive agricultural basins of the SW generally ranked higher on this priority list than those in the NE. This priority ranking can be used to more appropriately focus resources to address NPS pollution, such as education and training, technical and financial assistance, and best management practice (BMP) implementation and modification.

Education outreach has been accomplished by participation in agriculture field meetings, karst field trips, and regional watershed meetings. Groundwater maps and data have been and will be distributed to landowners and stakeholders. A poster summarizing the final report will be presented at conferences and distributed to government agencies and the public. The completed report will also be available at the Kentucky Division of Water website. Additionally, the karst-basin delineation and the priority ranking methods can be used as technical guidance for evaluating NPS pollution within similar complex karst groundwater basins.

Rank	***Spring***		***Weighted Value***
	Southwest	***Northeast***	
1	River Bend		9.15
2	Wright		8.83
3	Mill Stream		7.83
4	King		7.53
5	Cooks		7.10
6	Barkers Mill		6.88
7		French Creek	6.88
8	Walton		6.53
9		Boiling	5.68
10		Buttermilk Falls	4.05
11		Head of Wolf	4.00
12	Brelsford		3.58

Nonpoint-Source Pollution Priority Ranking of Twelve Sampled Karst Springs

ID #	Spring	Discharge L/s*	Basin Area km^2	% Agri.	% Forest	Maximum Nitrate-N mg/L	Maximum Atrazine mg/L^B	Weighted Score	Priority Rank
0860	River Bend	158.6	69.9^m	87.7	8.7	6.19	**0.00315**	9.15	**1**
1475	Wright	25.5	14.2	89.7	6.2	7.05	0.00115	8.83	**2**
0203	Mill Stream	82.1	182.1^m	73.8	21.9	6.73	0.00299	7.83	**3**
1489	King	59.5	28.2	85.2	11.5	4.81	**0.00993**	7.53	**4**
1141	Cook	93.4	41.7^m	75.3	17.1	5.49	**0.00615**	7.10	**5**
0859	Barkers Mill	169.9	69.2^m	93.0	3.0	6.19	0.00074	6.88	**6**
1838	French Creek	45.3	54.4	67.9	27.2	3.59	**0.00675**	6.88	**7**
1457	Walton	48.1	25.1	77.4	19.0	6.24	**0.0119**	6.53	**8**
0855	Boiling	277.5	327.6	52.7	45.6	3.03	0.00067	5.68	**9**
1824	Buttermilk Falls	22.7	12.7*est*	26.8	65.1	2.21	**0.00393**	4.05	**10**
1063	Head of Wolf Cr.	14 *est*	42.5	27.9	70.1	1.04	0.00294	4.00	**11**
1448	Brelsford	85 *est*	32.9	65.4	31.1	2.64	0.00145	3.58	**12**

Summary of Numerical Data Derived by this Investigation
(*Discharge during dry-season base-flow conditions; ^{m} Basin areas have been modified by subsequent research; $^{\mathbf{B}}$ Bold font indicates atrazine concentration above MCL)

INTRODUCTION

More than a decade ago, the US Environmental Protection Agency (EPA) began to recognize that nonpoint source pollutants from groundwater discharge was a significant source of contaminant loading in many surface waters throughout the US (Hoffer, 1991). More recently, the USGS showed that the lower Ohio River basin, draining a considerable amount of karst terrane within the Cumberland River and Green River watersheds in Kentucky, has some of the highest yields of pesticide runoff in the US (Crain, 2002). Although pesticide runoff from non-karst farmlands has been shown by the Division of Water to be a serious and increasing pollution problem in the lower Green River basin (Schaffer and Miller, 2002), the sensitive groundwater drainage of extensive karst terranes in the region is also a major contributor.

Soluble rocks, such as limestone, on which karst landscapes form, underlie over 50% of Kentucky. This terrane is considered to be karst because of the development of turbulent groundwater circulation through underground channels or conduits. Well-developed karst may contain naturally occurring closed topographic depressions or sinkholes with internal drainage, losing or sinking streams, caves, and large springs. Because of these features, most of the groundwater in Kentucky's karst drainage basins is under the direct influence of the surface by rapid infiltration of precipitation and surface-runoff water. Consequently, karst groundwater is widely recognized as highly sensitive to point- and nonpoint-source pollution from surface activities such as agriculture, transportation, and urban development. Although several aquifer studies have been undertaken within Kentucky's Mississippian Plateau, few broad-scale investigations of karst groundwater have been conducted in the most intensive agricultural areas.

The Technical Services Section of the Kentucky Division of Water's Groundwater Branch conducted a groundwater investigation where the primary goal was to produce a priority ranking of karst groundwater basins in areas of intensive agricultural land use in the Mississippian Plateau physiographic province of Kentucky. This ranking of karst groundwater basins will provide a framework to appropriately focus future nonpoint-source resources, such as BMP implementation and modification, public education, and technical and financial assistance in areas that have been established to have the most critical need.

PURPOSE AND SCOPE

This project studied twelve karst springs and several neighboring basins during two years for the purpose of identifying impacts from NPS pollution. Most karst drainage basins assessed by the study were previously unknown or known by limited data. Methods such as hydrogeologic inventory, tracer testing, and unit base flow measurements were employed in order to identify the basin drainage areas so that key water quality parameters can be attributed to appropriate karst watersheds. The primary objective of this project is a priority ranking of the twelve karst basins, as assessed by eight quarters of water quality analyses of the main springs and land use within their basins.

LOCATION AND EXTENT OF STUDY AREAS

Two primary study areas encompassing Mississippian-aged rocks of the Pennyroyal Plateau physiographic region were assessed during this investigation. Northeastern and southwestern sub-regions were evaluated and are shown in Figure 1.

The NE study area is located in Meade, Breckinridge, and Hardin counties, where four springs were sampled and 24 groundwater tracer tests were conducted in ten karst drainage basins. This study area covers about 775 km^2 (300 mi^2 or 192,000 acres) and includes all or part of the New Amsterdam, Mauckport, Lodiburg, Irvington, Guston, Rock Haven, Hardinsburg, Garfield, Big Spring, Kingswood, Custer, and Constantine 7.5 minute topographic quadrangles.

The SW study area is located in Trigg, Christian, and Todd counties, where 8 springs were sampled and 18 tracer tests were conducted in nine karst drainage basins. The study area covers about 390 km^2 (150 mi^2 or 96,000 acres) and includes all or part of the Cobb, Gracey, Cadiz, Caledonia, Church Hill, Johnson Hollow, Roaring Spring, Herndon, Oak Grove, Trenton, Guthrie, and Allensville 7.5 topographic quadrangles.

HYDROGEOLOGIC SETTING

Within the two regional study areas, the principle aquifer occurs in Mississippian-aged limestones of the Pennyroyal or Mississippian Plateau. In a broader context, this cavernous limestone region coincides with most of the Highland Rim Section of the Interior Low Plateaus region of central and western Kentucky. In some locations, especially the northeastern study area, karst drainage extends beneath the dissected uplands developed in Chester-age sandstones and limestones.

STRATIGRAPHY

Rocks within the study areas consist mainly of thick units of Ste. Genevieve and St. Louis limestones of the Meramecian Series of the Mississippian System (Figure 2). These limestones were deposited mainly in shallow seas. The purity and high solubility of the limestones make the terrane highly susceptible to karst development. Long-term bedrock dissolution of these limestones has strongly influenced the Pennyroyal's characteristic flat-lying to undulating topography, which contains numerous shallow sinkholes and caves, losing and sinking streams, stream-less valleys, intermittent lakes, and large springs.

The relative stratigraphic position of springs discharging from the Ste. Genevieve and St. Louis limestones are shown in Figure 2 with a spring symbol and are labeled with the names of springs investigated in this study. The two western-most springs, Brelsford and Cook, are shown on USGS Geologic Maps in the Upper Member of the St. Louis Limestone (Brelsford, GQ412) and in the Ste. Genevieve Limestone and Upper Member of the St. Louis Limestone (Cook, GQ-710). These are primarily nomenclature changes relative to quadrangles east of this area and for the purposes of this report are considered to be equivalent to the lower portion of the Ste. Genevieve.

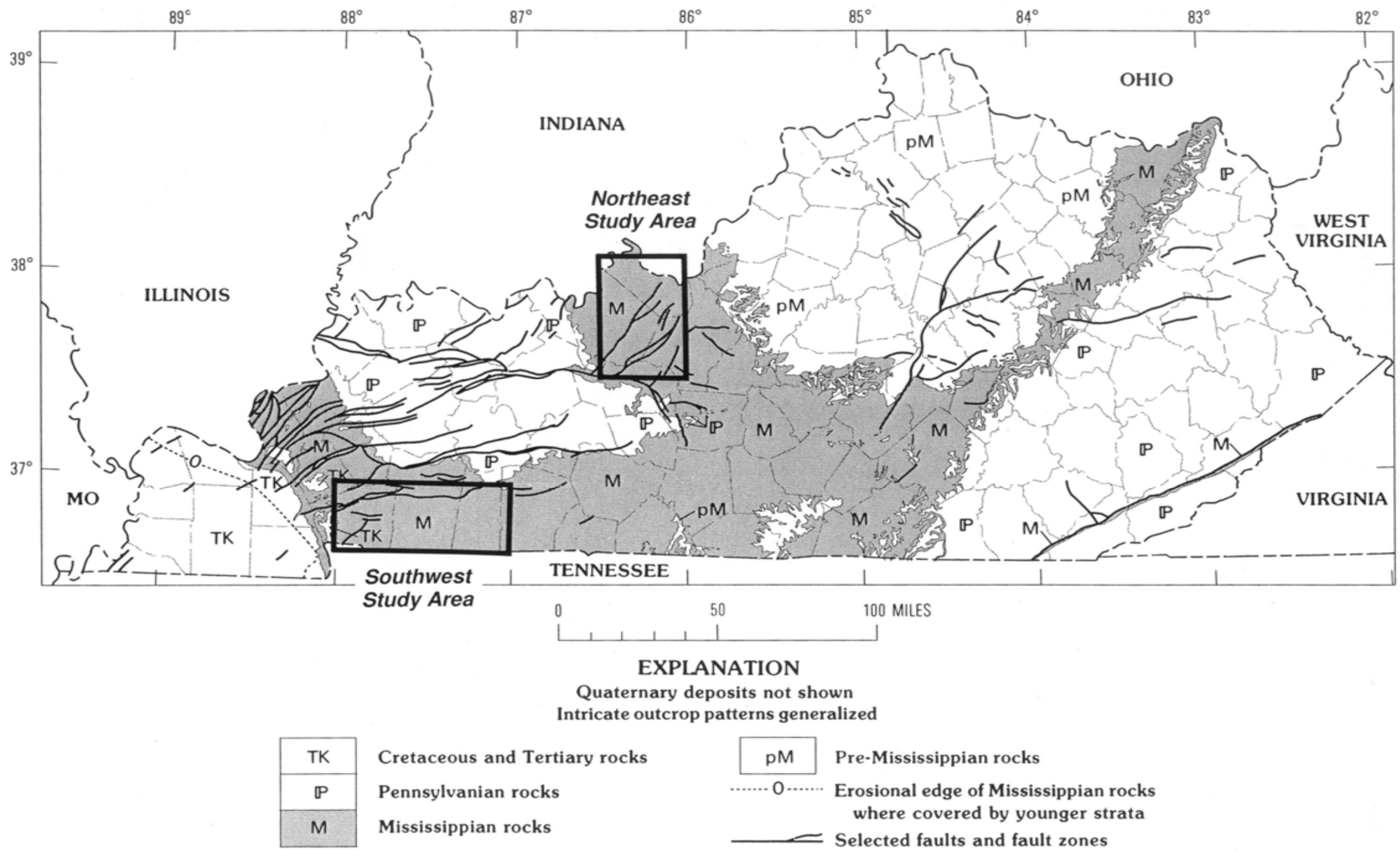

Figure 1: Index Map Showing the Location of two Study Areas within the Mississippian Plateau, Kentucky (Index base map adapted from Sable and Deaver, 1990).

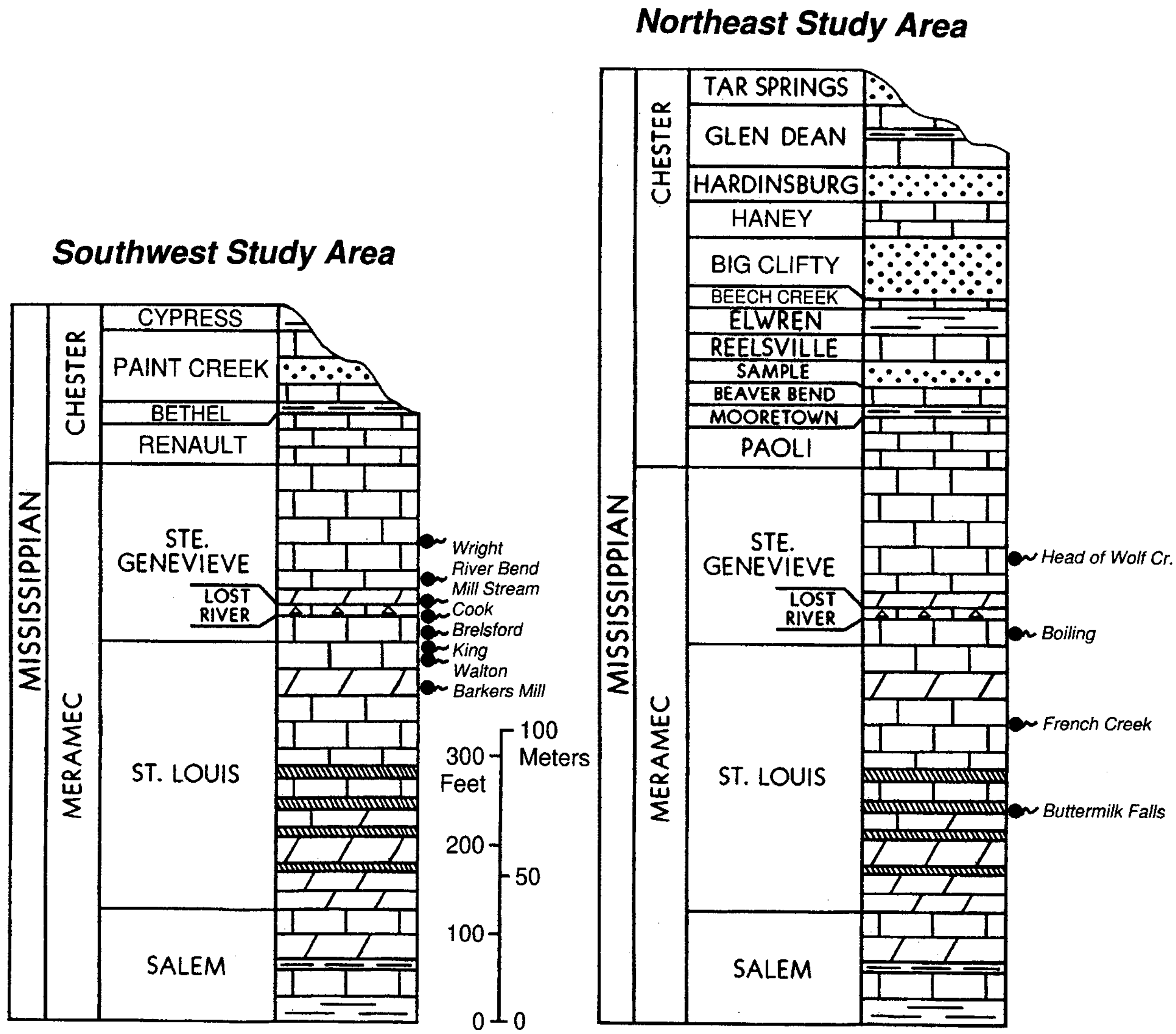

Figure 2: Generalized Stratigraphic Columns of the Southwest and Northeast Study Areas, Adapted from Ettensohn and Dever (1979)

The triangle-symbols labeled as Lost River near the base of the Ste. Genevieve Limestone, indicate a persistent chert horizon that tends to influence topography and groundwater flow. The diagonally hatchured zones in the lower section of the St. Louis Limestone identify gypsum and anhydrite beds. The lower portion of Chester-age rocks illustrate the similar lithology in both study areas but a regional variation in nomenclature. In the southwestern study area the units are named Renault, Bethel, Paint Creek, and Cypress, whereas in the northeastern study area these units are named Paoli, Mooretown, Beaver Bend, Sample, Reelsville, and Elwren. For the purposes of this report these rock units are considered to be equivalent.

Ste. Genevieve Limestone

Most of the karst drainage basins investigated in this study are developed within the Ste. Genevieve Limestone. The Ste. Genevieve is composed of thick-bedded, light-colored, medium- to coarse-grained, oolitic and bioclastic calcarenite; 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. The Ste. Genevieve typically ranges in thickness from 55-73 m (180 to 240 ft) in the study area (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. 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), and to decrease sinkhole density where it underlies the surface, such as the Bristow Plain east of Bowling Green (Quinlan & Ewers, 1981).

St. Louis Limestone

A few of the karst drainage basins in this study discharge from the top and middle of the St. Louis Limestone, which underlies the Ste. Genevieve Limestone. The St. Louis 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. Although this unit ranges from 90-145 m (300-475 ft) in thickness, most of the karst groundwater circulation relevant to this study occurs in the upper portion.

KARST HYDROLOGY

Because of the characteristics of karst terrane, rates of groundwater recharge, flow velocities, and potential dispersion within the study areas can be extremely high. 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 kilometers per day. Likewise, karst groundwater flow can be dispersive, potentially distributing pollutants over broad areas at a relatively long distance from the source. Three major hydrologic parameters of *recharge, flow, and dispersion*, were used to assess the groundwater sensitivity to pollution from surface activities in Kentucky (Ray, and others, 1994). 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 terrane of the Mississippian Plateau, *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 study areas are rated as "5", which is the most sensitive hydrogeologic settings for potential pollution from surface activities and nonpoint sources.

The 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.

Hydrogeology of the Northeastern Study Area

The principal aquifer in the NE study area is developed in up to 150 m (500 ft) thickness of the Ste. Genevieve and St. Louis limestones. These limestones generally dip west to northwest at about 4-7 m/km (20-40 ft/mi). Surface elevations range between 300 m (985 ft) MSL near Ekron, to 117 m (383 ft) on the Ohio River pool. The general elevation of the sinkhole plain is 185-215 m (600-700 ft). A minor fault zone including Locust Hill Fault and Cave Spring Fault trends northeast from the Rough Creek Fault Zone into the study area (Amos, 1976). The location of Fiddle Spring and the Flat Rock distributary may be influenced by these faults and possibly associated lineaments. Average rainfall is about 115 cm/yr (45 in/yr).

Whereas most regional springs are located in the Ste. Genevieve, springs flowing directly into the Ohio River discharge from the underlying St. Louis limestones. The northeastern portion of this study area is predominantly a stream-less, low-relief karst plain, dominated by sinkholes or dolines. The dissected Dripping Springs Escarpment or Chester Cuesta, in the higher-relief western portion, contains up to 70 m (230 ft) of alternating carbonate and siliciclastic units of the Chester Series of the Mississippian System. These include the Glen Dean Limestone, Hardinsburg Sandstone, Haney Limestone, Big Clifty Sandstone, Beech Creek Limestone, Elwren Sandstone (sandstone and shale), Reelsville Limestone, Sample Sandstone, Beaver Bend Limestone, Mooretown Formation (shale, siltstone, and sandstone), and Paoli Limestone. The interstratal soluble beds often develop minor springs perched on underlying sandstones or shales. These springs typically sink at the contact with the next lower limestone. This alternating surface and subsurface flow is typical within the dissected plateau.

The main surface drainage in the high-relief area is Sinking Creek, one of the largest losing streams in Kentucky. This system heads at Blue Fork and Stoney Fork springs, in eastern Breckinridge County, and gains substantial flow from the Flat Rock Spring distributary and

Fiddle Spring just NW of Rosetta. The main losing reach of Sinking Creek is about 5 km (3 mi) south of Irvington. A meandering 19 km (12 mi)-long dry channel trends NW from the losing reach to Boiling Springs, where Sinking Creek resurges (George, 1976; Ray, 2001). Webster Cave is an overflow distributary of the Sinking Creek system discharging at Webster Overflow Springs. Trunk groundwater flow from Sinking Creek can be observed in a cave-stream segment at the southern reach of this extensive cave. The cave-stream level declines as much as 15 m (50 ft) during flow recession (Bell, 1976). Trunk flow can also be observed in Penitentiary Cave, about one km east of Boiling Springs (Angelo George, written communication, 2001). Additional springs in the area include Hardin Springs, which discharges from the south into Sinking Creek, about three km (1.9 mi) southwest of Boiling Springs. About 8 km (5 mi) WNW of Boiling Springs, Burtons Hole Spring and runoff from Sugar Tree Run and Dry Valley drains from the north. Sinking Creek ultimately flows into the Ohio River at Stephensport.

Hydrogeology of the Southwestern Study Area

The principal aquifer in the SW study area is developed primarily in up to 200 m (650 ft) thickness of the Ste. Genevieve and St. Louis limestones. Perennial master streams are fairly common within this low-relief karst plain although sinkholes, karst windows, and losing and sinking streams exist locally. Low-relief surface drainage networks tend to influence the overall karst landscape to a greater extent than classic sinkhole-plain topography as found in the NE study area or the Mammoth Cave region. The main streams of the area are Little River and West Fork, which are moderately incised to depths of about 40 m (130 ft). Major tributaries of Little River include Muddy Fork, Sinking Fork, Casey Creek, and the North and South Forks of Little River. Major tributaries of West Fork include Little West Fork, Montgomery Creek, and Spring Creek. Another stream, Elk Fork is a northern tributary of Red River. Average rainfall is about 127 cm/yr (50 in/yr).

Jillson (1927) discussed the stream-dissected, fluvial character of much of the landscape in the western Mississippian Plateau. He termed the plateau west of Bowling Green "Karst", and described it as widely pitted with sinkholes, but with only partial subterranean drainage. This western area was distinguished from the region northeast of Bowling Green, which was described as a "Sink Hole" region, where most of the drainage is subterranean. The fluvial character of the western region is probably related to reduced stream incision depths, the influence of bedded cherts (such as the Lost River Chert) within the limestones, and thicker regolith cover in the far southwestern portion of the region. Karst basins in the southwestern part of the Mississippian Plateau tend to be smaller than those to the east, where drainage is controlled by the more deeply incised Green, Barren, and Ohio rivers. Still, most drainage in the southwest is subterranean, even though surface drainage networks are more pronounced and perennial streams are more common than in the eastern portion.

One distinct difference between the eastern and western Mississippian Plateau is the more common occurrence of intermittent and seasonal lakes in the west. The relatively shallow depth to trunk conduits allows groundwater to rise to the surface during large floods, and be stored in surface depressions, sometimes for months at a time (Crawford, 1981; Currens and Graham, 1993). This storage may be aggravated where the lateral transport capacity of shallow conduit networks is limited by constrictions or immature development (Aley and Thomson, 1981). Also, the more fluvial characteristic of this karst terrane also generates channelized (concentrated overland flow) storm-water runoff, which fills swamps, broad depressions, sinking stream basins, and locally disrupted valley segments. Because of this occasional phenomenon, flood-vulnerable development should not take place within closed topographic depressions (Ray, 2001).

METHODS OF INVESTIGATION

This investigation contains six basic components: Review of previous investigations and literature, Hydrogeologic inventory, Groundwater tracing, Unit base flow assessment, Water chemistry sampling and Land use assessment. The Results of Groundwater Investigations section describes the springs and groundwater-tracing data within basins, unit base flow assessment, and classification of karst basins. The Interpretation of Results section evaluates land cover and spring chemistry data and discusses the priority ranking of spring basins based on those data.

REVIEW OF PREVIOUS INVESTIGATIONS AND LITERATURE

Several previous investigations, concerning geology, hydrology, and speleology have been conducted in or adjacent to the karst regions studied in this project. These investigations are summarized below and referenced under the appropriate **Spring** sub-heading, in the **Results of Investigation** section.

Division of Water Investigations (Delineation of Spring and Wellhead Recharge Areas)

Northeast Study Area:

Ekron Public Water Supply Wells: In 1998, the Groundwater Branch conducted a groundwater tracer investigation of four public water supply wells at Ekron, in Meade County, Kentucky. The well at the Ekron Elementary School is 45 m (148 ft) deep, whereas the three wells supplying Ekron are of unknown depth. The site is a well-developed sinkhole-plain. This study was conducted by continually monitoring the wells with a pump-supplied garden hose tipped with a flow-through charcoal dye receptor. About 0.03 L/s (0.5 gallons per minute) of flow was continually passed through the charcoal during the study. While the wells were being monitored, fluorescent dyes were injected into sinkholes, sinking streams, or Class V Storm-water Injection wells in the area. Although the wells were not known for turbid water, which often indicates a direct surface connection, all four wells received dyes injected into sinkholes within 300 m (1000 ft). Therefore these wells were shown to be under the influence of surface water. These tests also revealed that the flow systems were rather complex since some sinkhole dye injections were not detected, even though they were within 300 m of a well. All traced groundwater from the area around Ekron was eventually detected at Hamilton Hill Bluehole, 11 km (6.8 mi) north-northwest, which discharges to the Ohio River. These traces were the first to be recovered in Hamilton Hill Bluehole and helped to identify the southeast portion of this basin.

Battletown and Payneville Elementary School Wells: In 1998, the Groundwater Branch conducted groundwater tracer investigations of two water supply wells located at elementary schools in Battletown and Payneville. The sites are on top of ridges formed of alternating limestones and sandstones that are deeply dissected. Six traces were attempted near the 475 ft deep Battletown well, four of which were not recovered. This is probably due to summertime conditions and the small amounts of dyes used. The conclusion from this study was that the well may be effectively isolated from the active karst system by local hydrologic perching units with the ridge, the deep casing depth, and the limited pumping rate of 0.6 L/s (10 gpm). One dye trace was recovered in Oolite Spring discharging to the Ohio River east of the Battletown well.

During the Payneville Elementary well study, four dyes were injected in the area around the school. Three traces were recovered in Head of Wolf Creek Spring, 9-10 km (6-7 mi) to the northwest, but not in the 480 ft deep well. The conclusion was that, like Battletown, the Payneville well derives supply primarily from the fractured limestone aquifer that is not closely connected to the main karst drainage system. The three traces recovered in Head of Wolf Creek Spring, 9-10 km (6-7 mi) to the northwest, are the only traces to identify this basin. They show that this is a sizable basin and at an estimated low flow of 15 L/s (0.5 ft^3/s), not all of the potential base flow is observed at the known discharge point. Therefore, Head of Wolf Creek Spring is a seasonal overflow spring with perennial flow from a local sub-basin.

Southwest Study Area:

Merriwether Spring Groundwater basin: The recharge area of Merriwether Spring, Guthrie, Kentucky's sole water-supply source at that time, was delineated with eight groundwater tracer tests conducted by Groundwater Branch personnel (Ray and Stapleton, 1996). The basin area is about 30 km^2 (11.5 mi^2) of primarily farmland. Merriwether Spring has a base flow discharge of 71 L/s (2.5 ft^3/s). The spring is a relatively constant-flow spring because most high-flow waters are discharged through a well-integrated subsurface overflow distributary from three springs at the southwest margin of the basin. Two of these springs are fed by conduits that pass beneath surface drainage to discharge on the far side of Spring Creek. Also, two surface overflow channels may be activated during high-flow conditions.

Trenton Water Well: The recharge area of a conduit-intersecting 27 m (90 ft)-deep water well, the water source for Trenton, was delineated by Groundwater Branch personnel during 1996-98. Eleven dye tests were conducted to identify a 17.6 km^2 (6.8 mi^2) sub-basin, centered around a sinking stream named Dry Branch, within the Hughs Bluehole karst drainage basin. In a normal year this sub-basin should yield a low-flow discharge of about 40 L/s (1.4 ft^3/s) whereas maximum pumping rate of the well is 19 L/s (300 gpm or 0.7 ft^3/s).

Pembroke Water Well: The recharge area of a conduit-connected 34 m (110 ft)-deep water well, the former water source for Pembroke, was delineated by Groundwater Branch personnel during 1997. Five dye tests were conducted which determined that the well was hydrologically connected to an unnamed losing stream with a watershed area of about 22 km^2 (8 mi^2), located northwest of Pembroke. The losing stream resurges at Hargrove Spring, 1.6 km (1 mi) to the south-southeast. Three other dye injections into local sinkholes indicated that the well's local recharge area extends outward as much as 120 m (395 ft) but less than 360 m or 470 m (1180 or

1540 ft). Therefore, a 305 m (1000 ft)-radius local recharge area was established around the well in addition to the losing stream watershed. In a normal year the losing stream sub-basin should yield a low flow discharge of about 45 L/s (1.6 ft^3/s) whereas the maximum pumping rate of the well, per eight-hour shift, is 6.3 L/s (100 gpm or 0.22 ft^3/s). Because the well was reputedly non-turbid after heavy rains, whereas the losing stream was often turbid, some filtration mechanism must function in the recharge zone of this high-volume well.

Todd County Water Well: Division of Water Groundwater Branch personnel delineated the recharge area of a conduit-connected 37 m (120 ft)-deep water well, the water source for Todd County Water District, in 1997. Six dye tests were conducted which determined that the well was hydrologically connected to Elk Fork, at some point or points about 305 m (1000 ft) northeast of the well. The Elk Fork watershed contributing to the well is 29.15 km^2 (11.25 mi^2) and the low flow of Elk Fork was estimated at about 15 L/s (0.5ft^3/s). Based on these values, the unit base flow of Elk Fork is calculated at only 0.04 $ft^3/s/mi^2$. The maximum pumping rate of the well, per eight-hour shift, is 6.3 L/s (100 gpm or 0.22 ft^3/s) or nearly half of the available low flow of Elk Fork. Therefore, drought could seriously impact the supply for this water well.

Additional Data from Literature

Fracture Control of Dolines, Caves, and Surface Drainage, Kastning & Kastning (1980)

In the Sinking Fork/Caledonia area of the SW study area, fracture analysis from topographic maps, cave maps, aerial photographs, and field inspections suggest that sinkhole (doline) alignments and straight-line stream reaches have been influenced by regional structures radiating or diverging from the west. Most caves of the area generally follow dominant fracture traces along major structural trends. Likewise, the orientation of much subsurface drainage suggests fracture control because of alignment of stream sinks, collapse areas, and springs.

Influence of Master Stream Incision on Cave Development, Trigg County, Moore & Mylroie (1979)

In Trigg and Christian counties, the incision of Sinking Fork into limestones has resulted in two basic patterns of cave formation: (a) meander cutoff caves formed by Sinking Fork drainage and (b) tributary caves transmitting drainage from the adjacent plateau to Sinking Fork. This study documented the aquifer diversion of Sinking Fork through Pipeline Cave and Boatwright Hole to Mill Stream Spring, 5.5 km (3.4 mi) to the east. This cutoff reduced the water flow path by 8 km (5 mi) resulting in a steepened gradient.

Meander Cutoff Caves and Self Piracy, Mylroie and Mylroie (1991)

This paper discusses the same topic as above and suggests that Cool Spring is recharged by piracy of Stillhouse Branch and that Steele Branch drains to Decibel Cave. Additionally, cutoffs on West Fork are described. Murphy Spring and Turners Bluehole are assumed to be cutoff springs. However, a replicated dye trace from the Watts Cave karst window to Turners Bluehole [01-22-JAR (Year-Dye trace number-Author's initials)] demonstrates that the spring, lying on the west side of West Fork, is the discharge point for a groundwater basin on the east side of West Fork. Conduit flow draining the basin is confined beneath West Fork. The basin of Murphy Spring is presently unknown but existing information supports the assumption that it is primarily fed by a cutoff from West Fork.

Groundwater Flow in the Vicinity of Gracy, Crawford, 1987; Crawford & Mylroie (unpublished)

A gasoline spill near Gracy, Kentucky, occurred with the rollover of a tanker truck along US 68-KY 80 on September 11, 1986. The spill site appeared to be in the headwaters of Steele Branch, which drains southwest to Sinking Fork. Crawford (1987) conducted a groundwater tracer study and mapped local water levels to determine the actual path that contaminants were likely to follow. An unpublished manuscript by Crawford & Mylroie describes the hydrogeology and emergency response to this gasoline spill. Groundwater flow from the site did not follow the surface watershed south to Sinking Fork as might be inferred from the topography. Instead, subsurface flow was to the northwest towards a graben structure and then parallel to the structure to the west, crossing the structure to discharge at Cook Spring, 13 km (8 mi) to the northwest. In this case, dye tracing and potentiometric-surface mapping was vital to determine the actual discharge point of groundwater potentially contaminated with spilled gasoline. This is one of only two tracer tests to be recovered in Cook Spring and identifies a chain of four large karst windows.

Trigg County Landfill, Ewers and Idstein (1991)

A dye-trace investigation was conducted to determine the destination of potential drainage from the Trigg County Landfill, north of Cadiz. Dye placed into the up-gradient monitoring well at the landfill site was traced primarily to Cadiz "Town" Spring, the water supply for Cadiz. A minor recovery of dye was also detected at 139 Bridge Spring to the north and at Logjam Spring, to the southeast. The dye was not detected in the down-gradient monitoring wells for the landfill, indicating that these wells are not reliable as monitoring points for the landfill. This trace was the first to be recovered in Cadiz Spring.

Cadiz Spring Groundwater Basin Delineation, Ewers and others (2001)

This Wellhead Protection study was conducted to determine the boundaries of the groundwater basin contributing to the Cadiz Spring, the town's water supply source. Four dye injections partially delineated the groundwater basin of Cadiz Spring. Green #6 Spring appears to be connected to the main flow route feeding Cadiz Spring. Traces were also recovered in Cook Spring and Fault Line Spring, draining to Muddy Fork, and in Sinking Fork upstream of Oliver Spring #2. Interstate 24 appears to be outside the Cadiz Spring basin.

Fort Campbell Military Reservation

Since 1985, basin delineation on and adjacent to the Fort Campbell Military Reservation in southern Christian County has been conducted by the USGS (Taylor, 1996; Hileman, 1997; Hileman and Ladd, 1998), Ewers Water Consultants, and students from Eastern Kentucky University (Ewers and others, 1989; Carey, 1985). Karst basins partially mapped include

Buchanan/Herndon Overflow and Quarles Spring. Also, tracer testing has been conducted for several Class V Injection wells near Oak Grove and the I-24/US-41A interchange. Basins partially mapped include Hunter Spring and Barkers Mill Spring.

Characteristics of Large Springs in Kentucky, Van Couvering (1962)

One of the 12 sampled springs, Mill Stream Spring, was studied during the 1950's by Van Couvering of the USGS, in cooperation with the KGS. Most of the data presented in this report was collected by Brown, Kulp, Lambert, Mull, and Whitesides.

Mill Stream Spring, in Trigg County, is described as issuing at the head of a narrow deep gorge from the St. Louis Limestone at 120 m (395 ft) elevation *(However, the site is mapped at the base of the Ste. Genevieve Limestone on GQ-604)*. It formerly powered a large mill. Fourteen discharge measurements were made from 1955 through 1960, with three measurements aborted due to high water during 1956 and 1957. The discharges ranged from 42.5 L/s (1.5 ft^3/s) to 5041 L/s (178 ft^3/s), a 118-fold increase. Water temperatures ranged from 46-65 degrees F, compared to average groundwater temperatures of 54-59 degrees F, showing the influence of losing stream flow rapidly contributing to the spring. In parts per million (ppm), bicarbonate ranged from 90 to 260, sulfate from 6 to 14, and chloride from 2 to 7.

The Van Couvering report provides data on two additional springs which were studied in the dye-tracing portion of the project, Garnett Spring and Head of Doe Run Spring (Schenley Spring). ***Garnett Spring***, in Trigg County, discharges from the St. Louis Limestone at an elevation of 125 m (410 ft), and was gaged 17 times from 1955 through 1960. The discharges ranged from 45 L/s (1.6 ft^3/s) to 821 L/s (29 ft^3/s), an 18-fold increase. Water temperature ranged from 50 to 58 degrees F. In ppm, bicarbonate ranged from 190 to 325, sulfate from 2 to 13, and chloride from 1 to 7.

Head of Doe Run Spring (Schenley Spring) in Meade County, discharges from the St. Louis Limestone at an elevation of 175 m (575 ft), and was gaged 24 times from 1952 through 1960, with one measurement aborted due to high water in 1956. The discharges ranged from 120 to 990 L/s (4.2 to 35 ft^3/s), an 8-fold increase. Temperature ranged from 54 to 59 degrees F. In ppm, bicarbonate ranged from 195 to 230, sulfate from 25 to 230, and chloride from 1 to 19.

Hydrologic Investigations Atlas HA-33, Brown & Lambert (1963)

Although seven of the eleven springs investigated in the NE study area were not shown on HA-33, data were provided for four springs:

Head of Doe Run Spring (Schenley Spring), in Meade County, has been extensively studied by the USGS. HA-33 provides the lowest recorded USGS discharge value for that period of 114 L/s (4.04 ft^3/s). This compares with a DOW low-flow measurement of 150 L/s (5.3 ft^3/s) (9-11-94) and a drought measurement of 93 L/s (3.3 ft^3/s) on 12-1-99 (38% less than the normal summer low flow of 150 L/s). Based on 150 L/s, the Head of Doe Run Spring ranks as the 18th largest-volume spring in Kentucky (Ray, unpublished data).

Head of Wolf Creek Spring, in Meade County, was listed in the HA-33 report at 91.5 L/s (3.23 ft^3/s). Flow observations by DOW revealed that the spring diminished to an estimated 15 L/s (0.5 ft^3/s) during summer low flow. With a tracer-identified drainage basin of at least 42.5 km^2 (16.4 mi^2), this spring should yield nearly 3 times this amount. Consequently, this spring must be considered a seasonal overflow feature with minor base flow contributed by local drainage. The USGS discharge must not be a low flow measurement, but an unrepresentative reading at some point during intermittent or seasonal overflow conditions. (A seasonal overflow spring with zero base flow in Todd Co. (related to Meriwether Spring) was likewise over-represented at 189.5 L/s (6.7 ft^3/s) in HA-34)

Head of Spring Creek Spring, in Meade County, was listed in the HA-33 report at 143 L/s (5.05 ft^3/s). Similar to Head of Wolf Creek Spring, DOW has determined that Head of Spring Creek Spring must also be a seasonal overflow spring, and the USGS value is unrepresentative. The partially delineated basin of ~96 km^2 (37 mi^2), should yield three times more low flow runoff than the gaged discharge of 27.2 L/s (0.96 ft^3/s) (9-17-98). Interestingly, this spring has produced a remarkable bluehole feature with a dimension of 40 x 24 m (130 x 80 ft), a maximum measured depth of 10.3 m (33.8 ft), and a large gravel/cobble natural levee. However, the large volume of water in the bluehole is not adequately circulated during low flow conditions to flush the tanic discoloration of water, causing it to appear stagnant. Neither of the perennial underflow springs related to Wolf Creek or Head of Spring Creek have been located. This is due to the unpredictable back-ponding of the spring run downstream, by the impounded Ohio River.

Boiling Springs, in Breckinridge County, is listed on HA-33 at an estimated discharge of 31.6 L/s (1.1 ft^3/s). This is a serious underestimation of the flow of the region's largest spring. At 277.5 L/s (9.8 ft^3/s) (average of four low-flow measurements) Boiling Springs is the tenth largest spring in Kentucky (Ray, unpublished data). The 1999 drought-discharge was down at least 36% to 178.4 L/s (6.3 ft^3/s).

Hydrologic Investigations Atlas HA-34, Lambert & Brown (1963)

Within the SW study area, HA-34 provides discharge data on three of the eight monitored springs:

Cook Spring, in Trigg County, is estimated at 190 L/s (6.7 ft^3/s). This estimate is nearly twice the low-flow discharge measurements made by DOW. The spring was gaged four times from 1994-1999, ranging from 88-133 L/s (3.1-4.7 ft^3/s). The average of the lower three measurements is 93 L/s (3.3 ft^3/s).

Mill Stream Spring, was named on HA-34 and listed with a minimum measured discharge of 42.5 L/s (1.5 ft^3/s). DOW gaged the spring in 1993 at 90.6 L/s (3.2 ft^3/s) and a 1999 drought measurement was 70.8 L/s (2.5 ft^3/s).

Wright Spring, in Todd County, is estimated on HA-34 at 45 L/s (1.6 ft^3/s). DOW gaged the spring 3 times during base flow from 1995 and 1999, ranging from 14-34 L/s (0.5-1.2 ft^3/s), for an average of 25 L/s (0.9 ft^3/s).

A fourth spring is shown about 1.2 km (0.75 mi) southwest of the actual location of Barkers Mill Spring. On HA-34 this unknown spring is estimated at 20 L/s (0.7 ft^3/s), which is nearly an order of magnitude lower than the gaged flow of Barkers Mill Spring. At a discharge of 170 L/s (6.0 ft^3/s), Barkers Mill Spring is the 16th largest Kentucky spring, and the largest known spring west of Logan County. Nine of the additional eleven springs studied in this region were not shown on HA-34.

Sinking Creek Hydrosystem, Angelo George (1970-76)

***Boiling Springs*:** Previous tracer tests were conducted in the Boiling Springs basin by Angelo George (1970-72 unpublished data) and others (Bell Engineers, 1974). A main flow route within Boiling Springs basin, from Big Spring to the springs on Sinking Creek, was dye-traced during caving expeditions from 1970-72. Extensive cave surveys were made in Big Bat, Webster, and Thornhill Caves. This work mapped a major flow route from the karst windows at Big Spring, through Gilpin Karst Window, Ross Karst Window, to the Flat Rock Spring distributary. Although a connection between the distributary and Fiddle Spring was determined by George, dye was not recovered in Fiddle Spring during tracing of the Flat Rock Spring distributary by DOW in low to moderate-flow conditions. An overflow connection between the two otherwise separate systems may exist.

Wellner & Fister (1989) conducted a tracer test from a disposal sinkhole, used by the Irvington wastewater treatment plant, to Boiling Springs. James Greer conducted two tracer tests in the headwaters of Stoney Fork Spring (1993, unpublished data).

***Hardin Springs*:** Watt Hole Karst Window was connected to Hardin Springs by George (unpublished data, 1976).

Potentiometric surface - Mississippian Plateaus, Plebuch, Faust, and Townsend (1985)

A regional study of the potentiometric surface and water quality in the principal aquifer of the Mississippian Plateaus Region, Kentucky, includes the two study areas of this report. The primary purpose of the study was to provide a potentiometric map of the principal aquifer for determining the general direction of groundwater movement, to aid in determining possible paths of pollutant movement, and to help in selecting drilling sites. A secondary purpose of the report was to describe the general water quality in the principal aquifer.

The principal aquifer refers primarily to the St. Louis and Ste. Genevieve limestones, but may also include units of the underlying Fort Payne Formation, Warsaw (Harrodsburg) Limestones, and Salem Limestone. Within the overlying Chesterian Series, the Renault Limestone, the Beaver Bend and Paoli limestones (or the Girkin Limestone, depending on the location in the plain) may also be considered part of the principal aquifer.

The delineation of karst drainage basins by tracer mapping provides a test of the primary purpose of the 1985 study, i.e., to help determine the general direction of groundwater movement and to infer possible paths of pollutant movement. In order to fulfill the stated purpose, the core of major groundwater basins should be suggested by a concavity of the potentiometric contours and major basin divides should be inferred by contour convexities or potentiometric highs. Because the contour interval is 50 ft (15 m), this objective can be met in only a very general way. As pointed out by Schindel and others (1994), potentiometric surface maps can only be used for *very general* predictions about karst groundwater movement. Data for the map were collected from 1975 to 1982, and also from earlier studies since regional groundwater levels have remained relatively stable for at least a quarter of a century (p. 2). Unfortunately, the density of water-level data points and the frequency of data rejection were not presented. These data would have helped to indicate the level of subjectivity employed in mapping water-level contours.

Comparison of Potentiometic Contours with Tracer-Mapped Karst Basins

In the NE study area, groundwater gradient and therefore flow direction is suggested by 400 to 650 ft (122 to 198 m) elevation potentiometric contours. The trunk path within the ***Boiling Springs*** basin is fairly well identified but flow in the headwaters tends to parallel the contours or cross convexities. ***Head of Wolf Creek Spring*** drainage is shown crossing a 400 ft (122 m) contour convexity, and is therefore not suggested by the map. ***French Creek Spring*** drainage is reasonably indicated with flow perpendicular to contours, as is ***Hamilton Hill Bluehole***. No tracer data were developed for ***Buttermilk Falls***, but the contours appear reasonable. Because the outcrop of the Ste. Genevieve-St. Louis limestones is highly generalized and partially covered by Chesterian series units in the western and southern portion of the NE study area, several lengthy groundwater flow paths were identified outside of the generalized outcrop area. The potentiometric surface contours were extended into these areas, however.

Other spring basins, where tracer data were obtained, include ***Head of Spring Creek Spring*** where the trunk is indicated but the headwaters tend to parallel the 450 ft (137 m) contour or follow a convexity. ***Head of Doe Run Spring*** is fairly well indicated, but with some flow parallel to contours in the headwaters. Two springs are poorly indicated: ***Burtons Hole*** drainage follows a prominent potentiometric ridge shown by the 450 (137 m) and 500 ft (152 m) contours. ***Hardin Springs*** drainage is perpendicular to a trough and ridge formed by the 450 ft (137) contour. These last two spring basins, and the destination of groundwater contaminants, would not be located if a search for aquifer discharge points was based on the potentiometric surface map.

In the SW study area, flow direction is indicated by 400 to 600 ft (122 to 183 m) elevation contours. ***Cooks Spring*** drainage is fairly well indicated, but with flow parallel to the 500 ft (152 m) contour in the headwaters. ***Mill Stream Spring*** drainage is well indicated with a prominent trough shown just north of Sinking Fork. ***Brelsford Spring*** drainage crosses contours in a perpendicular direction but no trough is shown. ***Walton Spring*** and ***King Springs*** are poorly indicated with flow perpendicular to two convexities in the 500 ft (152 m) contour. ***Wright Spring*** is shown draining perpendicular to a broad convexity in the 550 ft (168 m) contour. The two largest karst basins in the SW study area, ***River Bend Spring*** and ***Barkers Mill Spring***, are not well indicated by the potentiometric surface because of flow crossing convex contours. These major aquifer discharge points are not well suggested by the regional map.

In summary, the success of the regional water-level map in indicating groundwater and pollutant movement is marginal, with some of the largest spring basins, and therefore main aquifer discharge points, not inferred by the 50 ft-interval (15 m) contours. As stated by Plebuch and others (1985):

"Potentiometric maps, constructed from water-level data, indicate the general direction of movement but details of the local movement generally require other methods of study. Dye tracing is one such method and work on local water movement is being done in the Mammoth Cave area (see Quinlan and Ray, 1981). Some work on local water movement is also being done at Bowling Green, Kentucky, but much remains to be done in this regard throughout the entire Mississippian Plateaus region." (p. 32)

The current study fulfils the need for additional tracer-mapping of the principal aquifer for identifying local groundwater movement. This work is widely recognized as essential for the adequate protection of the karst groundwater system.

McCraken Springs Recharge Area Delineation, Taylor & McCombs (1998)

During a hydrologic study of the drainage area of McCraken Springs on Otter Creek (Taylor and McCombs, 1998), one dye trace was connected to Big Spring in the headwaters of the Boiling Springs basin. A second connection from 6 km (3.75 mi) to the east-southeast was documented in a supplementary dye trace in 2001. This work extended the known width of the Boiling Springs basin to greater than 28 km (17.5 mi). The Head of Doe Run Spring, which bounds Boiling Springs to the northeast, was partially delineated by three dye traces in the eastern part of the basin. A fourth, supplementary dye trace in 2001 extended the basin to the south for a total basin length of 16 km (10 mi).

HYDROGEOLOGIC INVENTORY

Even though some information was available in the literature concerning the locations of springs and swallets in the SW study area, major areas were not evaluated by published reports. For example, only five springs were shown on USGS topographic maps that include the Little River and its major tributary, Sinking Fork. Consequently, a 72 km (45 mi) spring survey was completed by canoe in November, 1997, and 24 additional km (15 mi) were surveyed by walking. Over 30 additional springs were mapped, ranging from 3-160 L/s (0.1-5.6 ft^3/s) (summer base flow). The largest inventoried spring was not known in the literature previous to this study even though it is estimated to drain a 70 km^2 (27 mi^2) basin. Surveys for springs, during previous Spring Protection Area studies by the Groundwater Branch, had been conducted on West Fork, Spring Creek, and Elk Fork.

The NE study area is bounded by the Ohio River to the north. One unnamed spring at the head of Wolf Creek appears on the topographic maps of the area. Five additional springs ranging from 14-96 L/s (0.5-3.4 ft^3/s) and a three-spring distributary at French Creek have been previously mapped during Wellhead Protection Area investigations by the Groundwater Branch. These include three large bluehole features ranging from 15-40 m (50 to 130 ft) in diameter, which are apparent seasonal overflow springs. The underflow springs related to Head of Wolf

Creek Spring and Head of Spring Creek Spring have not been located. A search for these additional discharge springs was conducted by boat on the Ohio River during the fall of 1998. No karst features were detected along the channelized Ohio River. An unusual feature at the Head of Spring Creek is a natural levee composed of cobbles deposited around part of the large bluehole. This coarse deposit indicates the turbulence of flood discharges from this overflow spring.

Data from the long-term caving and hydrologic work of Angelo George were vital in the NE study area. Over the last several years, he has provided information on the Boiling Springs hydrosystem, Hardin Springs, and Hamilton Hill Bluehole. A perennial underflow spring at the western part of the study area was predicted after the inventory of a large intermittent overflow spring near the confluence of Dry Valley and Sugar Tree Run (Gary O'Dell, personal comm., 1999). A search was launched for the underflow spring, which was discovered at the location of a narrow topographic contour reentrant, one km southwest near the mouth of Sugar Tree Run. The owner named this spring Burtons Hole Spring. The discharge could not be accurately gaged because of fluctuations in the flow of Sinking Creek, which is back-ponded by the impounded Ohio River. Based on the apparent basin area, the discharge is calculated at about 54 L/s (1.9 ft^3/s).

Tracer-injection points were selected through an iterative, step-by-step process where major trunk-flow features or estimated basin boundaries were targeted for tracer testing. Losing and sinking streams, karst windows, sinking springs, sinkholes, and a drainage well were tested by dye injections.

GROUNDWATER TRACING

Qualitative groundwater tracer tests, described by Quinlan (1986) and Aley (1999), were conducted using six non-toxic fluorescent dyes:

Uranine Conc [Disodium Fluorescein] (Color Index (CI) Acid Yellow 73)
Keyacid Rhodamine WT Liquid (CI Acid Red 388)
Ricoamide Red XB [Sulforhodamine B (SRB)] (CI Acid Red 52)
Eosine (CI Acid Red 87)
Phorwite AR Solution [Optical Brightener] (CI Fluorescent Brightener 28)
Keyamine Flavine 7GFF 500% (CI Direct Yellow 96)

As described by Schindel and others (1994) and Field and others (1995), these dyes are optimal for use in groundwater-basin delineation because of non-toxicity, availability, analytical detectability, low cost, and ease of use. The first four dyes are adsorbed onto activated granular carbon and analyzed for presence and relative intensity using a scanning spectrofluorophotometer. The last two dyes are adsorbed onto unbleached cotton and analyzed for presence and relative intensity under a long-wave ultraviolet lamp at the Division of Water's Laboratory in Frankfort, Kentucky.

Samples of the activated carbon dye receptors are washed with tap water and processed in a solution of 50% 1-propanol, 30% de-ionized water, and 20% ammonium hydroxide (Smart Solution). The eluted samples from this study were analyzed at the Department of Geology's Hydrogeology Laboratory at Eastern Kentucky University, prior to December, 1998, and afterwards at the Division of Water's Laboratory.

Background dye receptors were 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. Dye receptors were typically exchanged weekly. Positive dye recovery was identified when fluorescence intensity was at least four times greater than the background, although fluorescence of positives typically exceeded background by more than ten times. Dye-trace results were recorded on Division of Water Dye-Trace Record Forms. These documents included dye injection site information and a detailed record of each dye receptor recovered during the study (Appendix A).

Tracer Tests

During this project, 42 groundwater tracer tests were conducted for the purpose of basin delineation. The results of these investigations will be discussed individually for each basin, and are listed under abbreviated dye-trace ID numbers such as 99-20 (Year-sequence of dye injection; the senior author was the principal investigator for all 42 traces). Recovered dye-intensity level is ranked by qualitative plus symbols which equate to the general confidence level of a positive dye-trace connection:

(?) = Inconclusive
(+) = Positive
(++) = Very Positive
(+++) = Extremely Positive

Tracer data for the twelve sampled basins are presented below as well as information gathered for eleven neighboring basins (7 in NE; 4 in SW). Individual dye-trace data forms are included in Appendix C. A diagram of each of the twelve karst watersheds shows the final results of flow-path mapping and approximate basin boundary (groundwater flow routes are reported as minimum straight-line to curvilinear distances, which are less than actual conduit pathways). Each basin diagram includes a tabulation of discharge, basin area, unit base flow (UBF), and percent agricultural landuse.

Eighteen reconnaissance tracer tests have been completed within nine groundwater basins in the SW study area. More than 81 km (50 mi) of newly interpreted flow routes have been mapped or previous traces replicated. Seven newly identified groundwater basins, yielding a total summer base flow of about 565 L/s (20 ft^3/s), drain an area of about 280 km^2 (108 mi^2) of mostly agricultural watersheds. Unusual spring types documented within these basins include constant flow springs, seasonal overflow springs, perennial distributaries, and conduit underflow of the bedrock channel in Little River.

Twenty-four reconnaissance tracer tests have been completed within ten groundwater basins in the NE study area. More than 180 km (112 mi) of newly interpreted flow routes have been mapped or previous traces replicated. Seven newly identified groundwater basins, yielding a total summer base flow of about 283 L/s (10 ft^3/s), drain an area of about 390 km^2 (150 mi^2) of agricultural and forested watersheds. 57 L/s (2 ft^3/s) of estimated base flow from the Head of Spring Creek basin and 23 L/s (0.8 ft^3/s) of estimated base flow from Head of Wolf Creek basin are not included in the above total. The discharge points of these two basins have not been located due to back-ponding by the impounded Ohio River. Other hydrologic features documented within the NE study area include large intermittent to seasonal overflow springs, groundwater flow beneath major topographic divides, and depressed unit base-flow discharge apparently due to minimal base-flow runoff from sandstone caprock.

UNIT BASE FLOW ASSESSMENT

In addition to tracer testing, another method of assessment called ***unit base flow,*** or normalized base flow, was applied to the karst basins in both study areas. Unit base flow (base-flow discharge per unit area) is a useful easily calculated parameter that is characteristic of the base-flow groundwater hydrology of various terranes. As applied to karst terranes, this water-balance assessment can be used to estimate the recharge area of springs, characterize their basins, and assess hydrogeologic relationships (Carey & others, 1994; Quinlan & Ray, 1995; Brahana, 1997, and Paylor & Currens, 2001). Unit-base-flow analysis is based on the assumption that equivalent units of watershed within similar hydrogeologic settings and climate will produce about the same volume of base-flow groundwater runoff. When applied to a regional population of springs, the method can be useful to predict the occurrence of springs and unobserved discharge below stream level, infer sources of spring pollution, and target hydrogeologic and dye-trace investigations (Ray and Meiman, 1998).

Unit base flow (UBF) is calculated by dividing the summer base-flow discharge (BF) by the apparent basin area (A): BF/A = UBF, to produce a normalized flow per unit area. For example, a spring discharge of 10 L/s divided by a drainage area of 5 km^2 equals a unit base flow of 2 L/s/km^2. An unknown basin area can be estimated from a representative base-flow discharge value if the UBF of a typical reference basin, from a similar hydrogeologic setting, is known. The low-flow discharge of the spring draining an unknown basin is divided by the UBF of the reference basin to derive an estimated area of the unknown basin: BF/UBF = A. For example, a spring discharge of 10 L/s divided by a reference value of 2 L/s/km^2 equals a drainage area of 5 km^2. Considering the generalization of discharge and basin-area measurements, UBF calculations should be rounded off to the nearest hundredth.

Within the Mississippian Plateau, hydrogeologic settings composed of karst plain developed on Ste. Genevieve or St. Louis Limestones generally yield a UBF ranging from 1.6 to 2.3 L/s/km^2 (0.15 to 0.2 ft^3/s/mi^2). The base-flow groundwater runoff tends to be similar, whether it is sinkhole-plain type or flat-lying, fluvial-network type topography. Terrain formed on Chester Series limestones, such as Renault Limestone and alternating limestone and sandstone sequences, yield less UBF than the Meramec Series units. Although measurements have not been taken for the Chester Limestones, the headwaters of Mill Stream Spring and Little River yield significantly less groundwater runoff than the southwestern portion of the watersheds. Mill Stream Spring, with a basin of 168 km^2 (65 mi^2) generates a depressed UBF of only 0.44 $L/s/km^2$ (0.04 $ft^3/s/mi^2$), even though the southern half of the basin is developed in the Meramec Series limestones.

In the assessment of a regional group of springs, anomalies of unit base-flow, above or below the typical range, may suggest measurement errors or differing hydrogeologic conditions. Usual causes of anomalies include: inaccurate discharge measurements or basin area estimates; inadequate discharge measurements due to undiscovered springs: differences in hydrogeologic settings or climate; and industrial, agricultural, or urban activities and conditions such as excessive groundwater withdrawal or recharge and increased surface runoff. Extensive field investigations may be required to determine which of these situations cause an apparent anomaly. Although a recharge area can be estimated by the UBF method, the actual basin location can only be inferred and must be confirmed by tracer studies. Ray (2002) illustrated an example of attributing an inferred basin area to the wrong location, during the initial investigation of a complex artesian flow system in Boyle County, Kentucky.

UBF analysis based on mean flows for a particular site differs significantly from calculations based on summer low flow. Since daily mean flow includes all discharge data recorded over a period of time, including high flows, it is an inflated value, relative to summer base flow. The latter value reflects the sustained base flow discharge of a groundwater basin and is directly related to the basin size. Likewise, summer base flow can be reliably observed in the field over several months, typically from August to November, whereas mean flow is calculated from records kept over a much longer period of time. Therefore, the condition of mean flow is not easily recognizable in the field during karst hydrogeologic investigations, or for targeting discharge measurements.

UBF assessment based on mean flows may be desirable for specific applications. For sites with available stream flow data, mean flow periods may be derived for specific months by means of a radar plot where monthly means are compared to annual means. The annual mean is represented as a concentric circle on the radar plot, whereas monthly means delineate an oval. The oval is skewed higher than annual mean in winter and lower in summer. Therefore, certain "magic months" are located where the two plots intersect (Campbell and Singer, 2001). The use of this technique requires a significant discharge database and targeted gaging of stabilized base flow during the graphically pinpointed magic months. This level of background information is rarely available for most karst springs and is not required to calculate useful water balance data.

Karst Water Withdrawal for Agricultural and Turf-grass Irrigation

Agricultural and turf irrigation appear to be growing in popularity in Kentucky. Application of the unit base flow method provides data on quantities of available groundwater runoff per unit area. From these calculations, prudent limits can be established for irrigation from groundwater and streams in karst areas. For example, within most of the Mississippian Plateau, if about 2.2 L/s (90 gpm or 0.2 ft^3/s) of groundwater is withdrawn daily and lost through evapotranspiration, this operation could extract the base flow runoff from the equivalent of a square mile of karst terrane. During drought conditions, as measured in 1999 and previous droughts (Lambert, 1976), spring discharge may be reduced by one-third to one-half of the normal flow. Obviously, several high-volume irrigation projects could significantly impact water quantity and dependent aquatic communities in karst areas. This is especially true during drought when dwindling water supplies are under greatest demand. Because of potential stress on karst drainage during high-demand periods, only lake storage is recommended for non-essential water withdrawal during summer low-flow and drought periods. Essential water withdrawal refers to those water supplies required to maintain human and livestock populations.

WATER CHEMISTRY SAMPLING METHODS

Groundwater samples from twelve springs were collected quarterly over two years, from 1-19-99 though 5-16-01. Water temperature, pH, and conductivity were measured in the field using Cole-Parmer digital direct-reading (or equivalent) portable temperature-compensating meters and recorded on field data sheets. Discharge was either gaged or estimated and flow conditions were noted. The instruments were calibrated according to the manufacturer's instructions using standardized buffer solutions. After field measurements, all probes were rinsed in deionized water and stored appropriately. pH electrodes were stored in a solution of 10% KCl.

Water samples were collected as near to the spring water source as possible. Samples not requiring field filtration were collected by submerging the water sample container directly into the stream run, with the container opening oriented upsteam. Samples requiring field filtration (orthophosphate, total dissolved phosphorus, and dissolved metals) were collected in a disposable cubitainer, returned to the vehicle and filtered through a portable vacuum filtration system using a 0.45-micron filter. New filters and silicon tubing were used at each sample location. All sample containers were new. Preservatives were immediately added when required.

Chain-of-custody forms were completed for each sample. They included sample collection date and time, signatures of sampling and sample handling personnel, and a work order for the laboratory. Samples were stored in coolers packed with wet ice for transport to the appropriate analytical laboratory, and delivered within 48 hours. Advance notice of sample collection and delivery was given to the Kentucky Geological Survey (KGS) laboratory so that critical sample holding times would not be exceeded. The laboratory was responsible for laboratory QA/QC, selection of appropriate approved analytical methods, and for reporting analytical results. Periodically, sample duplicates and QA/QC blanks were submitted to the DES laboratory to verify analytical results and decontamination procedures.

Laboratory Analyses

Water analyses for the following parameters, shown in Table 1, were conducted by the KGS.

INORGANIC-NONMETAL	Atrazine	Boron
Alkalinity	Butylate	Cadmium
Chloride	Linuron	Calcium
Conductance	Metolachlor	Chromium
Fluoride	Metribuzin	Cobalt
pH	Pendimethalin	Copper
Sulfate	Simazine	Gold
	Trifluralin	Iron
		Lead
NUTRIENT		Lithium
Ammonia-Nitrogen	**Insecticide**	Magnesium
Kjeldahl-Nitrogen	Chlorpyrifos	Manganese
Nitrate-Nitrogen	Diazinon	Nickel
Nitrite-Nitrogen	Endosulfan	Phosphorous
Orthophosphate	Malathion	Potassium
	Permethrin	Selenium
		Silicon
RESIDUE		Silver
Total Suspended Solids	**Fungicide**	Sodium
Total Dissolved Solids	Chorothalonil	Strontium
Total Organic Carbon		Sulfur
Total Recoverable Phosphorus		Thallium
	INORGANIC METALS	Tin
	Aluminum	Vanadium
ORGANIC	Antimony	Zinc
Herbicide	Arsenic	
Acetochlor	Barium	
Alachlor	Beryllium	

Table 1: Analytical Parameters

LAND COVER ASSESSMENT

Digital land-use data for the study areas were obtained from the National Land Cover Data Set for the conterminous United States, developed by the U.S. Geological Survey. They were first completed in 1992 and an accuracy rate of about 66% is expected. Within the twelve sampled basins, five primary types were identified which incorporated land-cover percentages of 3% or greater. The largest three categories included *Deciduous Forest* and two agriculture types, *Pasture & Hay* and *Row Crops*. Two additional minor categories included *Mixed Forest* and *Woody Wetlands*. These five types accounted for land cover totals within the spring basins ranging from 92-98%. Additional secondary land-cover types, such as *Urban/Residential, Recreational Grasslands, Water, Limestone Quarry, Evergreen Forest, Emergent Herbaceous Wetlands, and Transitional* are identified in the legend of individual basin maps when they are visually significant.

RESULTS OF GROUNDWATER INVESTIGATIONS

Four karst springs were selected for investigation in the NE study area and eight springs were selected in the SW study area. Springs were chosen based on a lack of previous water-quality data, accessibility, and a high percentage of karst terrane with agricultural land-use. NE springs include Boiling, French Creek, Head of Wolf Creek, and Buttermilk Falls. SW springs include Barkers Mill, River Bend, Cook, King, Brelsford, Mill Stream, Walton, and Wright. A four-digit, unique Kentucky spring identification number is provided after the name of each spring. Brief descriptions of these twelve springs are given below with photographs, a basin map, basic measurements, and dye-trace data. Figure 3 is a legend for the tracer data shown on these basin maps.

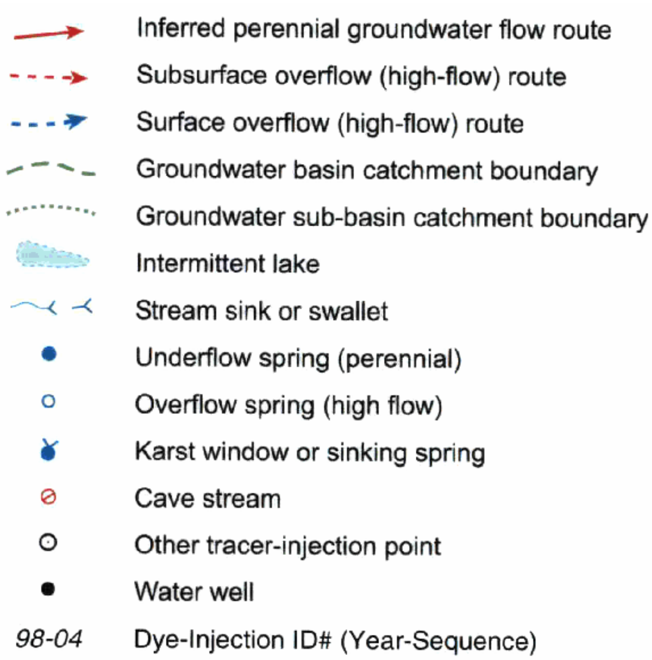

Figure 3: Legend for Tracer Data

DESCRIPTION OF SPRINGS AND BASINS, WITH SUMMARY OF TRACER TESTS

Northeast Study Area

Boiling (0855)

Boiling Springs (Figures 4a & 4b) is named at the northeastern corner of the Hardinsburg 7.5 minute Topographic Quadrangle, in north-central Breckinridge County [N37°-52′-9″; W86°-22′-41″]. Discharging from the Ste. Genevieve Limestone (Amos, 1975), Boiling Springs is a large 18 m-wide (60-70 ft) alluviated bluehole near the mouth of a local dry ravine at about 124 m (408 ft) elevation. The spring develops a 180 m-long (600 ft) spring run to Sinking Creek, where ruins of an old water mill exist. Above the confluence of Boiling Springs, Sinking Creek, which is primarily an overflow channel, discharges about 5.6 L/s (0.2 ft^3/s) of local flow during summer low flow conditions.

Over eight years Boiling Springs has been gaged six times during low flow, ranging from a high of 365 L/s (12.9 ft^3/s) to a low of 178 L/s (6.3 ft^3/s) during the 1999 drought. The typical low flow discharge averages 277 L/s (9.8 ft^3/s). Flood flow has been estimated at 56,000 L/s (2,000 ft^3/s) (George, 1976), 200 times greater than low flow. Numerous overflow features have developed around the bluehole's perimeter, which indicate a large fluctuation in discharge.

Figure 4a: Boiling Springs

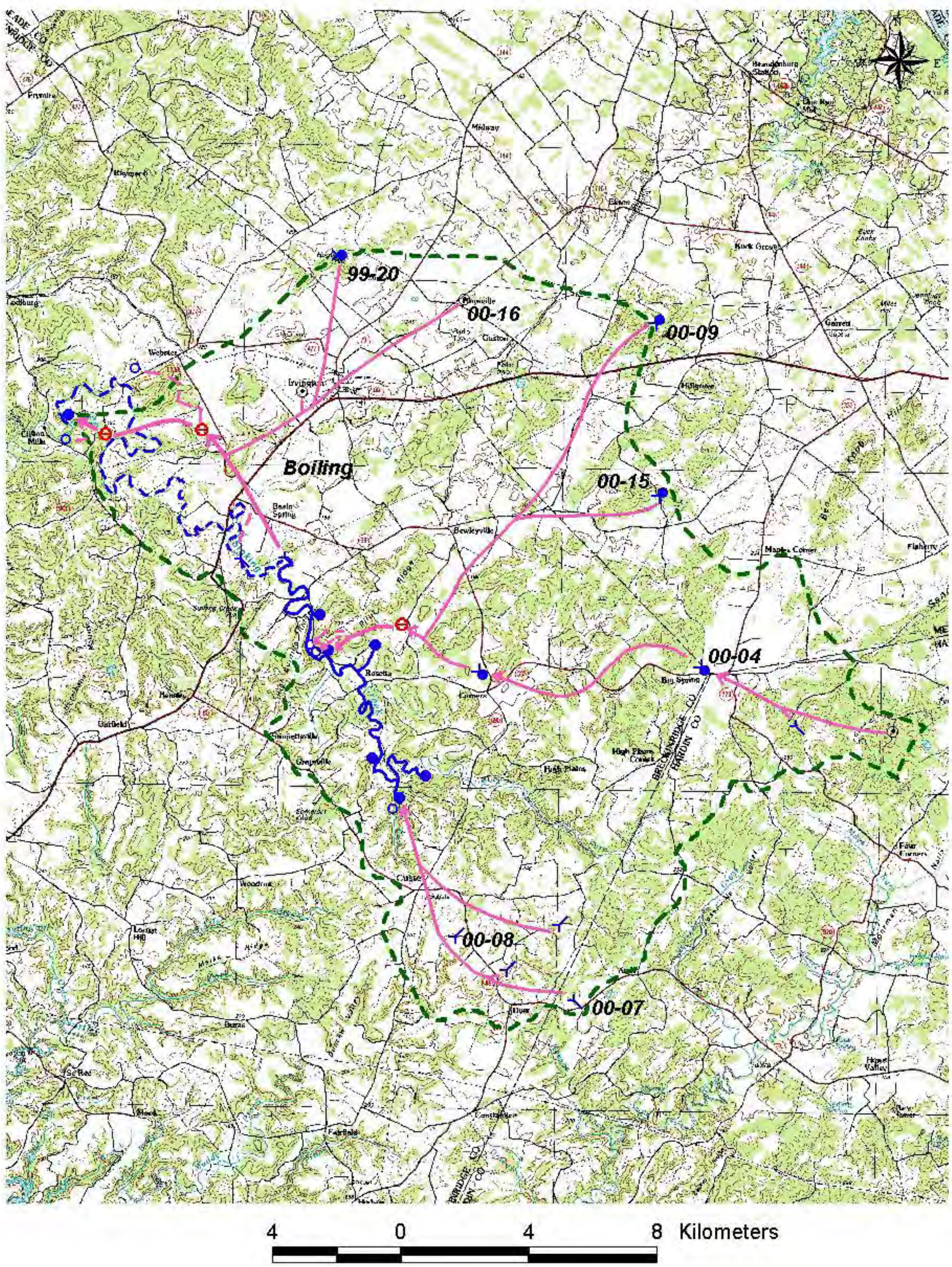

Figure 4b: Boiling Springs Basin:

Low-Flow Discharge 277.5 L/s (9.8 ft^3/s); Basin Area 327.6 km^2 (126.5 mi^2);
UBF 0.87 $L/s/km^2$ (0.08 $ft^3/s/mi^2$); Land-use 52.7% Agricultural, 45.6% Forest

Large overflow springs exist about 2.5 km (1.5 mi) to the northeast near Webster. These are known to be related to Boiling Springs by cave mapping but they were not active during recent tracer studies. Additional overflow springs, which have developed a large pocket valley to the southwest near Clifton Church, are suspected to be related to trunk groundwater flow from the basin as well as floodwaters from Sinking Creek overflow channel to the east (George, 1978).

Although Boiling Springs is the eleventh largest volume spring in Kentucky based on low flow, it drains a basin of 327.6 km^2 (126.5 mi^2). This ranks as Kentucky's second largest known karst basin. Because of large flow capacity, all winter base flow discharges through the main spring and consequently Boiling Springs yields the largest sustained winter base flow in Kentucky (estimated at about 1400-1700 L/s (50-60 ft^3/s).

Dye tests of Boiling Springs:

99-20

May 25, 1999: 765 g (27 oz) of fluorescein was injected at the swallet of a small sinking spring (**Millay Spring**) on Hogback Hill, during moderate flow conditions. Within five days, an extremely positive dye recovery was made 7 km (4.4 mi) to the southwest at the spring run of Parks Spring (+++), while Boiling Springs and six other sites were negative. On April 15, a second dye receptor exchange indicated that Burtons Hole (+++), 15.5 km to the west-southwest, as well as Boiling Springs (+), 9.5 km to the southwest, were also positive. A third exchange on April 22 showed dye recovery in Burtons Hole (+) and Parks Spring (+) had diminished, while Boiling Springs (-) was negative.

Interpretation:

Parks Spring has an estimated low flow of 8.5 L/s (0.3 ft^3/s) (10-1-93), and contains nearby overflow features. With a calculated area of approximately 5 km^2 (2.0 mi^2), a direct connection between Millay Spring and Parks Spring, which are 6.5 km (4 mi) apart, is unlikely. Therefore, the dye recovery in Parks Spring is interpreted to have arrived from the Burton Hole basin via an overflow route. The arrival of dye in Boiling Springs, at a later date than Parks Spring run, appears to indicate that dye initially split along the groundwater basin boundary between Burton Hole and Boiling Spring.

Map data from A. George (written comm., November, 2000) show a stream swallet about 2 km downstream from Parks Spring (Webster Bluehole). If this spring-run diversion, which most likely drains to Boiling Springs, was functioning during the dye trace, Boiling Springs should have been positive on the first exchange. This timing of dye recovery tentatively supports a separate, more lengthy flow route, though the Irvington area, within the Boiling Springs basin.

00-4

March 23, 2000: 400 g (14 oz) of eosine was injected into the swallet of **West Big Spring karst window**. This test was a replication of unpublished work within the Boiling Springs basin by George and others (1970). Within six days Gilpin Karst Window (++), Ross Karst Window

(++), Flat Rock Spring (++), 11.5 km (7 mi) to the west, were very positive, as well as two overflow springs just downstream. Board & Fiddle springs were not positive during these flow conditions, although higher-level overflow connections, as reported by George (1978), are possible.

00-7 Stoney Fork Spring sub-basin

April 18, 2000: 115 g (4 oz) of fluorescein was injected into a small stream **swallet** between **Dyer** and **Arch**, Kentucky. This trace was designed to test the southern boundary of the Boiling Springs basin. Eight days later Stoney Fork Spring (++), 8 km (5 mi) to the northwest was very positive while six other sites were negative. This spring, a major headwater of Sinking Creek, was also positive 16 days after injection.

00-8

April 18, 2000: 115 g (4 oz) of SRB was injected at the **swallet** of a small sinking stream on the **Alexander** property. Eight days later Stoney Fork Spring (++), 4.5 km (2.75 mi) to the north-northwest, was very positive while six other sites were negative. Traces # 7 & 8 confirm unpublished data by Greer (1993), that the headwaters of Muddy Prong have been pirated by the Sinking Creek/Boiling Springs system.

00-9

May 2, 2000: 225 g (8 oz) of fluorescein was injected at **Polly Brown Spring**, a minor sinking spring draining from an upland 4.25 km (2.5 mi) east of Guston. Seven days later Head of Doe Run (+++), 6.5 km (4 mi) to the northeast, was extremely positive while springs in Boiling Springs' Sinking Creek system, 14 km (9 mi) to the southwest recorded the leading edge of the dye slug. Flat Rock Spring (++) showed peak dye recovery within 14 days. The results documented a groundwater bifurcation along a basin boundary and indicated a conduit-flow velocity of 2 km/day during moderate conditions. The southwest tributary dye vector also joined the main Big Spring trunk between Ross (+) and Gilpin (-) karst windows. Dye persisted in both basins for about three weeks.

00-15

May 16, 2000: 115 g (4 oz) of eosine was injected at **Hicks Sinking Spring**, which was designed to help define the boundary between Boiling Springs and Head of Doe Run basins. Sixteen days later dye was detected at Flat Rock Spring (+), 11.5 km (7 mi) to the west-southwest, and Boiling Springs (+). Ross Karst Window was inconclusive (?) on June 7 and positive on the 13th (+). Dye detections were of low intensity during this trace, indicating that a larger quantity of dye should have been used.

00-16

June 1, 2000: In order to help define the northern boundary of Boiling Springs basin, 425 g (15 oz) of SRB was injected with 600 gallons of flush water into **Haysville Sinkhole**. Twenty and thirty five days later Boiling Springs (+), 13 km (8 mi) to the west-southwest was positive while nine other sites were negative.

French Creek (1838)

French Creek Springs (Figure 5a) is a 305 m (1000 ft)-wide distributary of two perennial springs, which provide the base flow of French Creek in north-central Meade County [main spring to east: N38°-01′-44″; W86°-14′-28″/ western spring: N38°-01′-44.5″; W86°-14′-39″].

Figure 5a: French Creek Spring (Major Perennial)

An additional large overflow spring [N38°-01′-44.5″; W86°-14′-55″] as well as two ravines contributes high-flow discharge to the creek that ultimately drains to the Ohio River. A large cobble bar formed by the overflow spring indicates highly turbulent discharge (Figure 5b). None of these springs are shown on the Mauckport 7.5 minute Topographic Quadrangle nor are they reported in the literature. Discharging from the St. Louis Limestone (Amos, 1972) at about 121 m (396 ft) elevation, the two perennial springs appear as free-draining gravity springs and develop short, rapid spring runs to the main French Creek channel. The overflow spring, located about 1525 m (5,000 ft) up-channel at 128 m (420 ft) elevation, is a bluehole spring of unknown depth. The most likely conduit-plumbing explanation is that the two related gravity springs drain through constricted distributaries dispersing from the trunk conduit that feeds the overflow rise pit. The capacity of the perennial spring distributary may approximate the base-flow volume, which is easily exceeded during high flow, thereby forcing overflow water from the more elevated bluehole spring. Consequently, the perennial distributary may be classified as a free-draining gravity system, but with an artesian overflow spring up-channel of the perennial springs. The system discharged 45 L/s (1.6 ft^3/s) on 10-21-98 and 40 L/s (1.4 ft^3/s) during drought (9-7-99).

Figure 5b: French Creek Overflow Spring

Figure 5c: French Creek Springs Basin:
Low-Flow Discharge 45.3 L/s (1.6 ft^3/s); Basin Area 54.4 km^2 (21.0 mi^2)
UBF 0.87 L/s/km^2 (0.08 $ft^3/s/mi^2$); Land-use 67.9% Agricultural, 27.2% Forest

Dye tests of French Creek:

99-21

March 25, 1999: 600 g (21 oz) of SRB was injected into a small sinking spring named **Lawson Spring**, during moderate flow conditions. Five days later the dye was recovered 9.5 km (6 mi) to the north-northeast in the French Creek distributary (++), but not in six other sites. The dye was also present at French Creek (+) on April 15, but negative thereafter.

99-28

April 30, 1999: 140 g (5 oz) of SRB was injected with 200 gallons of flush water into **Clark Sinkhole**. Six days later the French Creek system was tentatively positive with only two grains of charcoal salvaged from a damaged dye receptor. The eleven-day dye receptor was negative. M*ay 20, 1999:* The above inconclusive result prompted a replication with 450 g (16 oz) of fluorescein. Twenty-six days later French Creek (++), 10 km (6 mi) to the north, was very positive and after thirty-five days, Hamilton Hill Bluehole (++), 9 km (5.5 mi) to the north, was also very positive. This trace indicated that Clark Sinkhole is near the boundary between the basins of French Creek Springs and Hamilton Hill Bluehole.

00-17

June 21, 2000: 400 g (14 oz) of fluorescein was injected with 400 gallons of flush water into **Dooley Sinkhole**. Forty-one days later dye began to emerge from Hamilton Hill Bluehole (+), 11.5 km (7 mi) to the north, and grew stronger over the next few weeks. Nine weeks after injection, dye also began to emerge from French Creek springs (+), 12 km (7.5 mi) to the north. Dye recovery was delayed and prolonged because of low-flow conditions.

Buttermilk Falls (1824)

Buttermilk Falls Spring (Figures 6a & 6b) in north-central Meade County [N38°-00′-8″; W86°-09′-29″], is composed of two larger and four smaller perched springs discharging through a lateral spring horizon over a ~30 m (100 ft) outcrop of the St. Louis Limestone (Amos, 1972), at about 134 m (440 ft) elevation.

An additional minor spring is located next to an abandoned pump station about 60 m (200 ft) to the west. The main springs flow immediately through culverts beneath a limited-access gravel road paralleling the steep slope. Tufa deposits are located in the steep channels below the road. The springs are perched about 14 m (45 ft) above Flipping Creek, which borders the Ohio River bottoms. They discharge a combined 21 L/s (0.75 ft^3/s) during low flow (9-17-98).

During 1982, more than one hundred Meade County residents contracted hepatitis-A from drinking contaminated water from this spring. One fatality resulted from this outbreak (Environmental Quality Commission, Kentucky, 1992). An anecdotal dye trace by Meade County Health Center inferred the subsurface connection between a private septic system in Brandenburg and Buttermilk Falls Spring (Mull and others, 1989; P. Schultz, oral communication, 2002).

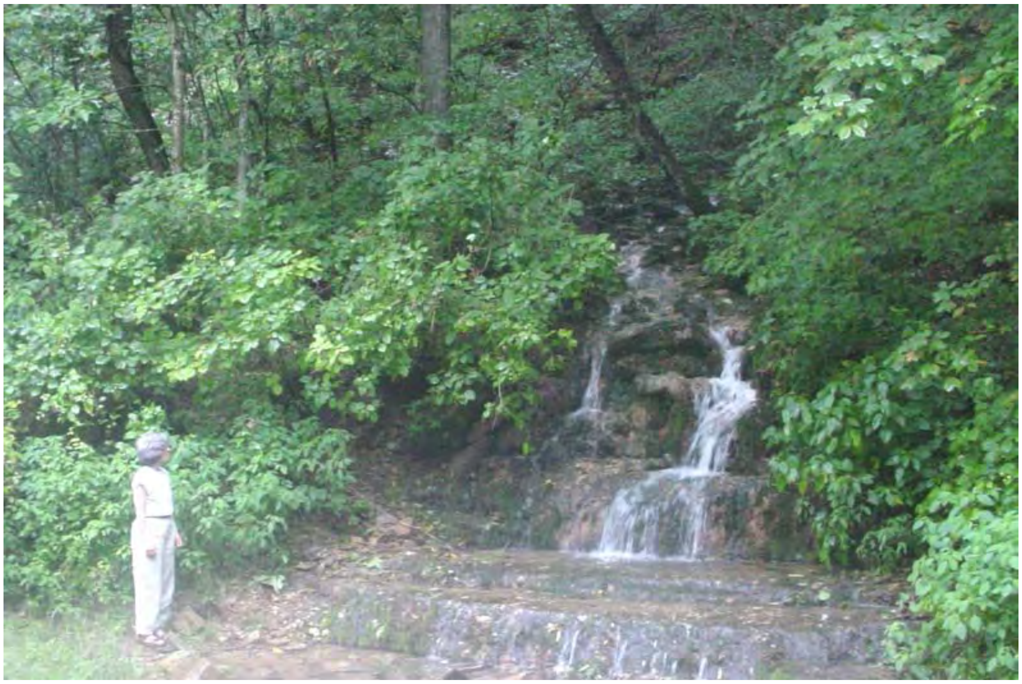

Figure 6a: Buttermilk Falls Spring

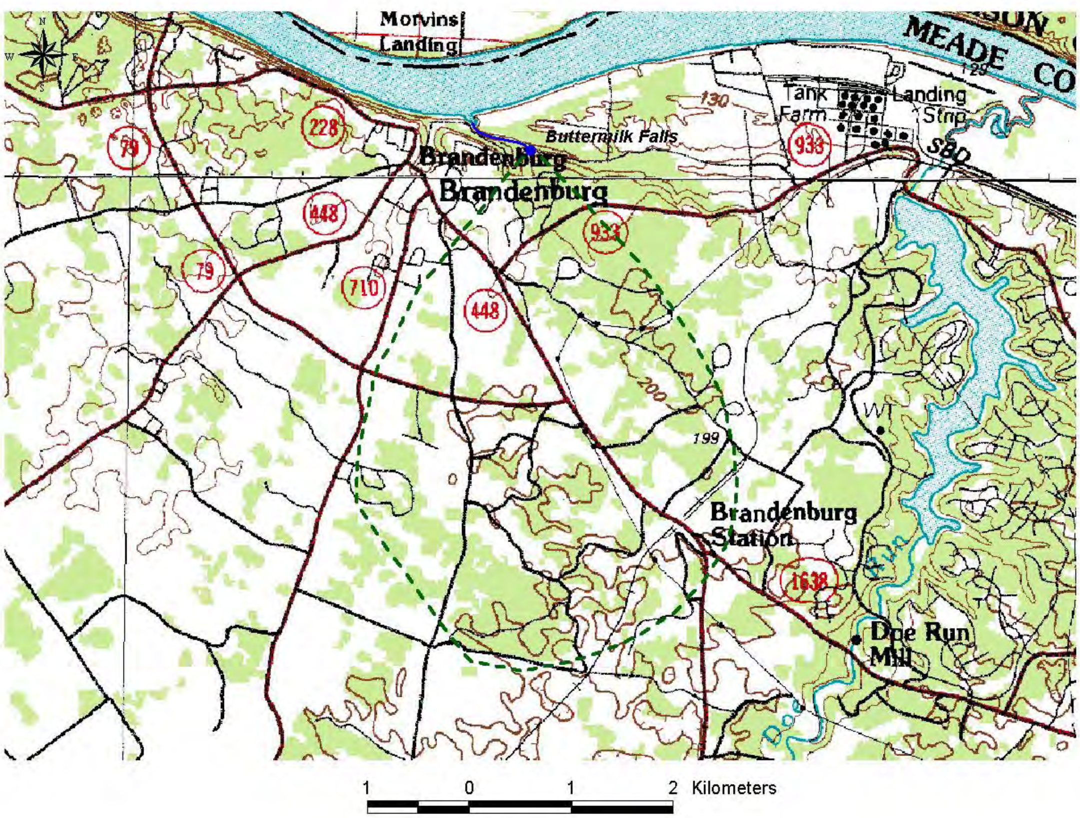

Figure 6b: Buttermilk Falls Spring Basin:
Low-Flow Discharge 22.7 L/s (0.8 ft^3/s); *Estimated* Basin Area 12.7 km^2 (4.9 mi^2);
UBF 1.7 L/s/km^2 (0.16 $ft^3/s/mi^2$); Land-use 26.8% Agricultural, 65.1% Forest

Head of Wolf Creek (1063)

Head of Wolf Creek Spring (Figures 7a & 7b) in northwest Meade County [N38°-03′-58″; W86°-21′-34″], is a 12 m-wide (40 ft) bluehole spring, partially encircled by a low limestone bluff and gravel road.

Figure 7a: Head of Wolf Creek

Head of Wolf Creek Spring is mapped with a spring symbol on the west-central portion of the New Amsterdam Quadrangle and is the head of perennial flow in Wolf Creek. It discharges from the Ste. Genevieve Limestone (Amos, 1972), at 123 m (402 ft) elevation, in ruggedly dissected terrain. This is the only spring mapped on the Kentucky portion of the New Amsterdam 7.5 minute Topographic Quadrangle (two map locations are named Cold Springs and Mints Springs but spring symbols are not shown; Cold Springs, which is renamed Lodale on GQ-990, is a minor sinking spring perched near the base of the Beech Creek Limestone Member). Head of Wolf Creek Spring is a seasonal overflow spring that commonly discharges 300-600 L/s (10-20 ft^3/s) during winter, but reduces to about 15 L/s (0.5 ft^3/s) of local drainage during low flow. The spring drains a sizable basin based on positive dye traces conducted by Groundwater Branch personnel from 10 km to the southeast.

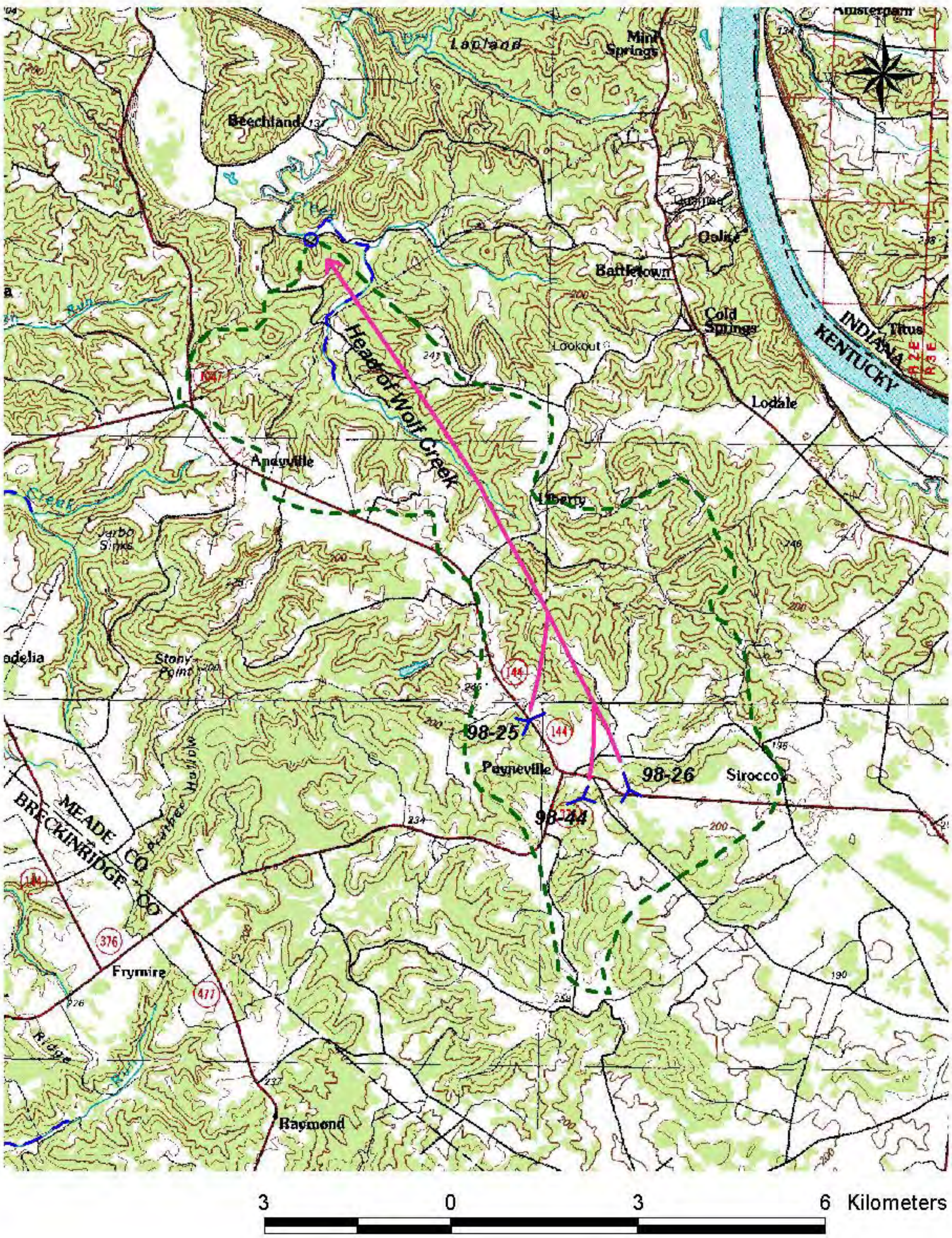

Figure 7b: Head of Wolf Creek Spring Basin:
Low-Flow Discharge 14 L/s (0.5 ft^3/s); Basin Area 42.5 km^2 (16.4 mi^2);
UBF 0.33 $L/s/km^2$ (0.03 $ft^3/s/mi^2$); Land-use 27.9% Agricultural, 70.1% Forest

Dye tests of Head of Wolf Creek:

98-25

April 22, 1998: 0.45 L (0.12 gal) of Rhodamine WT was injected in at **Payneville Culvert**, a losing seep. Fourteen days later a trace of dye was detected at Head of Wolf Creek (?), 8.5 km (5.25 mi) to the north-northwest, and within 36 days dye was positive at Wolf Creek (+). Four other sites were negative during this trace.

98-26

April 22, 1998: 280 g (10 oz) fluorescein was injected at **Mathews Swallet**, a sinking spring. Fourteen days later Head of Wolf Creek (+), 10 km (6.25 mi) to the north-northwest, was positive, whereas four other sites were negative. The spring was positive for eight weeks.

98-44

September 28, 1998: One Liter (0.25 gal) of Rhodamine WT was injected into a sinking stream at **Vessels Spring**. Because of dry weather, the dye was locally retained in a stagnant zone for more than two months and was not recovered. Dye monitoring was discontinued between October 8th and December. When monitoring was continued on December 9th, the dye was recovered in Head of Wolf Creek on four receptor exchanges until January 6th, 1999. None of the dyes injected into the Head of Wolf Creek basin, near Payneville, were recovered in the Payneville Elementary School water-supply well.

Southwest Study Area

Barkers Mill (0959)

Barkers Mill Spring (Figures 8a & 8b) in southeast Christian County [N36°-40′-38.2″; W87°-21′-17.7″], is a 9-12 m (30-40 ft)-wide bluehole spring that develops a 60 m (200 ft)-long spring run to West Fork.

Barkers Mill Spring discharges at about 132 m (432 ft) elevation near the top of the St. Louis Limestone (Klemic, 1966) and is used for a local domestic water supply. The spring exposes a low limestone ledge at the north edge of the bluehole, but the tree-lined, 6 m (20 ft)-wide spring-channel is formed in alluvium. Two minor karst windows are located just northwest of the bluehole. This is the largest known Kentucky spring west of Logan County and 18th largest in the state, but it is not mapped on the Trenton 7.5 minute Topographic Quadrangle nor the corresponding Geologic Quadrangle (Hammacksville). This spring was first mapped in 1988 during karst hydrologic studies of the Campbell Army Airfield, at Fort Campbell, Kentucky (Carey, 1990). The average low flow from three measurements is 170 L/s (6.0 ft^3/s), but drought flow (12-9-99) was about 40% less at 102 L/s (3.6 ft^3/s).

Figure 8a: Barkers Mill Spring

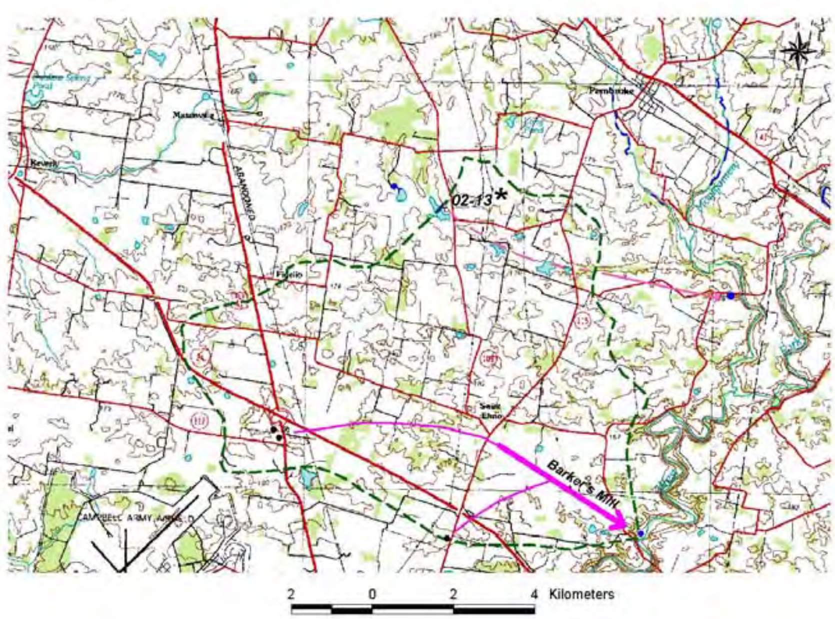

Figure 8b: Barkers Mill Spring Basin:

Low-Flow Discharge 170.0 L/s (6.0 ft^3/s); Basin Area 69.2 km^2 (26.7 mi^2);
UBF 2.4 $L/s/km^2$ (0.22 $ft^3/s/mi^2$); Land-use 93.0% Agricultural, 3.0% Forest
(*02-13: Recent dye trace from seasonal lake to Fredericks Spring)

Dye tests of Barkers Mill Spring by Ewers Water Consultants

River Bend (0860)

River Bend Spring (Figures 9a & 9b) in E Trigg County [N36°-48′-35″; W87°-44′-53″] is a rising spring that emerges from beneath a low limestone ledge at the head of a 3-5 m (10-15 ft)-wide, 30 m (100 ft)-long, doglegged spring run to Little River.

Figure 9a: River Bend Spring

River Bend Spring discharges at about 116 m (380 ft) elevation near the base of the Ste. Genevieve Limestone (Ulrich & Klemic, 1966). The 3 m (10 ft)-deep spring channel is formed in Little River alluvium. River Bend Spring is not shown on the Caledonia 7.5 minute Topographic Quadrangle, although a minor perched spring is mapped about 518 m (1700 ft) to the south. River Bend Spring is the 19th largest in the state and was first inventoried during this study.

The presence of a major regional underflow spring was initially hypothesized in this area due to the occurrence of large seasonal overflow springs on Boyd Lake Branch five km (three mi) to the east-northeast. River Bend Spring is located within 215 m (700 ft) of a mapped fault that may have influenced conduit and spring development at this point. The average low flow from three measurements is about 159 L/s (5.6 ft^3/s), but drought flow (12-8-99) was about 48% less at 82 L/s (2.9 ft^3/s).

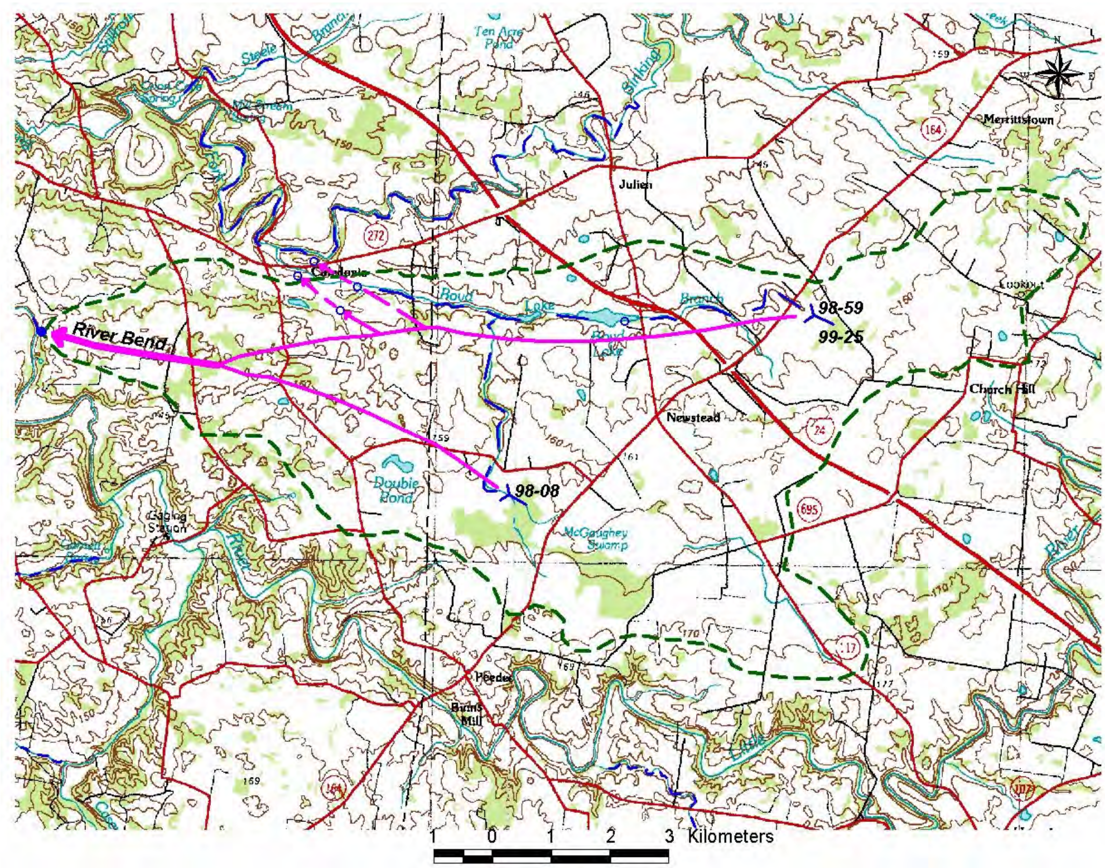

Figure 9b: River Bend Spring Basin:
Low-Flow Discharge 158.6 L/s (5.6 ft^3/s); Basin Area 70.0 km^2 (27.0 mi^2); UBF 2.3 L/s/km^2 (0.21 $ft^3/s/mi^2$); Land-use 87.7% Agricultural, 4.7% Forest (+4% Woody Wetlands)
(NOTE: The landowner does not permit driving across fields to gain access to this spring.)

Dye Tests of River Bend Spring:

98-08

March 17, 1998: 1.5 L (0.4 gal) of Rhodamine WT was injected at **Walker Swallet,** about 1.5 km (1 mi) to the northwest of McGaughey Swamp. Nine days later River Bend Spring (++), 8.5 km (5.25 mi) to the west-northwest, was very positive while eleven other sites were negative. River Bend Spring was positive on two additional dye-receptor exchanges over twenty days.

98-59

December 16, 1998: 310 g (11 oz) SRB was injected at **Moore Swallet**, 1.0 km (0.6 mi) east of Boyd Lake Branch. The flow condition was not ideal and some dye was lost to adsorption on sediment and organics due to inefficient inflow. Six days later an inconclusive dye recovery was made at Caledonia Bluehole (?), an overflow spring 9 km (5.5 mi) to the west. Thirty-eight days after injection Caledonia Bluehole (+) was positive, as well as nearby Cane Overflow (+), while River Bend Spring (?) was inconclusive.

River Bend Spring was hypothesized to be the primary underflow spring related to the group of four overflow springs in the Caledonia area. The 98-59 trace failed because an insufficient amount of dye was used. Therefore, in order to adequately test this important hypothesis, Moore Swallet was re-tested by injection 99-25, described below.

99-25

April 29, 1999: 280 g (10 oz) fluorescein was re-injected at **Moore Swallet**, which was visited several times before an acceptable flow condition was obtained. During this second dye injection, 6 L/s (0.2 ft^3/s) of stream-flow was actively running underground at a swallet that accepted all of the flow. The hypothesis was confirmed seven days later when River Bend Spring (+), 13 km (8 mi) to the west, was positive, while three additional sites were negative. In addition to Cane Overflow, which was previously positive, four other overflow springs in the Caledonia area were all positive (Because of their proximity, Caledonia East BH and USGS "Spring" are consolidated as one overflow-spring symbol). Recovery of subsequent dye receptors indicated that all of the tracer dye had exited the flow system within seven days. These data confirm a groundwater flow rate in excess of 1.9 km/day (1.1 mi/day) through a very efficient conduit.

Cook (1141)

Cook Spring (Figures 10a & 10b) in north Trigg County [N36°-55′-27″; W87°-48′-41″] is a 12 m (40 ft)-wide bluehole spring, adjacent to a low limestone ledge, that develops a 180 m (600 ft)-long spring run to Muddy Fork of Little River.

Figure 10a: Cook Spring

The steep alluvial channel banks of the spring are about 3 m (10 ft) high. Cook Spring discharges at about 113 m (370 ft) elevation from the Upper Member of the St. Louis Limestone (Seeland, 1968). It is not mapped on the Cobb 7.5 minute Topographic Quadrangle nor the geologic quadrangle. No related overflow springs are known. Cook Spring was originally inventoried during a regional hydrologic investigation of a gasoline spill near Gracy, Kentucky, in 1986. As suggested by Crawford and Mylroie (unpublished manuscript), the main trunk flow route of the Cook Spring basin is probably structurally controlled by east-west normal faults. The average low flow from three measurements is about 93 L/s (3.3 ft^3/s).

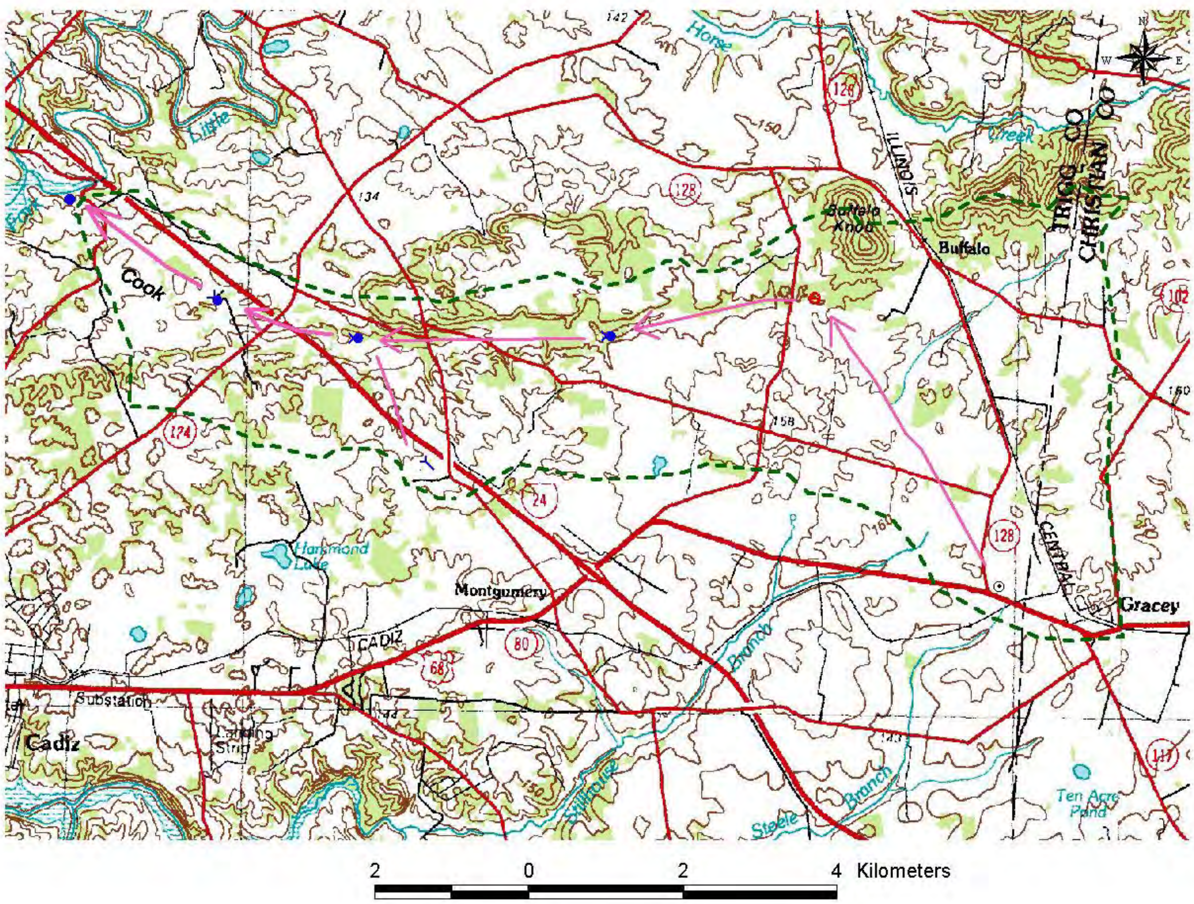

Figure 10b: Cook Spring Basin:

Low-Flow Discharge 93.5 L/s (3.3 ft^3/s); Basin Area 41.7 km^2 (16.1 mi^2);
UBF 2.2 L/s/km^2 (0.20 $ft^3/s/mi^2$); Land-use 75.3% Agricultural, 17.1% Forest

Dye tests of Cook Spring (Crawford, 1989 & Ewers, 2001)

King (1489)

King Springs, in southwest Christian County [N36°-44′-41″; W87°-36′-52.5″] is a three-spring perennial distributary draining to Little River. These springs, plus an additional overflow spring, are located along a 120 m (400 ft)-long Little River flood channel that is separated from the river by a narrow island. The distributary discharges from the top of the St. Louis Limestone (Klemic, 1966) at about 133 m (435 ft) elevation. A bluehole karst window is located about 90 m (300 ft) S of the main spring, which seasonally maintains a significant flow through a 5 m (15 ft) deep channel. This channel ends at a swallet about 25 m (75 ft) south of the main spring. During low flow the bluehole ceases discharge and becomes stagnant. None of the springs are mapped on the Herndon 7.5-minute Topographic Quadrangle nor the corresponding geologic map. They were inventoried during the early phase of this study.

The combined low-flow discharge of King Springs was 60 L/s (2.1 ft^3/s) on 11-19-97. The main downstream discharge point is a bluehole spring adjacent to a steep bank, which splits into two channels from a 1.5 m-wide (5 ft) rise pool. This main bluehole contributes about 50% of the total volume (Figure 11a). This spring (and an overflow spring) drains from the southwest end of the flood channel while two additional perennial springs, which appear to be free-draining gravity springs, join the river from the north end of the flood channel. The spring furthest upstream contributes about 37% of the total while the third spring adds the remaining 13%. See Figure 11b for a map of the drainage basin.

Figure 11a: King Spring (Major)

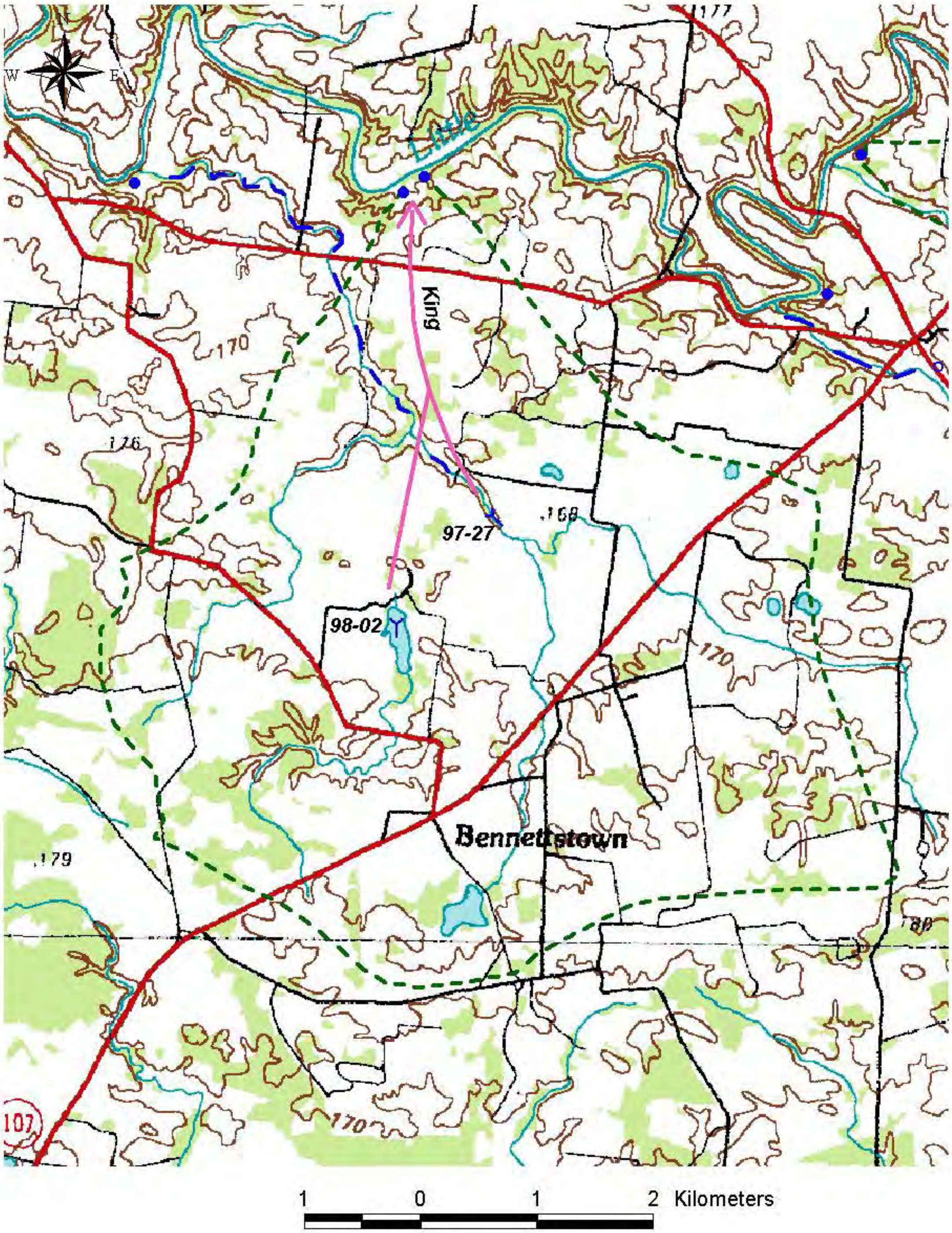

Figure 11b: King Springs Basin:
Low-Flow Discharge 59.5 L/s (2.1 ft^3/s); Basin Area 28.2 km^2 (10.9 mi^2); UBF 2.1 L/s/km^2 (0.19 $ft^3/s/mi^2$); Land-use 85.2% Agricultural, 7.4% Forest (4.1% Woody Wetlands)

Dye tests of King Springs:

97-27

December 4, 1997: 250 g (9 oz) of fluorescein was injected into **Thomas Pools**, where a losing stream was infiltrating a gravel channel. Eight days later, three perennial springs within the King Springs distributary, 3 km (2 mi) to the north, were extremely positive (+++) and two overflow springs were positive (+), while nearby McGraw Spring was negative.

98-02

January 13, 1998: 250 g (9 oz) of Direct Yellow 96 was injected at **Smithson Insurgence**. Nine days later King Spring (downstream), 3.5 km (2.25 mi) to the north, was positive on a cotton dye receptor, while King Spring (upstream) was inconclusive. On *April 9, 1998*, this injection was replicated, with 30 g (1 oz) of fluorescein, in order to confirm the distributary indicated from trace # 97-27. The dye receptor pickup 36 days later indicated that both King Spring, upstream (+) and downstream (+) were positive.

Brelsford (1448)

Brelsford Spring (Figures 12a & 12b) in east-central Trigg County [N36°-49′-19″; W87°-46′-35″] is a free draining gravity spring that flows from the base of a 12 m (40 ft)-high limestone bluff and forms a 120 m (400 ft) spring run to the south side of Little River.

Figure 12a: Brelsford Spring

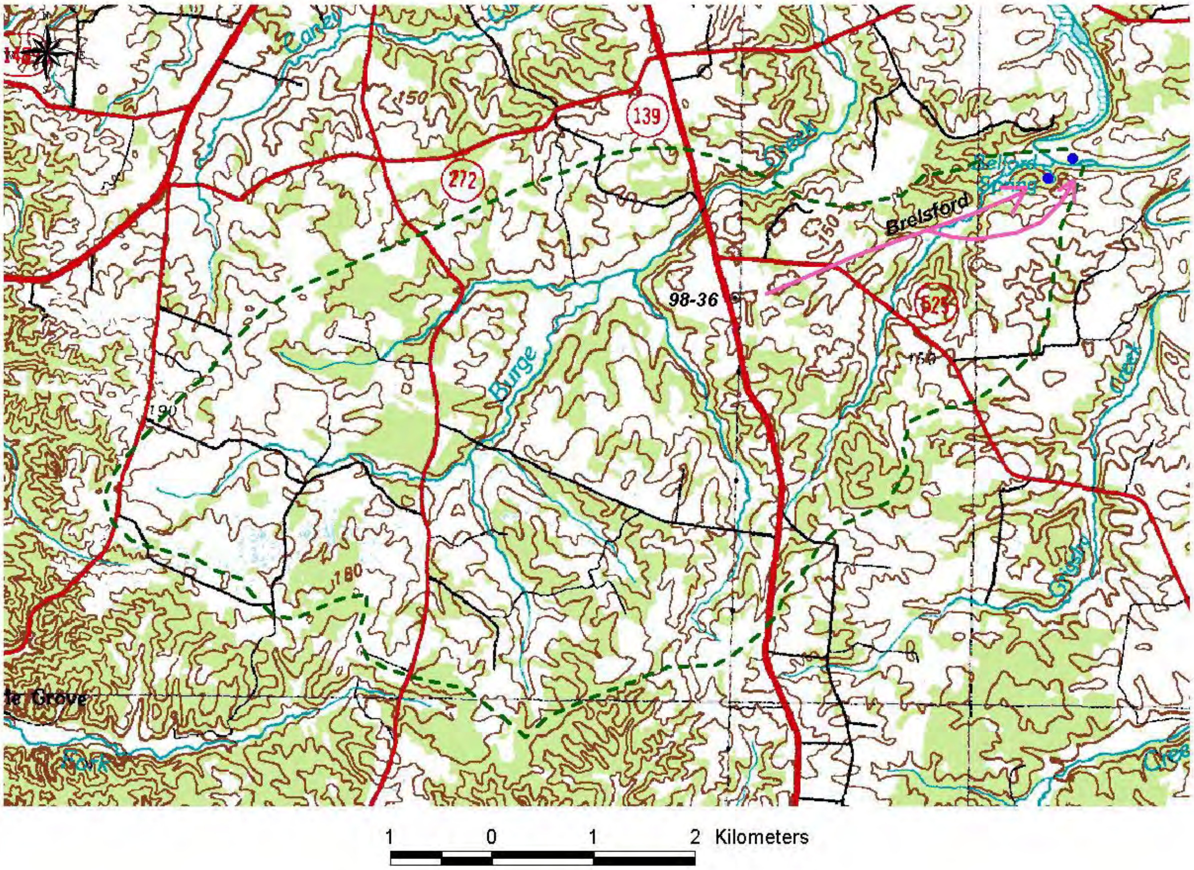

Figure 12b: Brelsford Spring Basin:
Estimated Low-Flow Discharge 85 L/s (3 ft^3/s); Basin Area 32.9 km^2 (12.7 mi^2);
UBF 2.6 L/s/km^2 (0.24 $ft^3/s/mi^2$); Land-use 65.4% Agricultural, 31.1% Forest

Brelsford Spring discharges from the Upper Member of the St. Louis Limestone (Fox, 1965) at about 114 m (375 ft) elevation. A second discharge point from this system occurs as a boil (Lawrence Boils) along the north bank of Little River about 275 m (900 ft) northeast of the main spring. The trend of the conduit feeding the boil may follow a steep, down-dip path, where the structure dips to the northeast about 15 m (50 ft) over the 275 m (900 ft) distance. A minor cave where the spring flow can be observed is located just northeast of the main spring (Dyas, 1979). Two higher-level short caves, which may have been the original outlets for the basin, are located about 90 m (300 ft) south of the main spring. A possible paleo-spring site may also exist about 180 m (600 ft) southwest of the spring. A 30 m (100 ft)-deep collapse sinkhole containing a 3-6 m wide perennial pool is located about 150 m (500 ft) east of the spring. This collapse sinkhole may be responsible for diverting the conduit flow into two separate discharge points, one of which is confined beneath the Little River.

The spring is named *"Belford Spring"* on the Cadiz 7.5 minute Topographic Quadrangle. However, Charles Morris, who lives nearest the spring, claims that the correct name for the caves is *"Brelsford"* and produced an old newspaper clipping that referenced the "Brelsford" spelling. According to the undated clipping, stories about the caves include the legends that the outlaw Lonz Pennington used the caves as a hide-out, guerilla bands reportedly hid there during the War between the States, and that a pewter half-dollar counterfeiting operation took place in the caves.

The spring is currently used for a local farm water supply. A submersible pump in the spring run pumps water uphill to the farm. The discharge was gaged at 70 L/s (2.5 ft^3/s) on 9-18-97 (before the related spring boil was discovered on the far side of the Little River). The common source of the two springs was determined in June, 1998. The boils, which are located in the edge of the river channel, cannot be easily gaged. However, its discharge was estimated at about 15-20 L/s (0.5-0.75 ft^3/s) during the canoe survey of Little River. Using the more conservative figure, the total discharge of Brelsford Spring basin is about 85 L/s (3.0 ft^3/s). (The main spring was also gaged during the drought of 1999 at 48 L/s (1.7 ft^3/s) (8-24-99). However, this is a less reliable figure because a beaver dam had recently back-ponded the spring run, and a greater portion of the basin's flow may have been diverted to the ungaged boil.)

Dye tests of Brelsford Spring:

98-21

April 8, 1998: 60 g (2 oz) of fluorescein was injected into a losing point through stream gravels on an eastern tributary of Burge Creek, 0.5 km (0.3 mi) north of Pleasant Hill Road, 4.2 km (2.6 mi) southwest of Brelsford Spring. The dye was expected to be recovered in Brelsford Spring but was never detected, probably because an inadequate amount of dye was used (a minimal amount of dye was used in order to avoid discoloring the farm water source).

98-36

June 2, 1998: 1L (0.25 gal) of Rhodamine WT was injected into **Kyler Tile Sink** with 750 L (200 gal) of flush water. This constructed drainage feature consisted of a 0.6 m (2 ft) diameter, 4.6 m (15 ft) deep concrete tile installed into the bottom of a broad sink (even with the drainage tile, the sink holds an intermittent lake for prolonged periods after heavy rains). Fifteen days later Brelsford Spring (+), 3.5 km (2 mi) to the northeast, on the south side of the Little River, was positive. Lawrence Boils (+), located on the north side of the Little River, 900 ft to the NW of Brelsford Spring, was also positive by July 1. This connection indicates that a water-bearing conduit, discharging at a minor bluehole, is confined beneath the bedrock channel of the Little River. With the exception of Little River, all of the streams shown on Figure 12b are dry except after heavy rains.

Mill Stream (0203)

Mill Stream Spring (Figures 13a & 13b), in east-central Trigg County [N36°-50′-38″; W87°-42′-49″], is a rising spring that flows from the base of a 8 m (25 ft)-high limestone bluff, through a 180 m (600 ft)-long pocket valley.

Mill Stream Spring discharges from the base of the Ste. Genevieve Limestone (Ulrich & Klemic, 1966) at about 119 m (390 ft) elevation. Ruins of an old water mill are located about 60 m (200 ft) from the springhead. Mill Stream Spring is one of four named springs on the Caledonia 7.5 minute Topographic Map.

The spring is the resurgence of Sinking Fork, which follows a 7.5 km (4.75 mi), east-west diversion beneath the plateau and rejoins the entrenched channel of Sinking Fork. Two minor sinking streams and numerous sinkholes contribute additional local recharge to the cutoff route, which passes through Pipeline Cave and Boatwright Hole (karst window), en route to Mill Stream Spring (Moore & Mylroie, 1979). The spring was gaged during low flow at 90 L/s (3.2 ft^3/s) and 70 L/s (2.5 ft^3/s) on 9-11-93 and 8-24-99, respectively. Earlier USGS measurements range from 42 L/s (1.5 ft^3/s) (1956) to 5041 L/s (178 ft^3/s) (Van Couvering, 1962).

Figure 13a: Mill Stream Spring

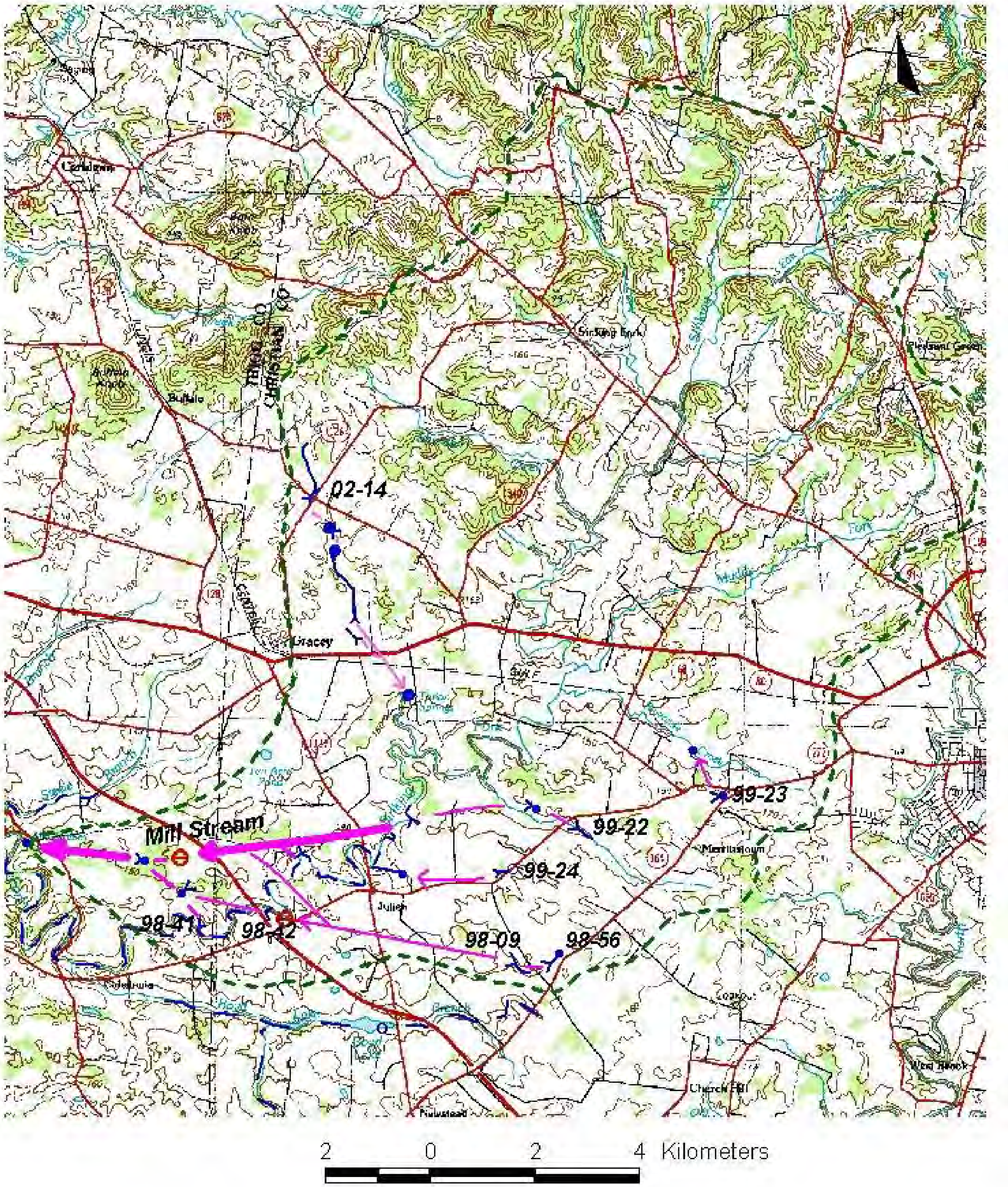

Figure 13b: Mill Stream Spring Basin:

Low-Flow Discharge 82.1 L/s (2.9 ft^3/s); Basin Area 182.1 km^2 (70.3 mi^2); UBF 0.4 L/s/km^2 (0.04 $ft^3/s/mi^2$); Land-use 73.8% Agricultural, 21.9% Forest

(NOTE: Due to access problems, the last two water samples were collected 1.8 km downstream.)

Dye tests of Mill Stream Spring:

98-09

March 17, 1998: 340 g (12 oz) of fluorescein was injected into **Bradey Lane Swallet**. Nine days later Mill Stream Spring (+++), 9.5 km (6 mi) to the west-northwest, was extremely positive while ten other sites were negative. A second site, Cane Spring (+), 5.5 km (3.4 mi) downstream of Mill Stream Spring, was also positive and is interpreted to have received dye from Sinking Fork via a cutoff conduit.

98-41

July 22, 1998: 0.8 L (0.2 gal) of Rhodamine WT was injected into **Old Bridge Swallet** along the channel of Sinking Fork. The Sinking Fork channel was dry except for a minor flow of about 6 L/s (0.2 cfs) runoff from a local small spring, 0.6 km (0.4 mi) upstream. Six days later McReynolds Karst Window (++), Boatwright Hole (+) (karst window), and Mill Stream Spring(++) were positive, while three other sites were negative.

98-42

July 22, 1998: 55 g (2 oz) of eosine was injected at a minor trickle **swallet**, within the dry channel of Sinking Fork, about 90 m (300 ft) downstream of Roaring Crack [Roaring Crack is an unusual feature where a subsurface waterfall can be heard "roaring" beneath the dry channel of Sinking Fork. This location coincides with a mapped fault crossing Sinking Fork. Although the flow could not be directly observed, a dye receptor was tied to the tip of a length of native river cane and pushed down into a bedrock crack. About 3.6 m (12 ft) down, the exposed portion of cane began to quiver when the lower part intercepted the turbulent waterfall. This uniquely placed dye receptor, in addition to an intermittent karst window just up-channel, was positive for dye reinjected at Bradey Lane Swallet, 4.5 km (2.75 mi) to the east-southeast]. Six days later, the same three features were positive as in the **Old Bridge Swallet** dye injection (98-41).

98-09 (Replication)

July, 22, 1998: 280 g (10 oz) of fluorescien was reinjected at **Bradey Lane Swallet** in order to refine the groundwater flow paths beneath the Sinking Fork dry channel, within the Mill Stream Spring basin. Six days later the waterfall beneath Roaring Crack (+++), the karst-window pool just up-channel of Roaring Crack (++), McReynolds Karst Window (+++), Pipeline Cave Stream (++), Boatwright Hole (++), and Mill Stream Spring (+++) were all positive, while Caledonia Bluehole (River Bend basin) was negative. Since Pipeline Cave was positive, this trace indicated a conduit bifurcation upstream of Roaring Crack that diverted a portion of flow north to the main trunk route of Sinking Fork, enroute to Pipeline Cave.

98-56

December 1, 1998: 450 g (16 oz) of fluorescein was injected into the low-flow swallet of **Lilly Spring**. During moderate and higher flow conditions, runoff from this sinking spring continues down-channel 0.8 km (0.5 mi) to the west to Bradey Lane Swallet. This test was designed to determine if recharge from the low-flow sinkpoint flowed to the same discharge point as Bradey Lane Swallet rather than to the south to River Bend spring. Fourteen days later Pipeline Cave (++) and Mill Stream Spring (+) were positive, showing that this portion of the Mill Stream Spring karst watershed was separate from the River Bend Spring basin.

Minor Sub-Basins within the Mill Stream Spring watershed:

99-22

April 14, 1999: 55 g (2 oz) of SRB was injected at **272 Swallet**, a perennial sinking creek. Seven days later dye was recovered at an intermittent karst window named John Zook Window (++), 1 km (0.6 mi) to the west-northwest, while eleven other sites were negative. This groundwater flow route is interpreted to continue 2.5 km (1.5 mi) to the west to join a trunk flow at the main upstream insurgence of Sinking Fork.

99-23

April 14, 1999: 55 g (2 oz) of eosine was injected at **Anderson Karst Window**, an intermittent bluehole. Six days later Ezell Spring (+++), 1 km (0.6 mi) to the northwest, was extremely positive. [Ezell Spring is a tributary of Riverside Creek and Sinking Fork. The minor amount of eosine used in this trace was slightly detected 13 km (8 mi) west-southwest in Mill Stream Spring (estimated at 25 cfs), whereas the same quantity of SRB, injected 20% nearer the spring was not].

99-24

April 20, 1999: 15 g (0.5 oz) of fluorescein was injected at **Price Spring Swallet**, a minor intermittent sinking spring. Nine days later Gee Spring (++), 2 km (1.25 mi) to the west, was very positive, whereas nine other sites were negative.

Walton (1457)

Walton Spring (Figures 14a & 14b), in southeast Trigg County [N36°-44′-32″; W87°-43′-57″], is a free-draining gravity spring that flows from the base of a 4.5 m- (15 ft)-high limestone bluff and develops a 490 m- (1,600 ft)-long spring run to Casey Creek.

Walton Spring discharges from the top of the St. Louis Limestone (Klemic & Ulrich, 1967) at about 134 m (440 ft) elevation. Classic karst windows are located 60 m (200 ft) southeast and 120 m (400 ft) south of the spring. Neither the spring nor the karst windows are mapped on the Roaring Spring 7.5 minute Topographic Quadrangle and were located during hydrogeologic survey for this study. Five low-flow measurements indicate that the spring discharge is about 47 L/s (1.7 ft^3/s) (9-18-97 - 8-23-00) with a drought volume of 25 L/s (0.9 ft^3/s) (12-9-99).

Figure 14a: Walton Spring

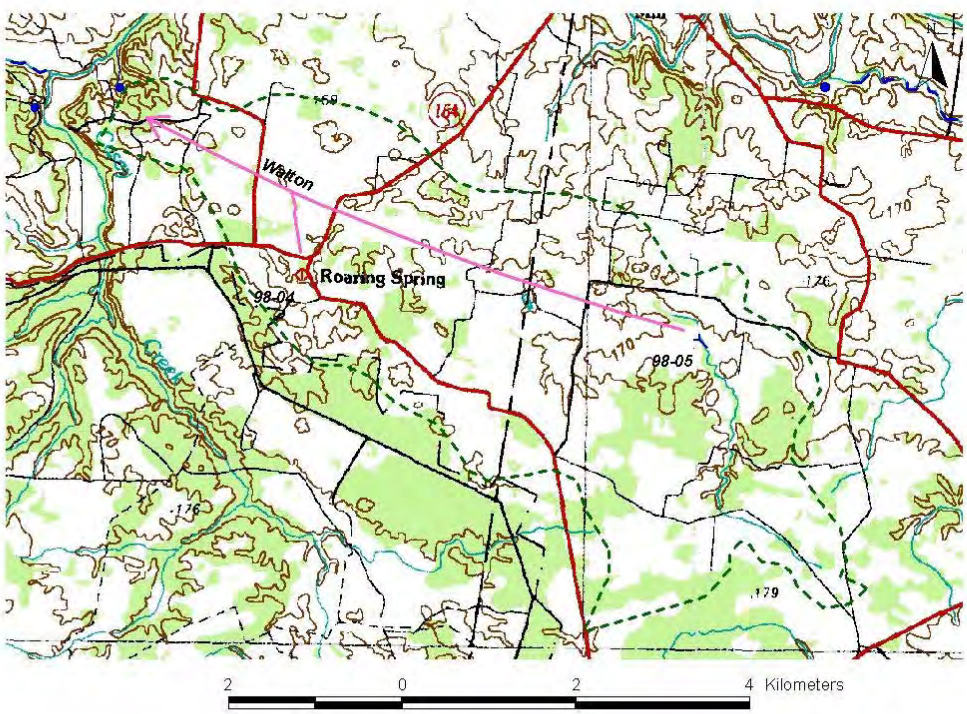

Figure 14b: Walton Spring Basin:

Low-Flow Discharge 48.1 L/s (1.7 ft^3/s); Basin Area 25.1 km^2 (9.7 mi^2); UBF 2.0 L/s/km^2 (0.18 $ft^3/s/mi^2$); Land-use 77.4% Agricultural, 7.8% Forest (+11.2 Woody Wetland)

Dye tests of Walton Spring:

98-04

January 29, 1998: 5.7 L (1.5 gal) of optical brightener was injected at **Roaring Spring Sink**. Eight days later Walton Spring (++), 3 km (2 mi) northwest, was very positive, while six other sites were negative. Two karst windows just up-gradient of Walton Spring were also positive.

98-05

January 29, 1998: 340 g (12 oz) of fluorescein was injected at an unnamed creek identified as **Garnett Sinking Creek**. On the second dye receptor exchange, twenty-two days later, Walton Spring and the karst windows (+++), 7 km (7.5 mi) to the west-northwest, were extremely positive, while 7 other sites were negative.

Wright (1475)

Wright Spring (Figures 15a & 15b), in southeast Todd County [N36°-42′-24″; W87°-06′-22″], is a bluehole spring that discharges from the base of a 4 m (12 ft)-high limestone bluff and flows 550 m (1,800 ft), where it sinks at three main swallets over a 120 m (400 ft) channel reach.

Figure 15a: Wright Spring

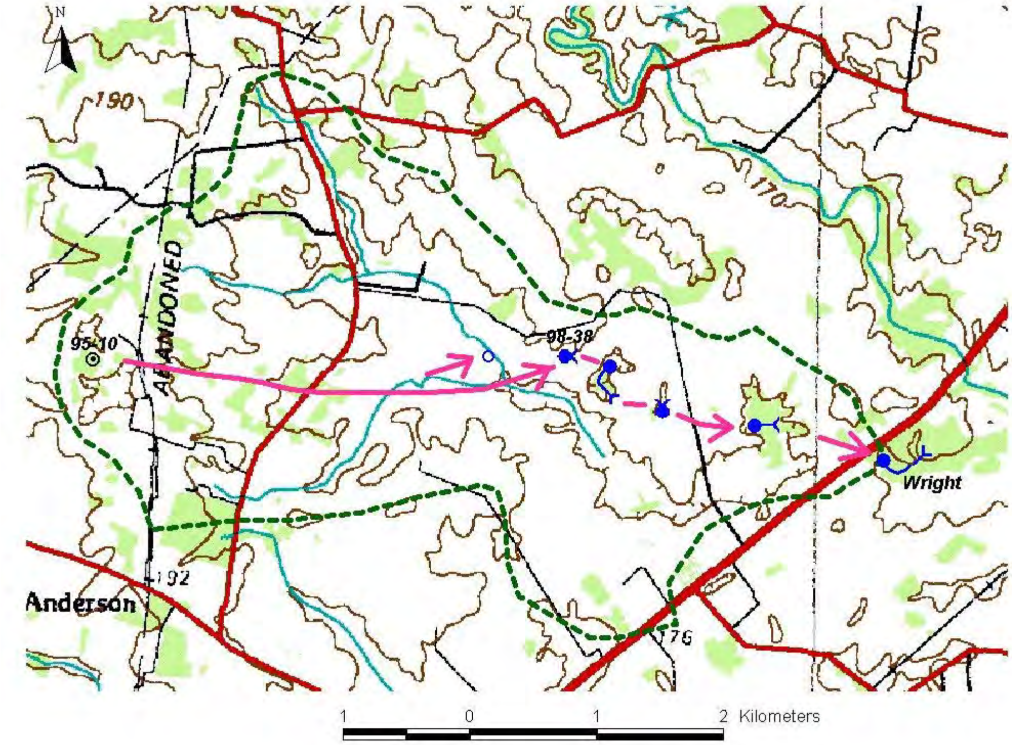

Figure 15b: Wright Spring Basin:
Low-Flow Discharge 25.5 L/s (0.9 ft^3/s); Basin Area 14.2 km^2 (5.5 mi^2);
UBF 1.7 $L/s/km^2$ (0.16 $ft^3/s/mi^2$); Land-use 89.7% Agricultural, 6.2% Forest

Wright Spring is a long, depression-type karst window, which is mapped on the Allensville 7.5 minute Topographic Quadrangle, but not on the corresponding geologic map. Additionally, four classic collapse-type karst windows (unmapped) are located down-gradient, within 210 m (700 ft) of the primary swallet. Five perennial and one overflow karst windows occur upgradient of Wright Spring. One of the karst windows is pumped as the water supply for a swine operation. Wright Spring discharges from the Ste. Genevieve Limestone (Klemic, 1966) at about 166 m (545 ft) elevation. Low-flow discharge is about 31 L/s (1.1 ft^3/s).

Dye tests of Wright Spring:

Wright Spring, a karst window, was identified in 1995 during Spring Protection Area delineation fieldwork, for Merriwether Spring in Guthrie, Kentucky (Ray & Stapleton, 1996)

95-10

November 30, 1995: 1.4 kg (3 lb) of Direct Yellow 96 was flushed into **Kanagy Sink** with 570 L (150 gal) of water from a local domestic supply. Six days later Franks Bluehole (+), 4 km (2.5 mi) to the east was positive. This livestock water supply spring, which is in the mid-portion of the Wright Spring sub-basin, was positive for two additional weeks. A nearby overflow spring feeding Franks Stream was also positive during the trace.

96-02 (Replication)

February 14, 1996: **Wright Spring swallet** was traced with 680 g (1.5 lb) of Direct Yellow 96, beneath the bedrock channel of Elk Fork to Underflow Spring, 1.5 km (1 mi) to the northeast. This test initially failed because only springs on the west side of Elk Fork were monitored.

98-38

July 1, 1998: An additional test was conducted in 1998. 30 g (1 oz) of fluorescein was injected in the downstream portion of **Franks Bluehole** karst window. Eight days later dye was recovered over a 1.6 km-long (1 mi) flow route through four karst windows upstream of Wright Spring.

Summary of Additional Groundwater Tracer Tests

Northeast Study Area

98-43 Hamilton Hill Bluehole

September 23, 1998: During a tracer study for a Wellhead Protection Area in Ekron, Kentucky, 60 g (2 oz) of fluorescein was injected into **McCoy Sinkhole** and flushed with 1500 L (400 gal) of water. Twelve days later Hamilton Hill Bluehole (+), 11 km (7 mi) to the north-northwest, was positive. This determination was supported by additional traces from the Ekron area.

98-55

October 1, 1998: 160 g (4.5 oz) of fluorescein was injected into a **modified sinkhole drain at Ekron Trailer Court** with 750 L (200 gal) of flush water. Twenty days later Hamilton Hill Bluehole (+), 11 km (7 mi) to the north-northwest, was positive.

99-28

See results from French Creek Spring basin.

00-17

June 21, 2000: 400 g (14 oz) of fluorescein was injected with 1500 L (400 gal) of flush water into **Dooley Sinkhole**. Forty-one days later dye began to emerge from Hamilton Hill Bluehole (+), 11.5 km (7 mi) to the north, and grew stronger over the next few weeks. Nine weeks after injection, dye also began to emerge from French Creek springs (+), 12 km (7.5 mi) to the north. Dye recovery was delayed and prolonged because of low-flow conditions.

99-27 Burtons Hole

April 30, 1999: 115 g (4 oz) of eosine was injected into **Stull Sinkhole**. Eleven days later, Mystic Spring (+) 14.5 km (9 mi) to the west-southwest, an overflow spring for Burtons Hole, was positive. Twenty days after injection, Burtons Hole (+), 15 km (9.5 mi) to the west-southwest, and Parks Spring run (+) 7.5 km (4.75 mi) to the southwest were positive. An overflow connection between Burtons Hole basin and Parks Spring overflow features was active during this trace.

May 20, 1999: 450 g (16 oz) of eosine was reinjected with 750 L (200 gal) of flush water into **Stull Sinkhole**. Burtons Hole (+++) was extremely positive 5-6 weeks later, including four additional receptor exchanges. Monitoring was discontinued at Mystic Spring since it was previously established as an overflow spring of the Burtons Hole basin. The overflow connection between Burtons Hole basin and Parks Spring run was not active during the lower-flow conditions of this replication.

99-14 Head of Spring Creek

March 4, 1999: 750 g (26.5 oz) of fluorescein was injected into a sinking spring near **Montgomery Cave**. Twelve days later, the Head of Spring Creek overflow (++) 13.5 km (8.4 mi^2) to the northwest was very positive while seven additional sites were negative.

99-15

March 11, 1999: 85 g (3 oz) of eosine was injected into a small tributary sinking into gravel (**Cabin Swallet**), in the headwaters of Sugar Tree Run. Eight days later the Head of Spring Creek overflow (+), 11.5 km (7 mi) to the north was positive, while eight sites were negative. This spring was also positive fourteen days after injection. Because Burtons Hole lies at the mouth of Sugar Tree Run, an intermittent stream, this trace was hypothesized to flow to Burtons Hole. Instead, this dye flowed north beneath a sandstone-capped topographic divide, into the Head of Spring Creek basin.

99-16 Burtons Hole

March 11, 1999: 140 g (5 oz) of SRB was injected at **Dutchke's Swallet**, a minor karst window. Five days later Burtons Hole (++), 9.5 km (6 mi) to the west-southwest, and Mystic Overflow (++) were both very positive, while seven other sites were negative. This karst window is in the topographic basin of Dry Valley, a tributary to Sugar Tree Run, and was expected to drain to Burtons Hole.

00-10 Head of Doe Run

May 3, 2000: 225 g (8 oz) of SRB was injected at a small sinking spring called **Red Barn Spring**. Within six days Head of Doe Run (+), 11 km (7 mi) to the north-northeast, was positive and remained positive until May 23. Ten additional sites were negative for dye. This trace indicated a groundwater velocity in excess of 2 km/day (1.2 mi/day).

00-11 Buffalo Creek Spring

May 4, 2000: 15 g (0.5 oz) of fluorescein was injected into the **swallet of Lost Run**. Five days later Buffalo Creek Spring (++), 2.5 km (1.5 mi) to the southwest was very positive. The dye receptor located in Dyer Cave, just south of the swallet, had been removed from the flow and was dry. The flow in Dyer Cave may be related to Lost Run, although the cave discharge appears to be less than the swallet volume.

00-12 Hardin Springs

May 4, 2000: 170 g (6 oz) of eosine was injected into **Lucas Swallet**, about 3 km (1.9 mi) northwest of Custer. This dye was hypothesized to drain northeast to the headwaters of Sinking Creek or southwest to Buffalo Creek Spring. Five days later six monitoring sites were negative. Seven days later, on May 11, new dye receptors were located at three additional sites. On May 23, 19 days after injection, eosine was recovered from Hardin Springs (+), 15 km (9.5 mi) to the northwest of Lucas Swallet. Watt Hole (++), a deep karst window that is a tributary to nearby Hardin Springs, was also very positive for eosine.

00-13 Head of Drakes Creek

May 4, 2000: 30 g (1 oz) of fluorescein was injected into **Keesee Branch Swallet**. Five days later Head of Drakes Creek (+++), 2.5 km (1.5 mi) to the southwest, was extremely positive, while five sites were negative. The spring was also positive on May 16.

00-14

May 10, 2000: 60 g (2 oz) of SRB was injected into a stream **Swallet**, in a large sink 12 km (7.5 mi) east-southeast of Dyer, near a mapped elevation point of **630 ft** (192 m). Seven days later Head of Drakes Creek (++), 4 km (2.5 mi) to the southwest, was very positive, whereas the headwater springs of Sinking Creek were negative. Traces #00-13 and #00-14 help to define the southern limit of the Boiling Springs basin.

00-19 Hardin Springs

August 8, 2000: In order to help define the western boundary of Boiling Springs basin, 225 g (8 oz) of SRB was injected at a **Swallet** in **Sugar Cane Sink**, only 2 km (1.2 mi) west of Sinking Creek. Twenty-two days later dye was very positive at Hardin Springs (++), 10 km (6.25 mi) to the northwest, but was negative in the Boiling Springs system.

Southwest Study Area

98-20 Garnett Spring

April 8, 1998: 55 g (2 oz) of eosine was injected at **Sholar Swallet**, a losing point on Potts Creek. Seven days later Garnett Spring (+++), 4 km (2.5 mi) to the east-northeast, was extremely positive whereas Brelsford Spring was negative.

98-21 (non-recovery)

April 8, 1998: 55 g (2 oz) of fluorescein was injected at **Adams Swallet**, a losing point in the headwaters of Burge Creek. This dye was not recovered at Brelsford or Garnett springs after five weeks. The most likely interpretation was that an inadequate amount of dye was used for this injection point.

98-32 Head of Casey Creek

May 15, 1998: 170 g (6 oz) of fluorescein was injected at the **Swallet** of **Skinner Creek**, a losing stream. Four days later Head of Casey Creek (++), 3.5 km (2 mi) to the northeast, was very positive, while three other sites were negative. Dye emerged from the spring for at least three weeks.

98-22 Adams Spring

April 9, 1998: 85 g (3 oz) of eosine was injected at **Brame Karst Window**, that was hypothesized to flow to River Bend Spring. Dye was not recovered after monitoring 14 sites for three weeks. Pete Idstein, of Ewers Water Consultants, later informed DOW that eosine had been detected during this time, in Little River at the I-24 bridge.

Additional spring surveying along Little River discovered Adams Spring, which lay 2 km (1.2 mi) upstream of our initial survey starting point. On *June 3, 1998*, 115 g (4 oz) of fluorescein was reinjected at Brame Karst Window. Six days later Adams Spring (+++), 3 km (2 mi) to the northeast, was extremely positive. Three nearby overflow springs were likewise positive.

99-26 Johnston Spring

April 29, 1999: 55 g (2 oz) of SRB was injected at **Garnett Swallet**, an intermittent sinking stream. Six days later a string of four karst windows (+) to the southwest and Johnston Spring (+), 5 km (3 mi) to the west-southwest, were positive. On June 3, two additional windows were found along this line and based on proximity and volume, were assumed to be connected to the flow path. The two windows just west of the dye injection point were also determined to be intermittent.

Information Exchange and Public Education

Initial meetings with County Extension and NRCS agents have been made and preliminary data have been exchanged. A presentation on karst groundwater and pollution prevention was made at the Trigg County Farm Field Day. A presentation of regional information was made at a field and cave trip (7-14-03) within the Boiling Springs groundwater basin to raise awareness of sensitive karst and cave environments. On 11-19-03, a review of karst data generated by this study was presented at the Four-Rivers Workshop at Lake Barkley, sponsored by Kentucky Water Watch. Dye-tracing data and numerous information booklets concerning agricultural problems in karst areas have been made available to many farmers and land owners that have graciously granted access to their land and springs for this study. These dye-tracing data comprise a significant portion of the forthcoming Tell City and Hopkinsville, Kentucky Karst Atlas maps to be published by the Kentucky Geological Survey in cooperation with the Kentucky Division of Water. Consequently, this important regional karst-groundwater information, available in a GIS format, will be provided to Federal, State, and Local authorities on a continuing basis. A poster summarizing the final report will be presented at conferences and distributed to government agencies and the public. The completed report will also available at the Kentucky Division of Water website.

RESULTS OF UNIT BASE FLOW ASSESSMENT AND COMPILATION OF BASINS

Selected springs in the study areas were gaged during the fall of one or more of the years, 1997-2001. Drainage basin configurations were estimated, largely from groundwater tracer data and topographic divides. Tracer tests were used to adjust estimated basin outlines to better approximate actual basin boundaries. Data quality was categorized as "poor", "fair", or "good", depending on the level of basin delineation by tracer testing and the apparent quality and number of discharge values. Table 2 (presented in both metric and English versions) indicates that based on the best quality data, a typical volume of base-flow runoff is about 2.19 $L/s/km^2$ (0.20 $ft^3/s/mi^2$) for the main karst areas in the SW study area and about 1.64 $L/s/km^2$ (0.15 $ft^3/s/mi^2$) in similar settings of the NE study area. Base flow groundwater runoff is about 25% greater in the SW area than the NE. This increased groundwater runoff value in the SW is probably due to 10% higher average rainfall, in addition to greater long-term groundwater storage within thicker soils of the SW study area. Epikarst development and base-flow discharge in both of these regions is assumed to be maximized within the soil-covered outcrop of the Ste. Genevieve and St. Louis limestones. Figure 16 shows the distribution of spring basins in the NE study area.

Among the best-quality data, the 327.6 km^2 (126 mi^2) Boiling Springs basin yields a relatively low UBF of 0.87 $L/s/km^2$ (0.08 $ft^3/s/mi^2$), about one half of the region's typical value of 1.64 $L/s/km^2$ (0.15 $ft^3/s/mi^2$). Although neighboring Hardin Springs basin is largely estimated, its low UBF of 0.68 $L/s/km^2$ (0.06 $ft^3/s/mi^2$) tentatively supports its estimated basin area. These apparent low anomalies are hypothesized to result from hydrogeologic settings that differ significantly from the typical sinkhole-plain type setting.

About 35%, or 116 km^2 (45 mi^2), of Boiling Spring's basin is capped by Chester siliciclastics, such as the Sample Sandstone. Groundwater runoff from these caprocks is typically reduced to zero during late summer and fall low-flow conditions. Also, much of the exposed Ste. Genevieve Limestone within the southern half of the basin is deeply dissected with fairly rugged relief. The epikarst, which contains most groundwater storage, may be less developed in this type of erosionally dissected limestone surface. Together with thinner soils, the less mature epikarst may yield less groundwater runoff than mature epikarst beneath a flat-lying karst plain.

Assuming groundwater runoff equal to the reference value of 1.64 $L/s/km^2$ (0.15 $ft^3/s/mi^2$) for 210 km^2 (81 mi^2) of the limestone outcrop portion of the basin and zero contribution from the sandstone caprock portion, the low-flow basin discharge is calculated at 340 L/s (12 ft^3/s). This volume is only 22% higher than the average gaged low-flow discharge of 278 L/s (9.8 ft^3/s) for Boiling Springs. Accounting for low-storage, immature/shallow soil epikarst in the southern portion of the basin, the average UBF for the limestone area of this basin may be about 1.31 $L/s/km^2$ (0.12 $ft^3/s/mi^2$). This estimate suggests that the low anomaly for Boiling Spring's UBF may be due primarily to the hydrogeologic variation of limestone versus sandstone caprock.

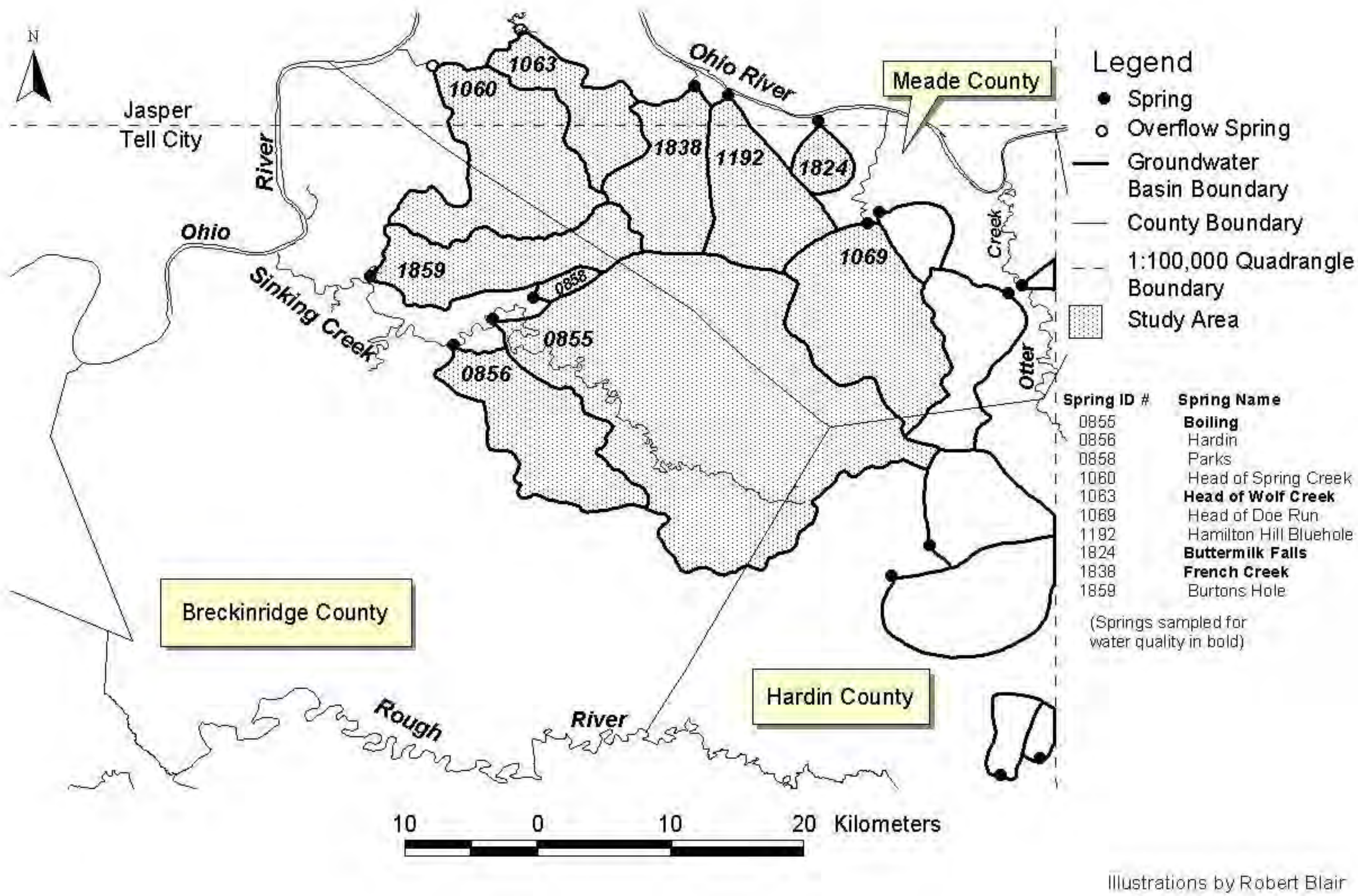

Figure 16: Karst Drainage Basins within the Northeast Study Area

Spring	ID #	Discharge (L/s)	Basin Area (km^2)	UBF ($L/s/km^2$)	Data Quality
Northeast					
Boiling	0855	277.5	327.6	**0.85**	Good
French Creek	1838	45.3	54.4	**0.83**	Fair
Head of Wolf Cr	1063	*14.2 Est*	42.5	*0.33 OF*	Poor
Buttermilk Falls	1824	22.7	12.7	**1.79**	Poor
Head of Doe Run	1070	150.1	94.0	**1.60**	Good
Hamilton Hill BH	1192	93.4	59.3	**1.58**	Fair
Hardin	0856	48.1	71.2	**0.68**	Poor
Head of Spring Cr	1060	28.3	95.8	*0.3 OF*	Poor
Parks	0858	*8.5 Est*	5.2	**1.64**	Poor
Blue	1070	28.3	17.1	**1.66**	Poor
McCraken	2229	87.8	49.0	**1.79**	Good
Burtons Hole	1859	*53.8 Cal*	62.9	*0.85 Ref*	Poor
Southwest					
Mill Stream	0203	82.1	182.1	**0.45**	Fair
Barkers Mill	0859	169.9	69.2	**2.46**	Fair
River Bend	0860	158.6	69.9	**2.27**	Good
Cook	1141	93.4	41.7	**2.24**	Fair
Brelsford	1448	*85.0 Est*	32.9	**2.58**	Poor
King	1489	59.5	28.2	**2.11**	Good
Walton	1457	48.1	25.1	**1.92**	Fair
Wright	1475	25.5	14.2	**1.79**	Fair
Buchanan	0569	42.5	40.1	**1.06**	Fair
Spring Hill/Herndon	1857/1445	53.8	39.9	**1.35**	Fair
Cooksey	0566	101.9	36.3	**2.81**	Good
Hughs BH	1485	62.3	31.3	**1.99**	Good
Meriwether	0038	70.8	30.0	**2.36**	Good
Garnett	1456	76.5	27.2	**2.81**	Fair
Cadiz	0854	59.5	24.1	**2.47**	Fair
Hunt	1487	62.3	54.4	**1.15**	Poor
Henderson	1484	19.8	12.2	**1.63**	Fair
Turner BH	1910	53.8	24.9	**2.16**	Poor
McCraw	1845	11.3	4.9	**2.30**	Poor
Glovers Cave	1486	34.0	15.0	**2.26**	Poor
Hunter	1140	31.1	14.0	**2.23**	Fair
Quarles	2542	45.3	19.4	**2.33**	Good
Head of Casey Cr.	1458	76.5	64.0	**1.20**	Poor
Torian	3117	9.9	12.4	**0.80**	Poor
Murphy	2520	68.0	4.4	**15.44**	Poor
Johnston	1460	*65.1 Cal*	29.8	*2.19 Ref*	Poor
Adams	1905	*31.1 Cal*	14.0	*2.23 Ref*	Poor
Frederick	1867	*11.9 Cal*	5.4	*2.19 Ref*	Poor
Interstate	1858	*65.1 Cal*	29.5	*2.21 Ref*	Poor

Table 2M: Metric Version: Unit Base Flow (UBF) data for NE and SW Portions of the Western Mississippian Plateau.

UBF (shown in bold) is derived by dividing a spring's base-flow discharge by its basin area. Spring volumes that are difficult to gage may be calculated (*Cal*) by multiplying the apparent basin area by the reference (*Ref*) value (basins with calculated discharges, shown in italics, were not used in regression analyses). Three spring volumes were estimated (*Est*). The low UBF of two large overflow (OF) springs results from the diversion of most of the basin's base flow to an unknown location. The metric conversion factor is: **10.931** x ___ $ft^3/s/mi^2$ = ___ $L/s/km^2$. The English conversion factor is: **0.0915** x ___ $L/s/km^2$ = ___ $ft^3/s/mi^2$. *(Some basin areas and UBF have been modified by subsequent research).*

Spring	ID #	Discharge (ft^3/s)	Basin Area (mi^2)	UBF ($ft^3/s/mi^2$)	Data Quality
Northeast					
Boiling	0855	9.8	126.5	**0.08**	Good
French Creek	1838	1.6	21.0	**0.08**	Fair
Head of Wolf Cr	1063	0.5 *Est*	16.4	**0.03** *OF*	Poor
Buttermilk Falls	1824	0.8	4.9	**0.16**	Poor
Head of Doe Run	1069	5.3	36.3	**0.15**	Good
Hamilton Hill BH	1192	3.3	22.9	**0.14**	Fair
Hardin	0856	1.7	27.5	**0.06**	Poor
Head of Spring Cr	1060	1.0	37.0	**0.03** *OF*	Poor
Parks	0858	0.3 *Est*	2.0	**0.15**	Poor
Blue	1070	1.0	6.6	**0.14**	Poor
McCraken	2229	3.1	18.9	**0.16**	Good
Burtons Hole	1859	*1.9 Cal*	*24.3*	*0.08 Ref*	Poor
Southwest					
Mill Stream	0203	2.9	70.3	**0.04**	Fair
Barkers Mill	0859	6.0	26.7	**0.22**	Fair
River Bend	0860	5.6	27.0	**0.21**	Good
Cook	1141	3.3	16.1	**0.20**	Fair
Brelsford	1448	*3.0 Est*	12.7	**0.24**	Poor
King	1489	2.1	10.9	**0.19**	Good
Walton	1457	1.7	9.7	**0.18**	Fair
Wright	1475	0.9	5.5	**0.16**	Fair
Buchanan	0569	1.5	15.5	**0.10**	Fair
Spring Hill/Herndon	1857/1445	1.9	15.4	**0.12**	Fair
Cooksey	0566	3.6	14.0	**0.26**	Good
Hughs BH	1485	2.2	12.1	**0.18**	Good
Meriwether	0048	2.5	11.6	**0.22**	Good
Garnett	1456	2.7	10.5	**0.26**	Fair
Cadiz	0854	2.1	9.3	**0.23**	Fair
Hunt	1487	2.2	21.0	**0.10**	Poor
Henderson	1484	0.7	4.7	**0.15**	Fair
Turner BH	1910	1.9	9.6	**0.20**	Poor
McCraw	1845	0.4	1.9	**0.22**	Poor
Glovers Cave	1486	1.2	5.8	**0.21**	Poor
Hunter	1140	1.1	5.4	**0.20**	Fair
Quarles	2542	1.6	7.5	**0.21**	Good
Head of Casey Cr.	1458	2.7	24.7	**0.11**	Poor
Torian	3117	0.35	4.8	**0.07**	Poor
Murphy	2520	2.4	1.7	**1.41**	Poor
Johnston	1460	*2.3 Cal*	*11.5*	*0.20 Ref*	Poor
Adams	1905	*1.1 Cal*	*5.4*	*0.20 Ref*	Poor
Frederick	1867	*0.42 Cal*	*2.1*	*0.20 Ref*	Poor
Interstate	1858	*2.3 Cal*	*11.4*	*0.20 Ref*	Poor

Table 2E: English Version: Unit Base Flow (UBF) data for NE and SW Portions of the Western Mississippian Plateau.

UBF (shown in bold) is derived by dividing a spring's base-flow discharge by its basin area. Spring volumes that are difficult to gage may be calculated (*Cal*) by multiplying the apparent basin area by the reference (*Ref*) value (basins with calculated discharges, shown in italics, were not used in regression analyses). Three spring volumes were estimated (*Est*). The low UBF of two large overflow (OF) springs results from the diversion of most of the basin's base flow to an unknown location. The metric conversion factor is: **10.931** x ___ $ft^3/s/mi^2$ = ___ $L/s/km^2$. The English conversion factor is: **0.0915** x ___ $L/s/km^2$ = ___ $ft^3/s/mi^2$. ***(Some basin areas and UBF have been modified by subsequent research)***

Other anomalous data from the NE study area are indicated by the excessively low UBF of the two overflow springs, Head of Wolf Creek and Head of Spring Creek. Because sizeable basins are demonstrated by the tracer tests, a significant volume of perennial underflow is indicated, which is yet to be discovered. The fluctuating ponding of tributaries by the channelized Ohio River has prevented a thorough search for these two underflow springs. Using a reference value of 0.87 L/s/km^2 (0.08 ft^3/s/mi^2), 57 L/s (2.0 ft^3/s) of additional discharge is estimated by UBF calculation for the Head of Spring Creek underflow, while the unobserved underflow of Head of Wolf Creek is estimated at about 23 L/s (0.8 ft^3/s).

Figure 17 shows the distribution of spring basins in the SW study area.

Most of the sampled springs were near the reference UBF value of 2.19 L/s/km^2 (0.20 ft^3/s/mi^2). Anomalies include Mill Stream Spring, which as stated above, is reduced by contribution from a large portion of the watershed containing thinner epikarst development and less soluble rocks. Brelsford Spring, at 2.73 L/s/km^2 (0.25 ft^3/s/mi^2), has a slightly higher than normal UBF. Although the basin area and part of the discharge from its distributary is estimated, a greater thickness of soil in the Brelsford Spring basin may account for the higher UBF. This appreciable soil thickness also reduced the development of sinkholes which hampered the search for dye injection points. Brelsford Spring ranked relatively low in the level of nitrate-N contamination (1.15-2.64 mg/L), which may relate to thicker soils as well as less intensive nutrient application. Nearby Garnett Spring, where the basin is similarly estimated from topographic divides and thicker soils are expected, also has a slightly high UBF at 2.84 L/s/km^2 (0.26 ft^3/s/mi^2).

An initial low UBF at King Spring of 1.20 L/s/km^2 (0.11 ft^3/s/mi^2), based on gaging of only the major spring, was revised upward to 2.08 L/s/km^2 (0.19 ft^3/s/mi^2) by discovery and gaging of additional springs within the basin distributary. The two additional perennial springs were mapped during a systematic spring survey by canoe and were linked to the major spring by a tracer test.

An initial high UBF at Cooksey Spring of 2.84 L/s/km^2 (0.26 ft^3/s/mi^2) was explained when the apparent basin area was enlarged after a connecting dye trace from a losing reach of West Fork. This trace revealed that Cooksey Spring was augmented by stream flow through a meander cutoff. Subtraction of an estimated cutoff contribution of 20 L/s (0.75 ft^3/s) from the Cooksey Spring discharge yielded a more appropriate UBF of 2.19 L/s/km^2 (0.20 ft^3/s/mi^2).

Other low UBF anomalies in the region include three spring basins that are tributary to Little River from the south. These are Buchanan Spring at 1.09 L/s/km^2 (0.10 ft^3/s/mi^2), Spring Hill/Herndon distributary at 1.20 L/s/km^2 (0.11 ft^3/s/mi^2), and Head of Casey Creek Spring at 1.20 L/s/km^2 (0.11 ft^3/s/mi^2). The first two basins are hypothesized to contribute an unobserved underwater discharge to Little River. Head of Casey Creek Spring may lose significant underflow through large deposits of coarse chert alluvium that cover the valley floor below the spring.

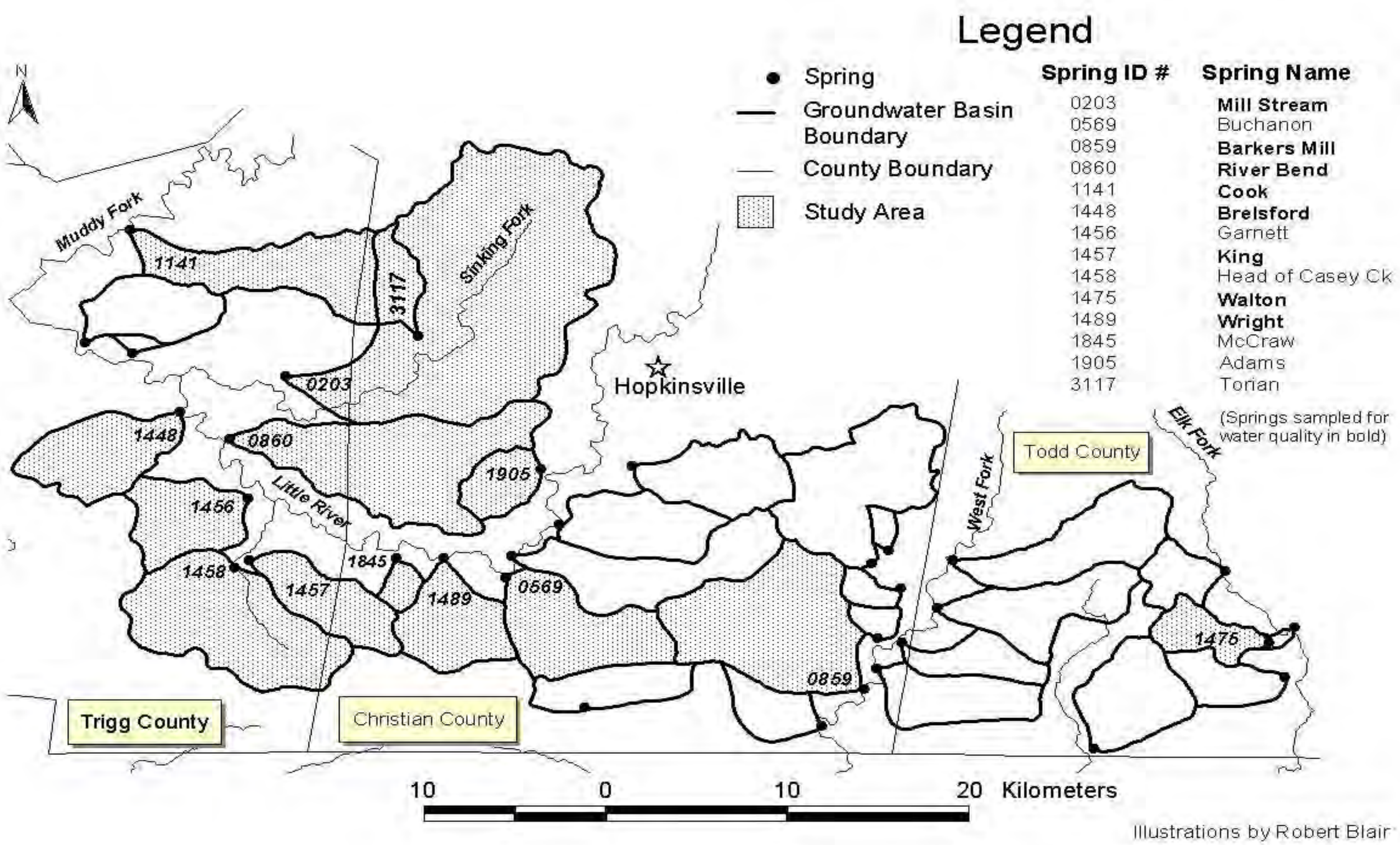

Figure 17: Karst Drainage Basins within the Southwest Study Area

The largest UBF discrepancy, however, is an excessively high anomaly at Murphy Spring, just upstream of Barkers Mill Spring. Murphy Spring, at 15.4 $L/s/km^2$ (1.41 $ft^3/s/mi^2$), is over six times the regional reference value for groundwater runoff. This high anomaly may be related to cutoff augmentation from West Fork. Previous literature suggests that Murphy Spring is the discharge point of a cutoff route from West Fork, originating at Buzzards Folly Cave, a bluff maze cave (Mason, 1982, McDowell, 1983). Mylroie & Mylroie (1990) also illustrate the Buzzards Folly cutoff route, expanding on McDowell's diagram. Cutoff augmentation from a surface stream can greatly exaggerate the UBF of a spring if the additional watershed of the cutoff contribution is not included in the calculation. A search for the cutoff origin near the maze cave has located several modest high-level overflow swallets that are activated only when West Fork rises to bank-full conditions. Therefore, at some zone beneath water level, West Fork could be losing a portion of base flow that is not obvious.

Scatter Plots of UBF Data

Discharge and *Basin Area* data were compared in a separate regression analysis for each of the two study areas. The R^2 value, "goodness of fit", represents the percentage of variation in base-flow discharge that can be explained by the basin area. Figure 18 relates discharge to basin area for ten springs in the NE study area, where the R^2 is 0.82 (1.00 is a perfect fit of data to the regression line). This indicates that a fairly strong direct relationship exists between base-flow discharge and basin area.

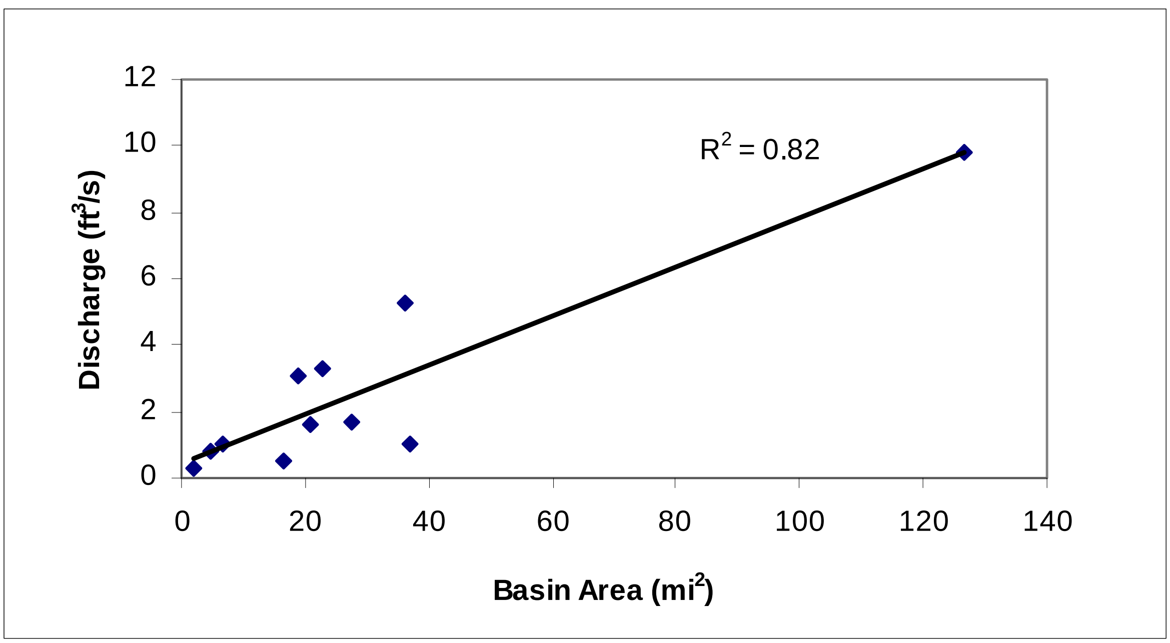

Figure 18: Scatter Plot; Discharge vs. Basin Area; NE Study Area (All Springs)

Two hydrogeologic settings exist within the NE study area: *Sinkhole Plain* (SP) karst and dissected *Sandstone Caprock* (SC) overlying soluble rock. The latter setting also includes two basins discharging from seasonal overflow springs, comprising a third sub-group. Figure 19 illustrates that discharge of seven SP basins are directly related to basin area with a strong goodness of fit (R^2) at 0.89. The two SC basins lie below the SP basins because of significantly less discharge per unit area. The two basins draining to overflow springs yield anomalously low base-flow runoff because of ungaged drainage.

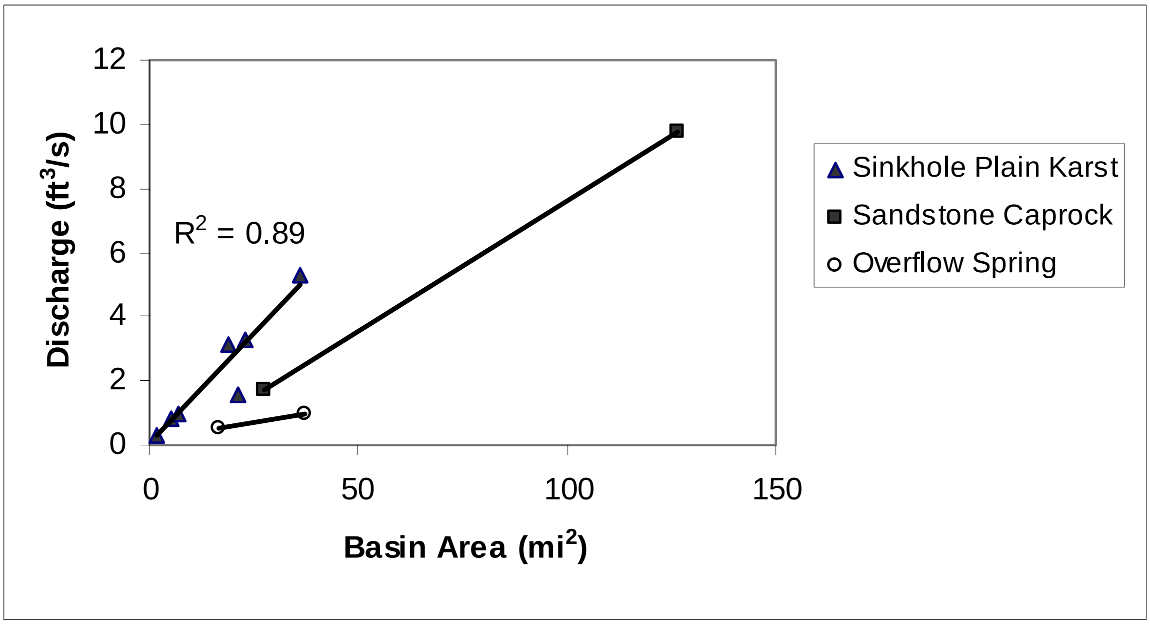

Figure 19: Scatter Plot; Discharge vs Basin Area (Northeast Study Area)

Figure 20 shows discharge/basin area intercepts for 25 springs in the SW study area. However, the goodness of fit is poor at an R^2 of 0.24. Nevertheless, a distinct trend can be seen within the data points, lying between Mill Stream and Murphy springs. After excluding the low-discharge anomaly, Mill Stream Spring, from the graph (Figure. 21), the trend-line more closely approximates the cluster with a much higher R^2 of 0.63. Murphy Spring, a high-discharge anomaly, remains far above the trend line. Murphy Spring is excluded in Figure 22, increasing the goodness of fit of the remaining springs to an R^2 of 0.71. Five additional low-discharge anomaly basins (Torian, Buchanan, Spring Hill-Herndon, Hunt, and Casey Creek, ranging from 0.8-1.3 $L/s/km^2$ [0.07-0.12 $ft^3/s/mi^2$]) are located well below the trend line. When these five basins are excluded in addition to Mill Stream and Murphy springs, the remaining 18 basins (72% of the SW population) produce a very strong direct relationship with an R^2 of 0.97 (Figure 23). This assessment of SW springs indicates that within a select core of basins, 97% of the variability of spring discharge is explained by basin area.

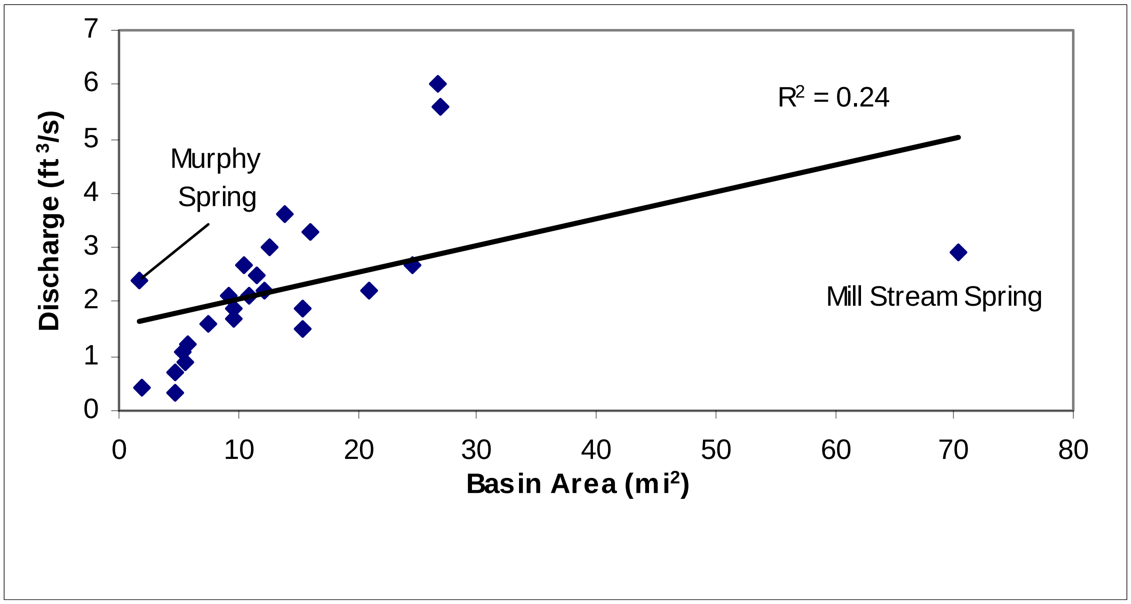

Figure 20: Scatter Plot; Discharge vs Basin Area; SW Study Area (All Springs)

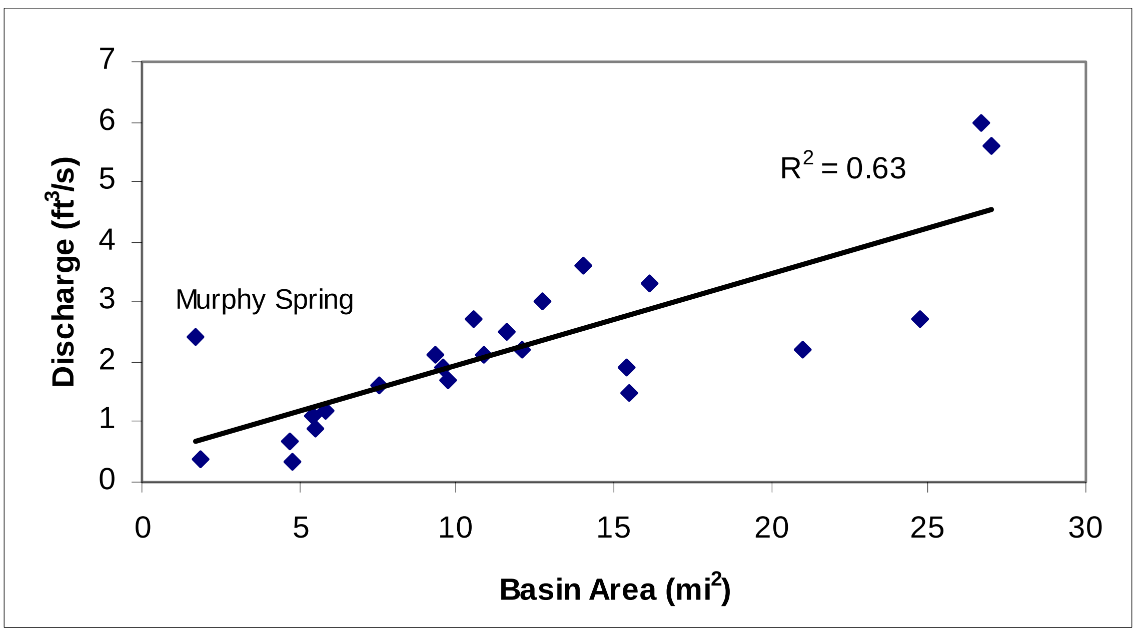

Figure 21: Scatter Plot; Discharge vs Basin Area; SW Study Area (Excluding Mill Stream Spring)

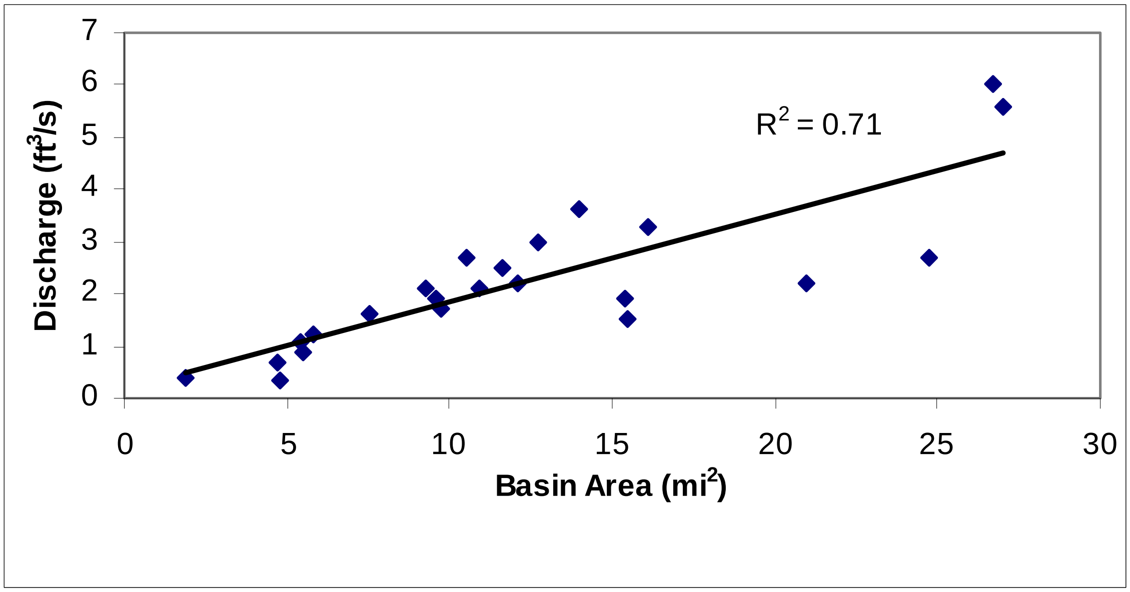

Figure 22: Scatter Plot; Discharge vs Basin Area; SW Study Area (Excluding Mill Stream and Murphy Springs)

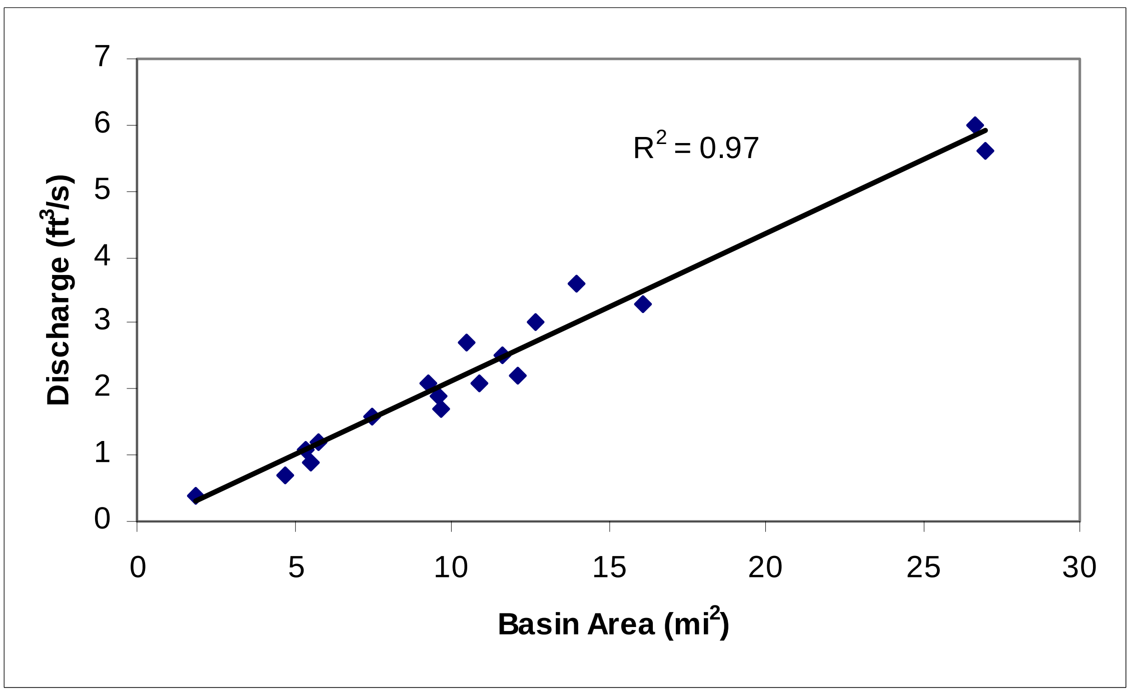

Figure 23: Scatter Plot; Discharge vs Basin Area; SW Study Area (Anomalies Excluded)

Three hydrogeologic settings exist within the SW study area and are assessed separately in Figure 24. Most basins are located within the flat-lying *Sinkhole Plain* (SP) setting in southern Christian and Todd counties. Because the population includes some anomalous UBF values, such as the high value calculated for Murphy Spring, the R^2 is lower at 0.76. Three basins are influenced by *Shallow Karst* (SK), which results in lower UBF. These basins (Torian, Hunt, and Mill Stream springs) are formed within the upper Ste. Genevieve, Renault and Paint Creek limestones. In addition, the northern part of the Mill Stream Spring watershed is a non-karst sandstone terrain with relatively low UBF. The R^2 of these three SK basins is 0.74. The third group is termed *Thick Cover* (TC) karst, which is characterized by minimal sinkhole development because of abnormally thick soils to depths of 24 m (80 ft). Whereas Brelsford and Garnett springs exhibit a UBF 25% above normal, due to thick soils and greater groundwater storage, Head of Casey Creek Spring has only half of the expected UBF. This low-UBF anomaly causes the TC springs to yield a meaningless R^2 of 0.14. The low UBF of the latter spring is suspected to result from some underflow through coarse gravel that was not measured.

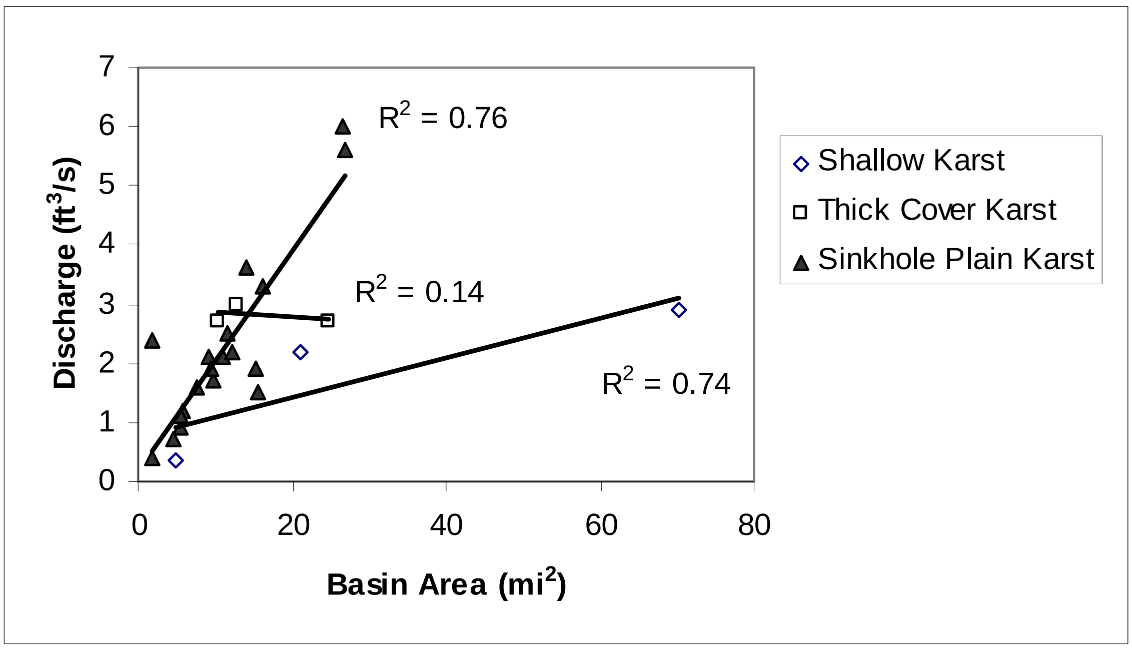

Figure 24: Scatter Plot; Discharge vs Basin Area (Southwest Study Area)

CLASSIFICATION OF KARST DRAINAGE BASINS

The interpretation of groundwater tracer data to delineate coherent drainage networks can be substantially aided by a conceptual classification of karst basins (Ray and Currens, 1996). This classification centers on the dominant recharge component that controls the development and configuration of trunk flow within a basin, and is derived from assessing hundreds of karst basins mapped in Kentucky. The following scenario describes fluvial networks encountering highly soluble rocks in a simple evolutionary sequence (Ray, 1999, 2001).

A conduit flow route may initially develop when a fluvial system begins to incise soluble rocks. Flow along secondary bedrock porosity evolves and a subsurface conduit such as a meander cutoff route or a valley-paralleling conduit forms an incipient groundwater basin. In these initial cases most of the returning spring-flow is derived from the nearby stream sink or losing reach. The capacity of this initial groundwater route may be less than the stream's low flow or equivalent to base or moderate flow volumes. Consequently, higher flows continue to erode the prevailing surface channel. Basins containing losing streams that maintain viable surface overflow channels across the watershed are termed *Overflow Allogenic* or *Type I* basins (illustration "*a*" in Figure 25). Boiling, Mill Stream, Brelsford, and River Bend spring basins are examples of Overflow Allogenic basins (Allogenic flow is defined as non-local stream drainage from either insoluble or soluble rock terrane). Also, substantial portions of Head of Wolf Creek and King spring basins contain surface overflows.

When the capacity of a trunk conduit evolves to the point that all ranges of allogenic flow are channeled underground, the surface stream is beheaded, thus creating a blind valley at the margin of an abandoned karst valley or sinkhole plain. An *Underflow Allogenic* or *Type II* basin (illustration "*b*" in Figure 25) results when allogenic overflow routes are no longer maintained across a karst basin. Cook, Walton, and Wright spring basins are examples of Underflow Allogenic basins. Both basin types I & II can be considered *influent or fluviokarst* drainage systems (White, 1988).

These karst-basin types not only reflect a reasonable evolutionary sequence but also may help to explain flood response and water quality of some resurgent springs (Worthington and others, 1992). Suspended sediment and contaminants mobilized during flooding may partially bypass springs draining Type I basins. This overflow-route bypass is not available in Type II basins where springs drain the entire karst watershed. A similar classification was developed by Jones (1997) where *open* karst basins maintain through-flowing surface drainage networks, whereas *closed* basins do not.

A third type of karst watershed lacks significant allogenic recharge and is termed a *Local Autogenic* or *Type III* basin (illustration "*c*" in Figure 25). These typically smaller basins are primarily recharged by infiltration of precipitation through the land surface and internal runoff into sinkholes. They are commonly located on the margins of stream-less karst plateaus. Barkers Mill, French Creek, and Buttermilk Falls spring basins are examples of primarily autogenic recharge basins.

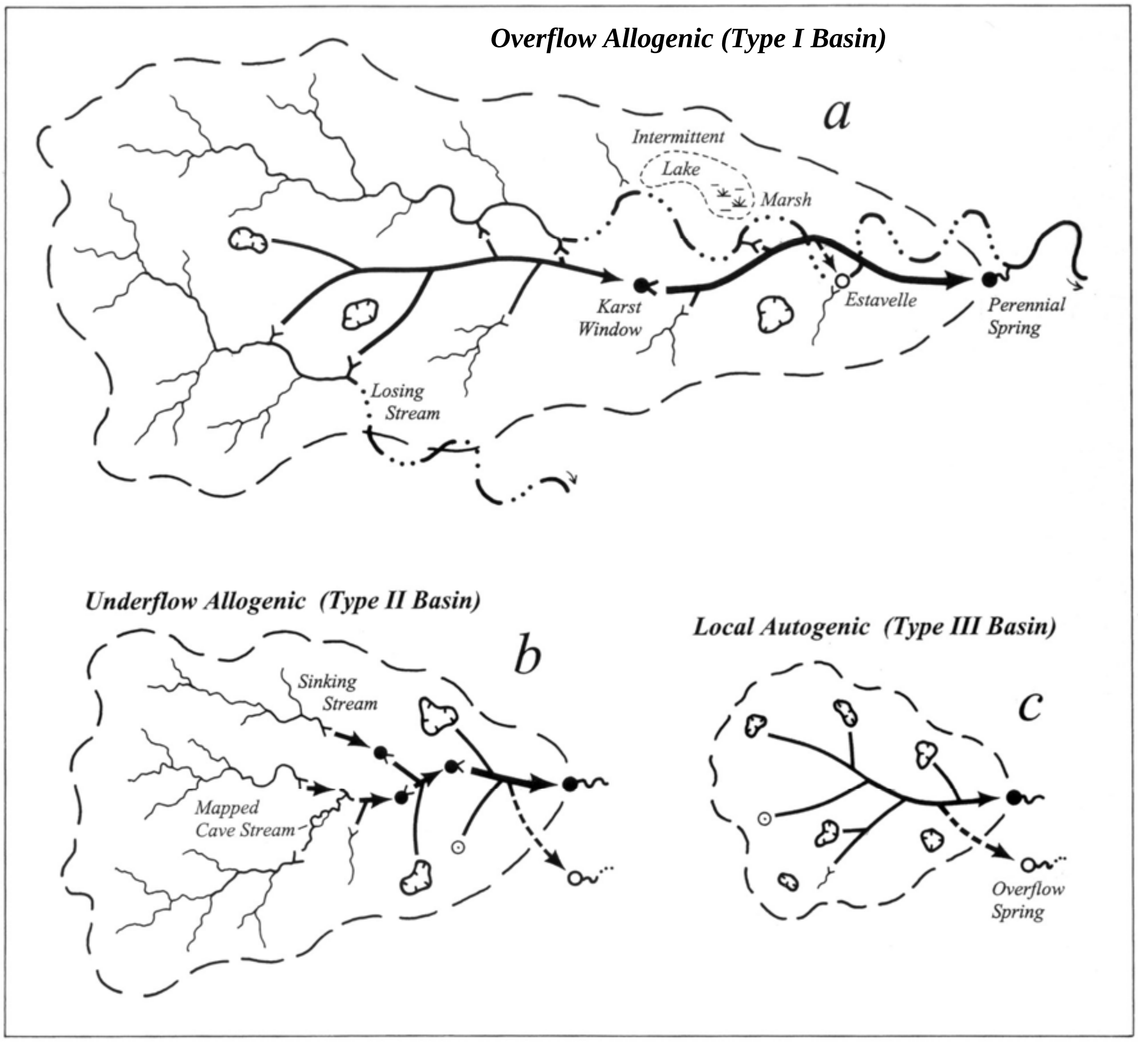

Figure 25: Major Types of Karst Drainage Basins

INTERPRETATION OF RESULTS

DISTRIBUTION OF PRIMARY LAND COVER

Land cover data were acquired from the National Land Cover Data Set for the conterminous United States, developed by the US Geological Survey (Vogelmann and others, 2001). Compilers used satellite data and a variety of additional information including topography, census, agricultural statistics, soil characteristics, other land cover maps, and wetlands data to determine land cover at a 30 m (100 ft) resolution. Twenty-one classes of land cover were identified. Fifteen classes appear in Kentucky. A subsequent accuracy assessment indicated that the coverage was 66% accurate. Figure 26 shows a simplified land-cover map of Kentucky. The dense agricultural activity in the SW area is indicated by the buff color, whereas a mixture of agricultural and forested land in the NE area is shown by mixed green and buff colors.

For this study, Primary Land Cover includes any type with as much as three percent cover in any of the studied groundwater basins. These primary types include *Row Crop, Pasture & Hay, Deciduous Forest, Mixed Forest, and Woody Wetland.*

Row Crops

In the SW study area *Row Crops* averaged 38.6% of the total land area, ranging from a high of 47.1% (Walton) to a low of 13.2% (Brelsford). This represents a total of 17,617 ha (43,530 ac; 68.0 mi^2; 176.1 km^2)

The NE study area had less row-crop area with an average of 21.6%, ranging from a high of 9.3% (Boiling) to a low of 15.2% (Head of Wolf). This represents a total of 11,784 ha (29,119 ac; 45.5 mi^2; 117.8 km^2).

Pasture & Hay

In the SW study area *Pasture & Hay* averaged 42.3%, ranging from a high of 52.2% (Brelsford) to a low of 30.3% (Walton). This represents a total of 18,367 ha (45,385 ac; 70.9 mi^2; 183.6 km^2).

In the NE study area *Pasture & Hay* averaged 22.3%, ranging from a high of 43.9% (French Creek) to a low of 9.1% (Buttermilk Falls). This represents a total of 10,727 ha (26,505 ac; 41.4 mi^2; 107.3 km^2).

Deciduous Forest

In the NE study area *Deciduous Forest* averaged 48.4% of the total land area, ranging from a high of 66.8% (Head of Wolf) to a low of 27.2% (French Creek). This represents a total of 18,259 ha (45,118 ac; 70.5 mi^2; 182.6 km^2).

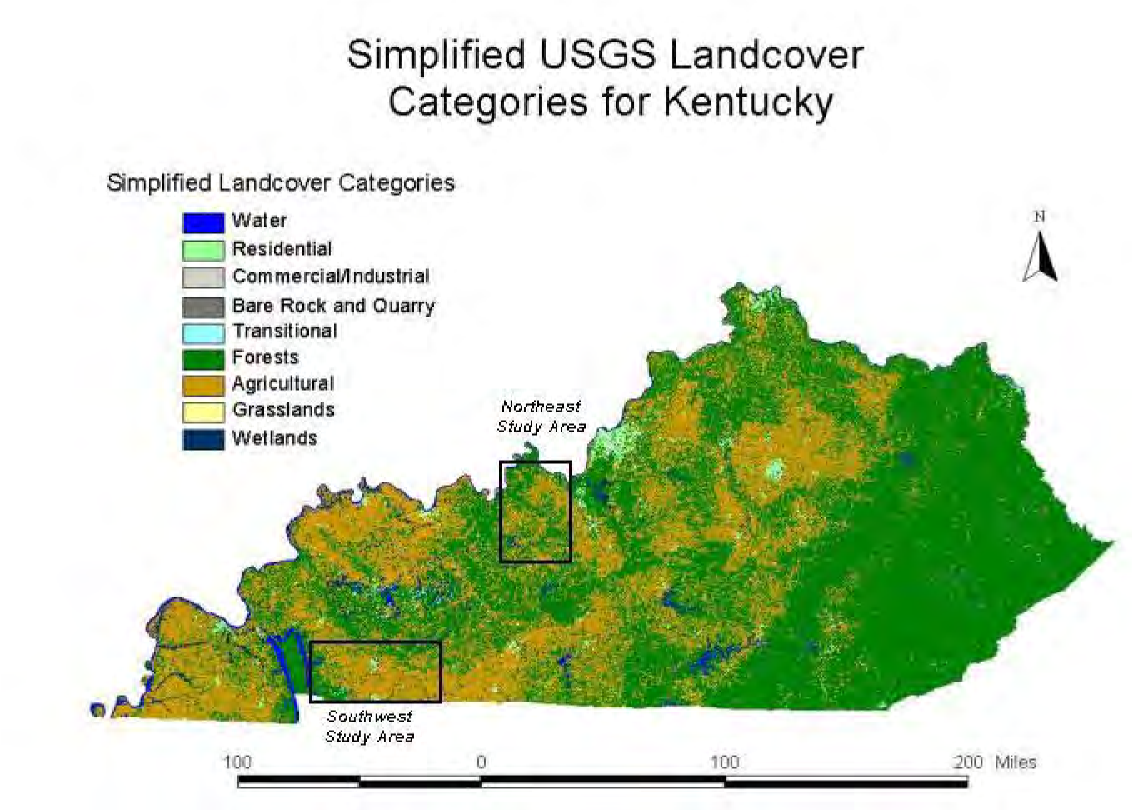

Figure 26: Simplified Land-Cover Map of Kentucky

In the SW study area *Deciduous Forest* averaged only 11.7% of the total land area, ranging from a high of 26% (Brelsford) to a low of 3% (Barkers Mill). This represents a total of 6,302 ha (15,573 ac; 24.3 mi^2; 62.9 km^2).

Mixed Forest and Woody Wetlands

The remaining two categories with three percent or greater total basin area were *Mixed Forest* and *Woody Wetlands*. In the NE area, Boiling, Head of Wolf, and Buttermilk Falls contained 5.4, 3.3, and 5.8%, respectively, of *Mixed Forest*. Only Brelsford, in the SW area, contained a significant amount of *Mixed Forest* at 5.1%.

Percentages of primary land cover in each basin are shown in Table 3. Figures 27-38 illustrate the land cover in the vicinity of individual groundwater basins, which are identified by the main spring and a green dashed groundwater-basin boundary.

ID #	Spring Name	Deciduous Forest	Mixed Forest	Pasture & Hay	Row Crop	Woody Wetland	Total
0855	**Boiling**	40.22	5.37	23.44	29.30	-	98.33
1838	**French Creek**	27.16	3.65	43.90	24.03	-	98.73
1824	**Buttermilk Falls**	59.30	5.80	9.06	17.74	-	91.89
1063	**Head of Wolf Creek**	66.81	3.30	12.70	15.23	-	98.03
0859	**Barkers Mill**	3.31	-	49.07	43.23	-	95.61
0860	**River Bend**	4.55	-	42.81	45.39	3.74	96.49
1141	**Cook**	16.20	-	43.87	33.28	-	93.35
1448	**Brelsford**	25.99	5.12	52.20	13.22	-	96.53
0203	**Mill Stream**	22.05	-	34.62	38.97	-	95.64
1489	**King**	7.42	-	38.25	46.80	4.22	96.69
1457	**Walton**	8.04	-	30.03	46.03	12.27	96.38
1475	**Wright**	6.17	-	47.53	42.16	-	95.86

Table 3: Percentages of Primary Land Cover in each Basin (> 3%)

Secondary Land Cover Types

Additional minor land cover types amounting to less than three percent of basin area are commonly visible on these maps, and are included in the legend as Secondary Land Cover. These types include *Urban/Residential, Recreational Grasslands, Water, Limestone Quarry, Evergreen Forest, Emergent Herbaceous Wetlands, and Transitional* (Fort Campbell Military Reservation).

A minor misinterpretation of land cover was noted in Figure 37, showing Walton Spring. The *Woody Wetland* represented in the area around Walton Spring, in the northwestern portion of the basin, is actually *Deciduous Forest*. This terrain is known to be a rugged dissected ravine and therefore cannot contain woody wetland vegetation. Likewise, another ravine network in the northeast portion of Figure 37, lying outside of the Walton Spring basin, is misrepresented as woody wetland. Both of these areas have been observed in the field and contain mature deciduous forest. When the land cover for Walton Spring basin is corrected, the *Deciduous Forest* type land cover increases from 7.8% to 8.6% and the *Woody Wetland* decreases from 11.2% to 10.4%.

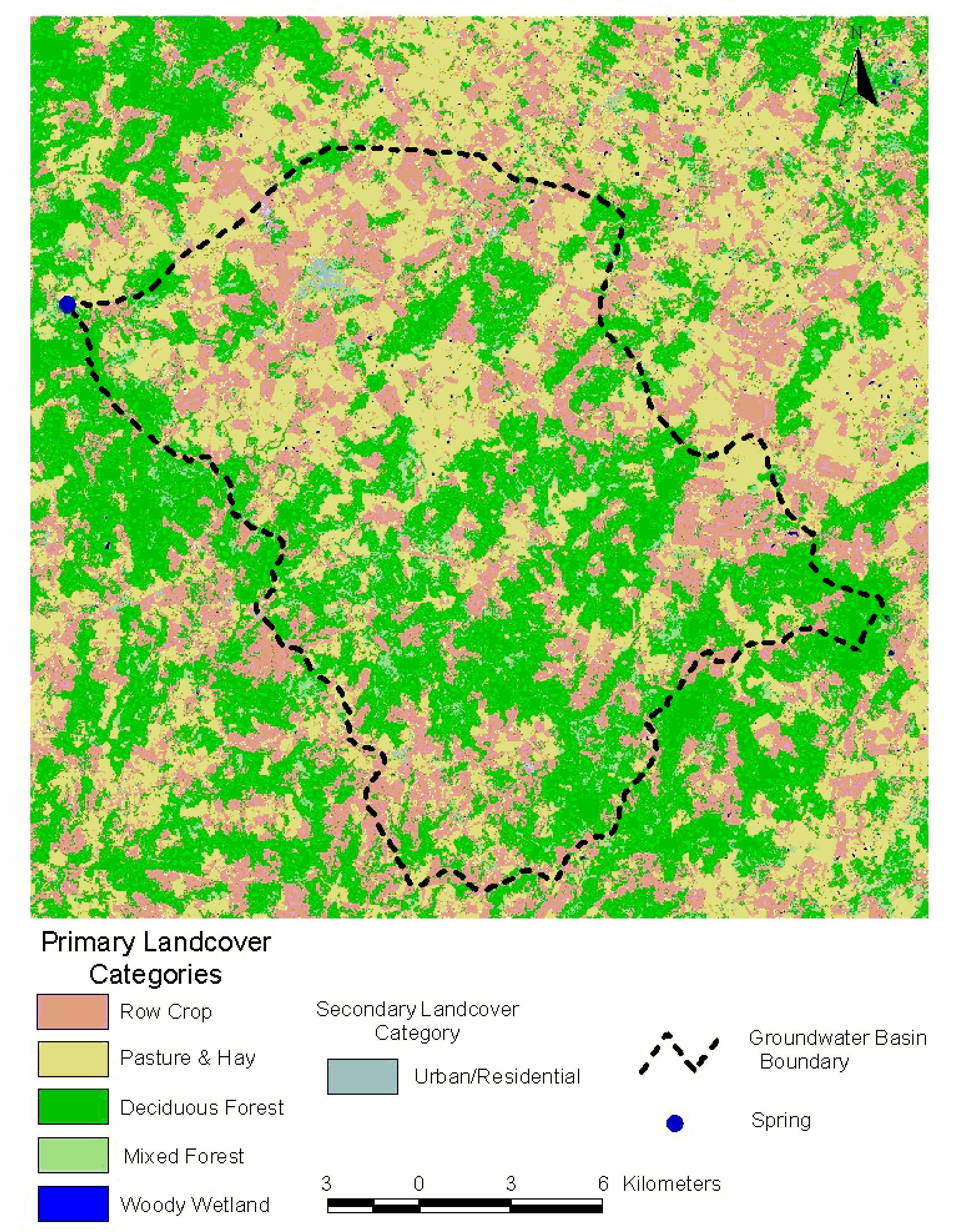

Figure 27: Boiling Springs Basin Land Cover

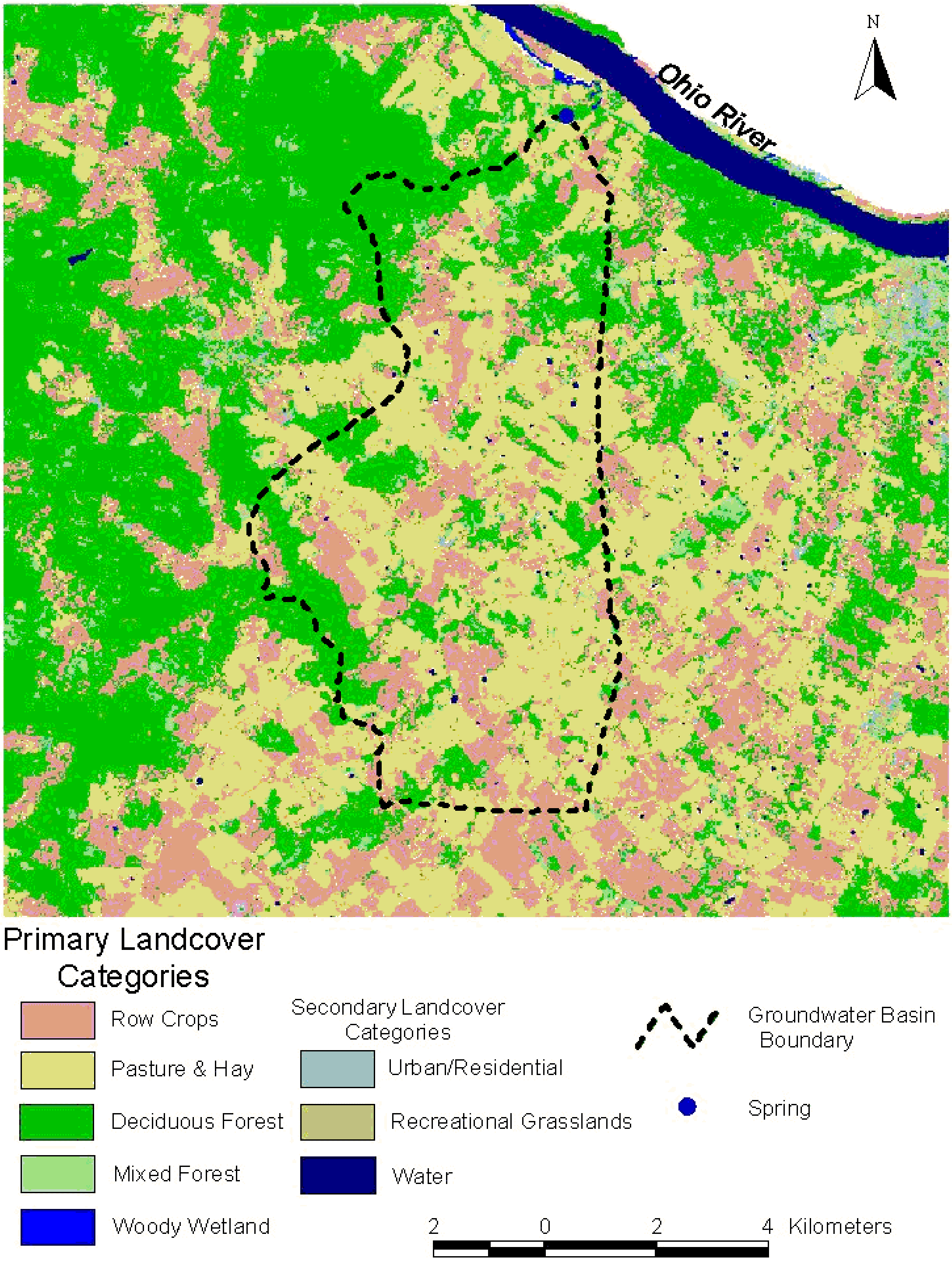

Figure 28: French Creek Springs Basin Land Cover

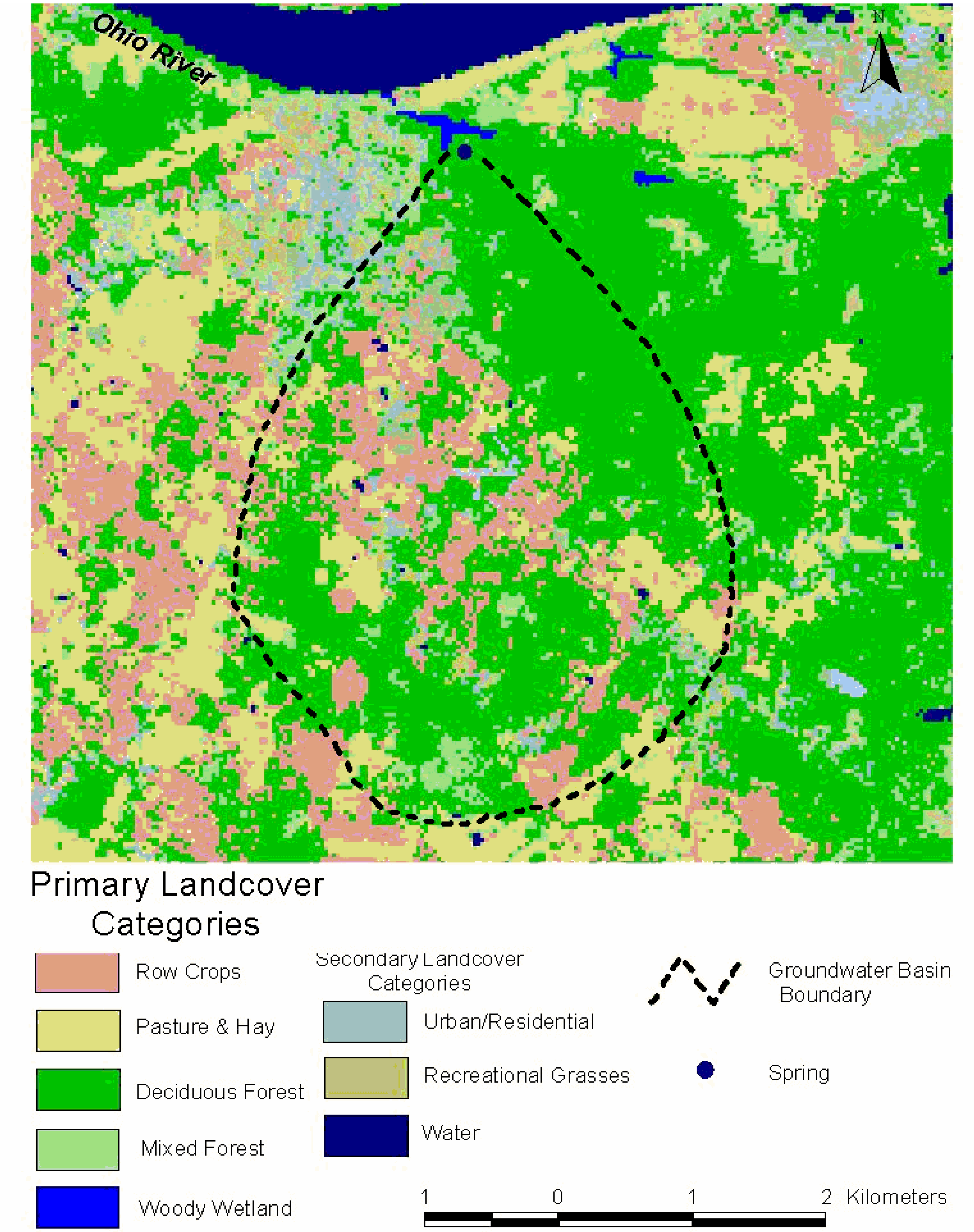

Figure 29: Buttermilk Falls Spring Basin Land Cover

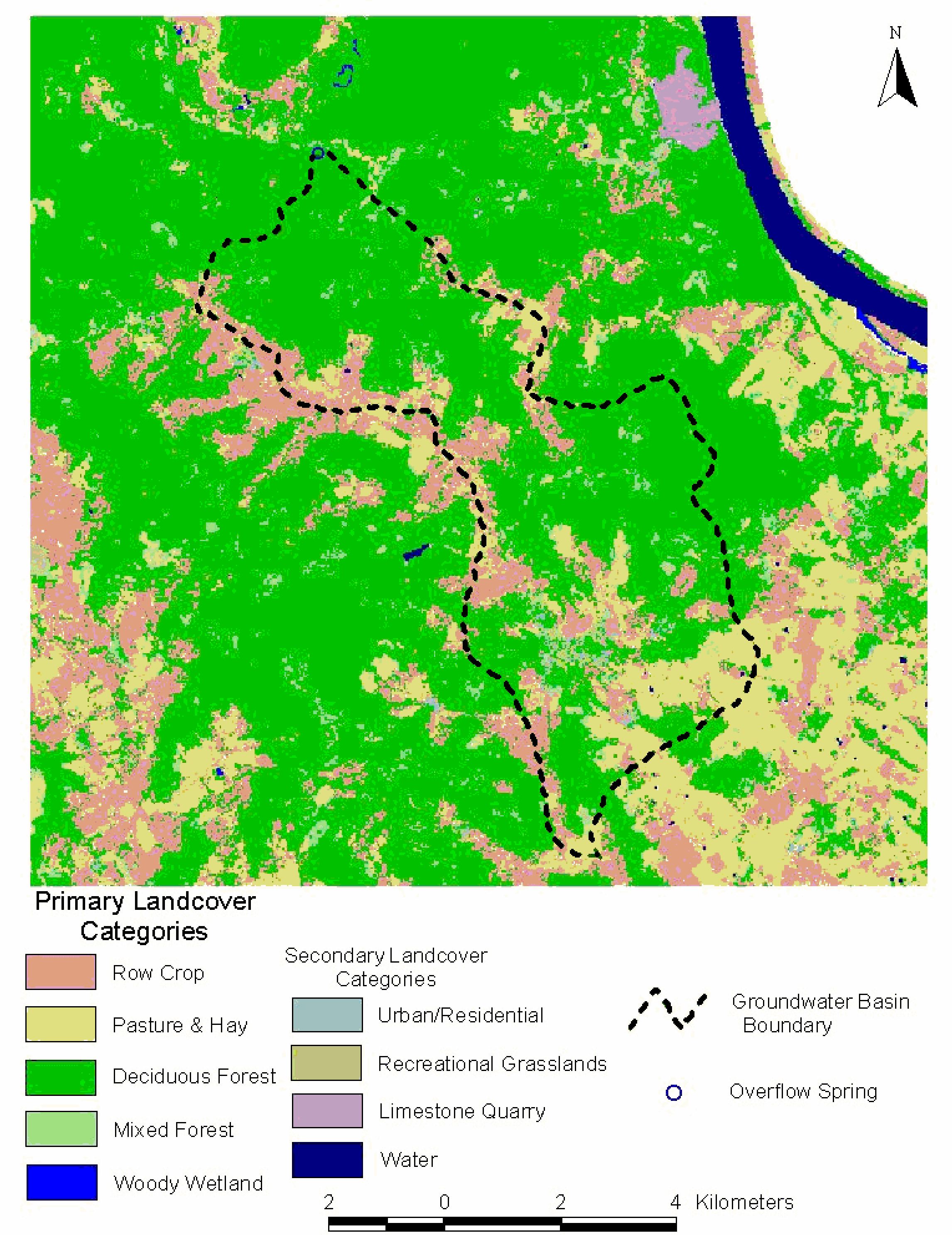

Figure 30: Head of Wolf Creek Spring Basin Land Cover

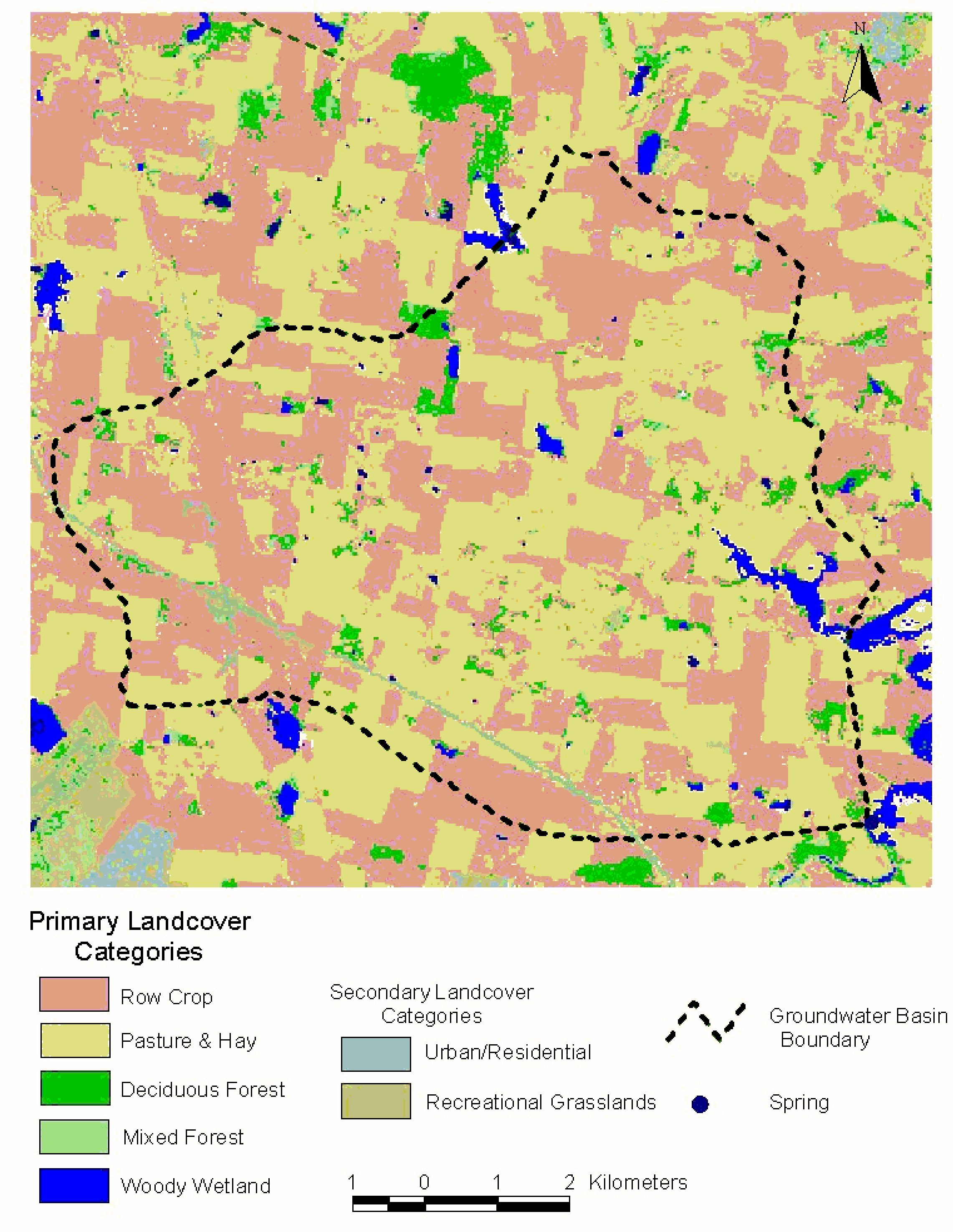

Figure 31: Barkers Mill Spring Basin Land Cover

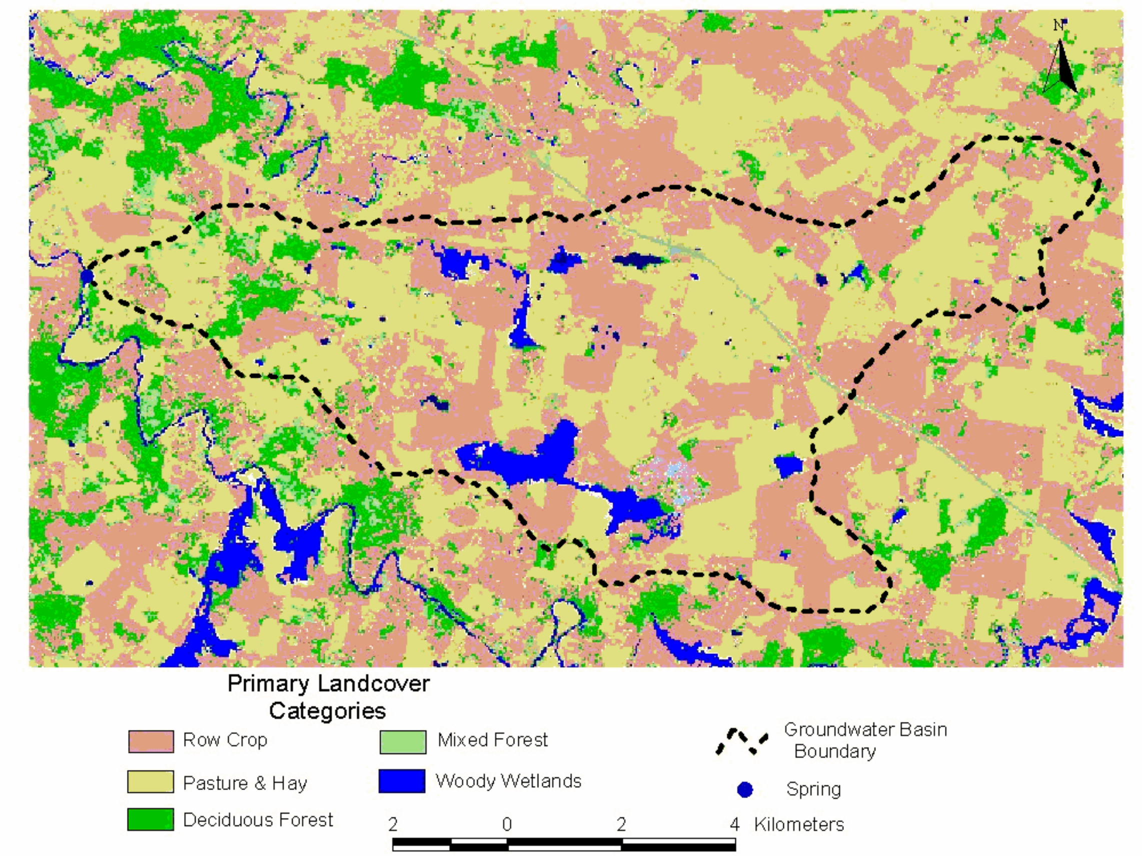

Figure 32: River Bend Spring Basin Land Cover

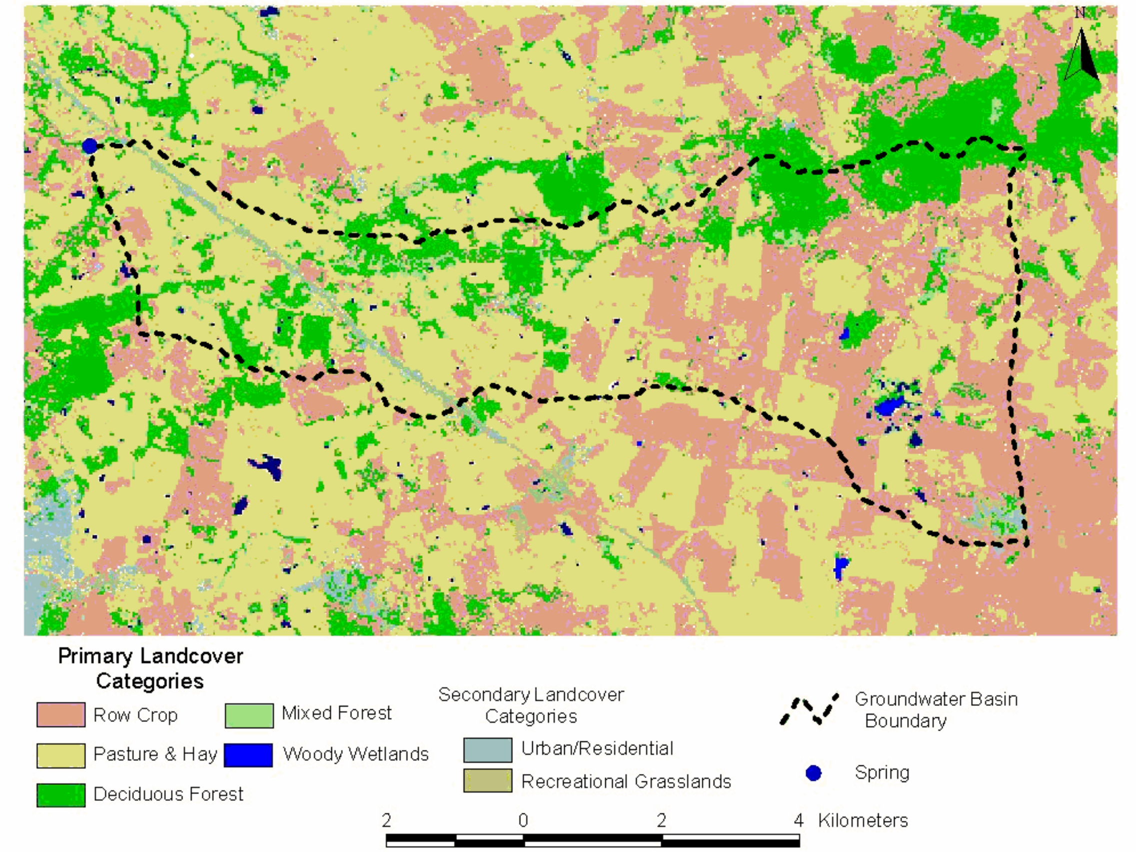

Figure 33: Cook Spring Basin Land Cover

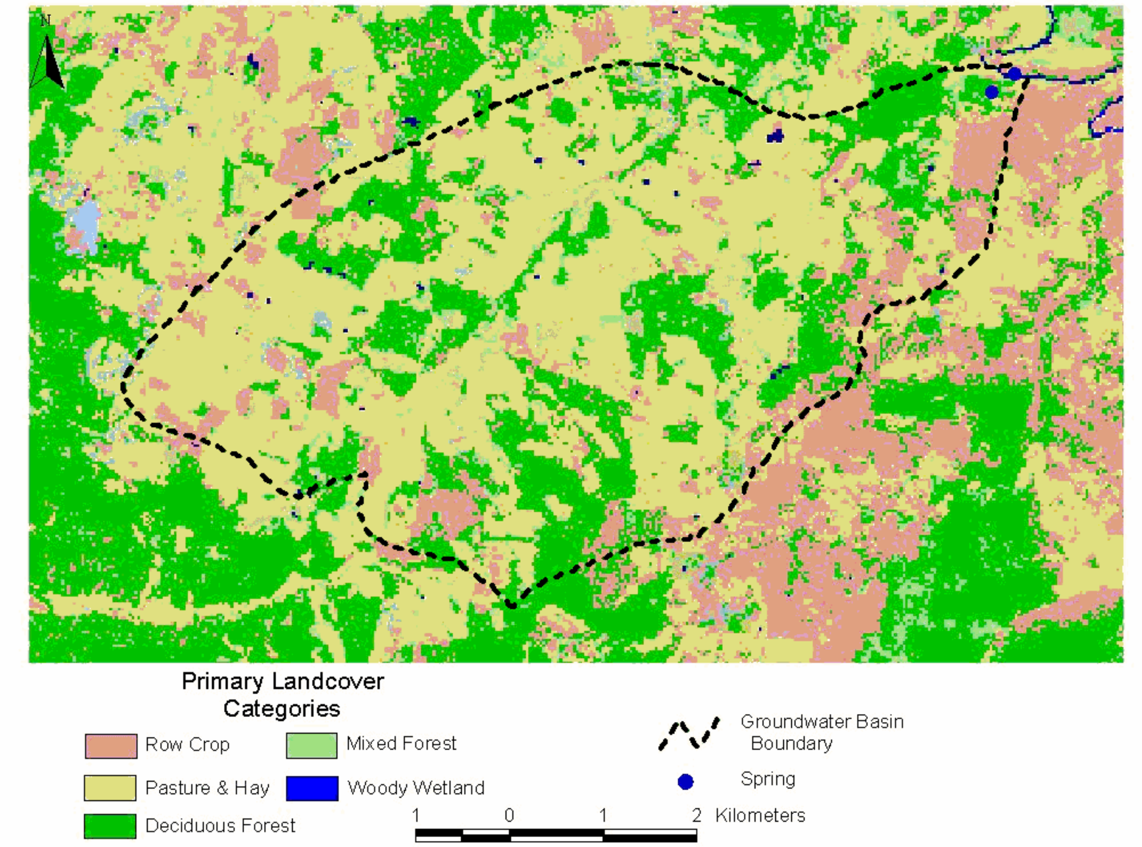

Figure 34: Brelsford Spring Basin Land Cover

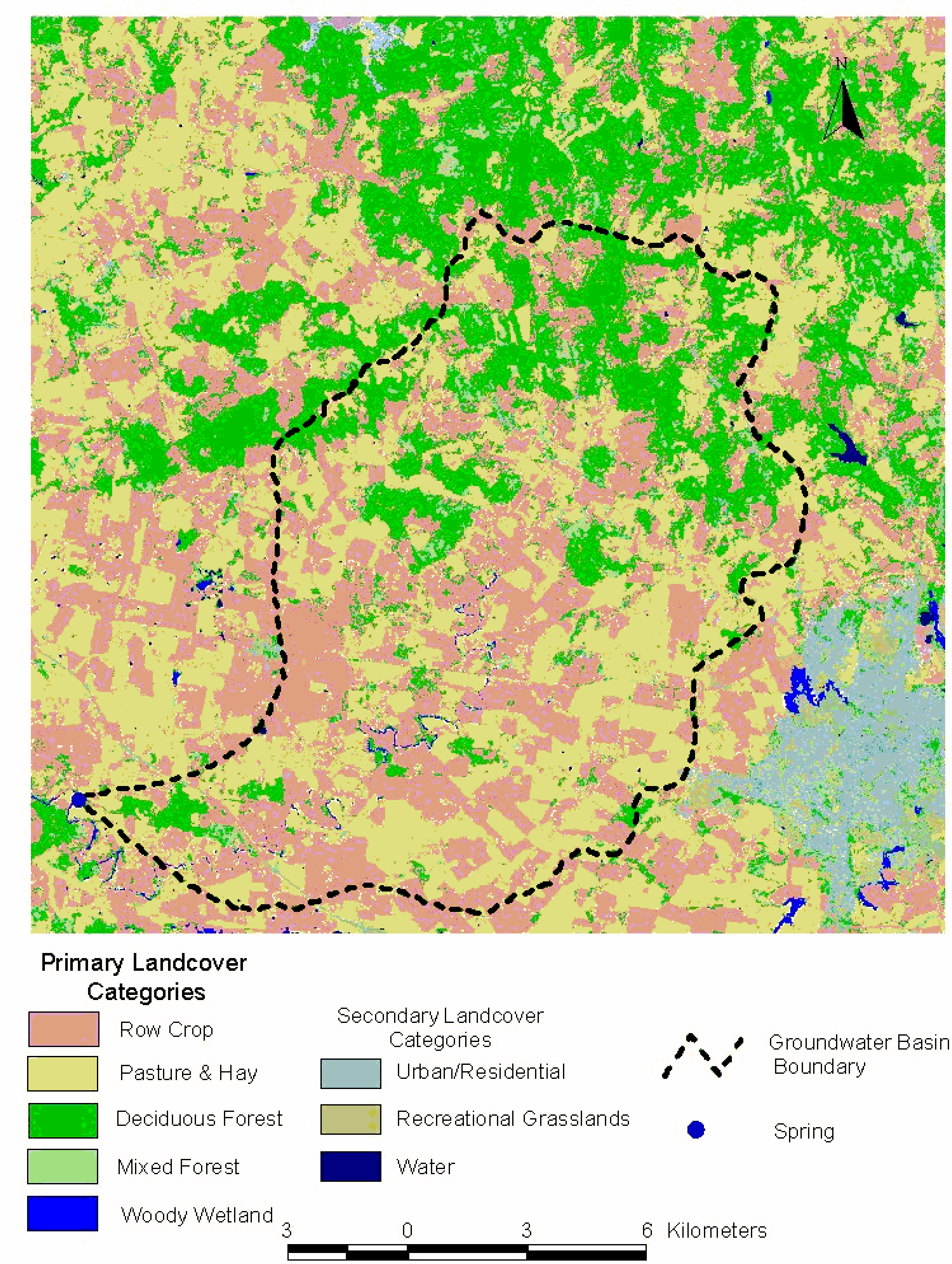

Figure 35: Mill Stream Spring Basin Land Cover

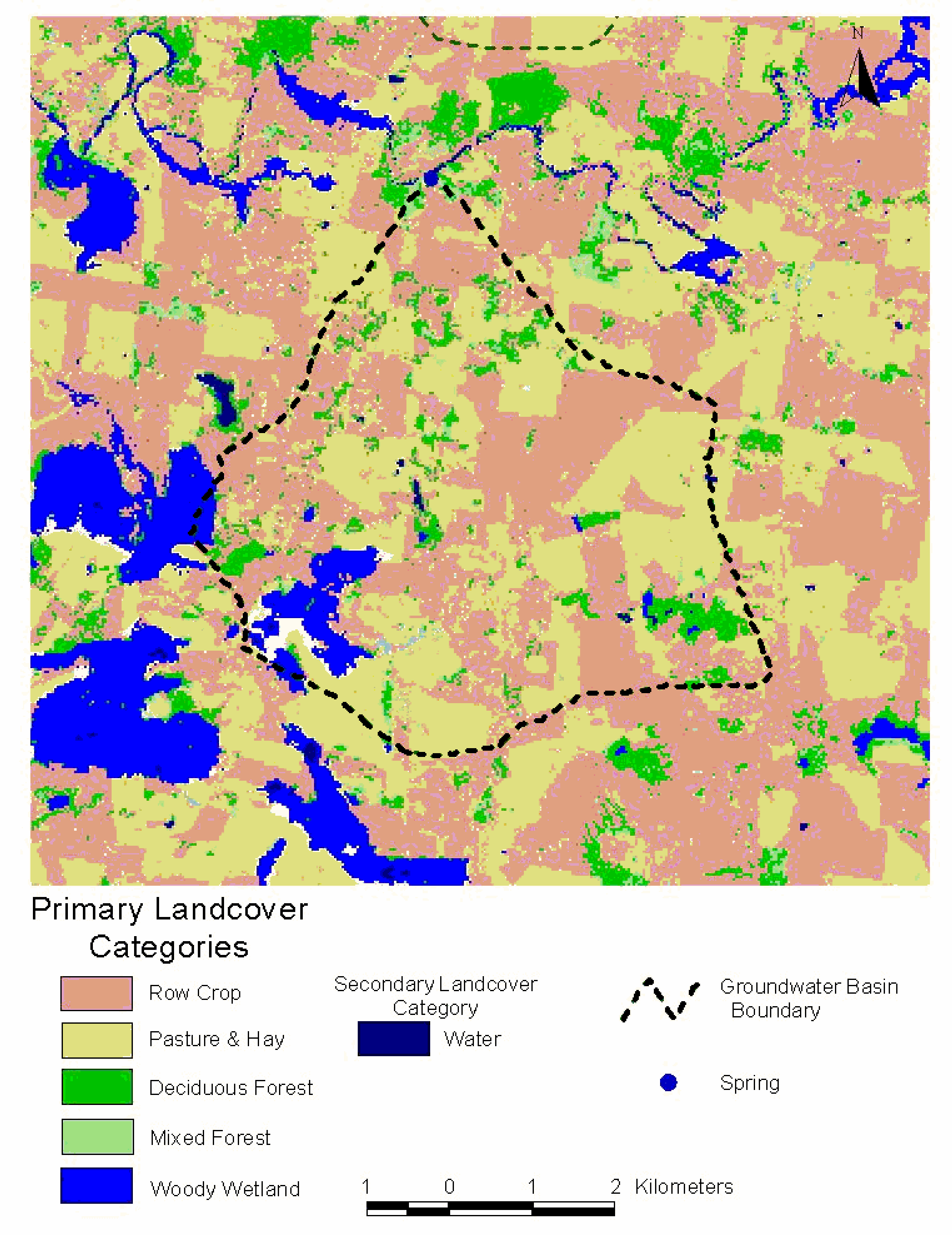

Figure 36: King Springs Basin Land Cover

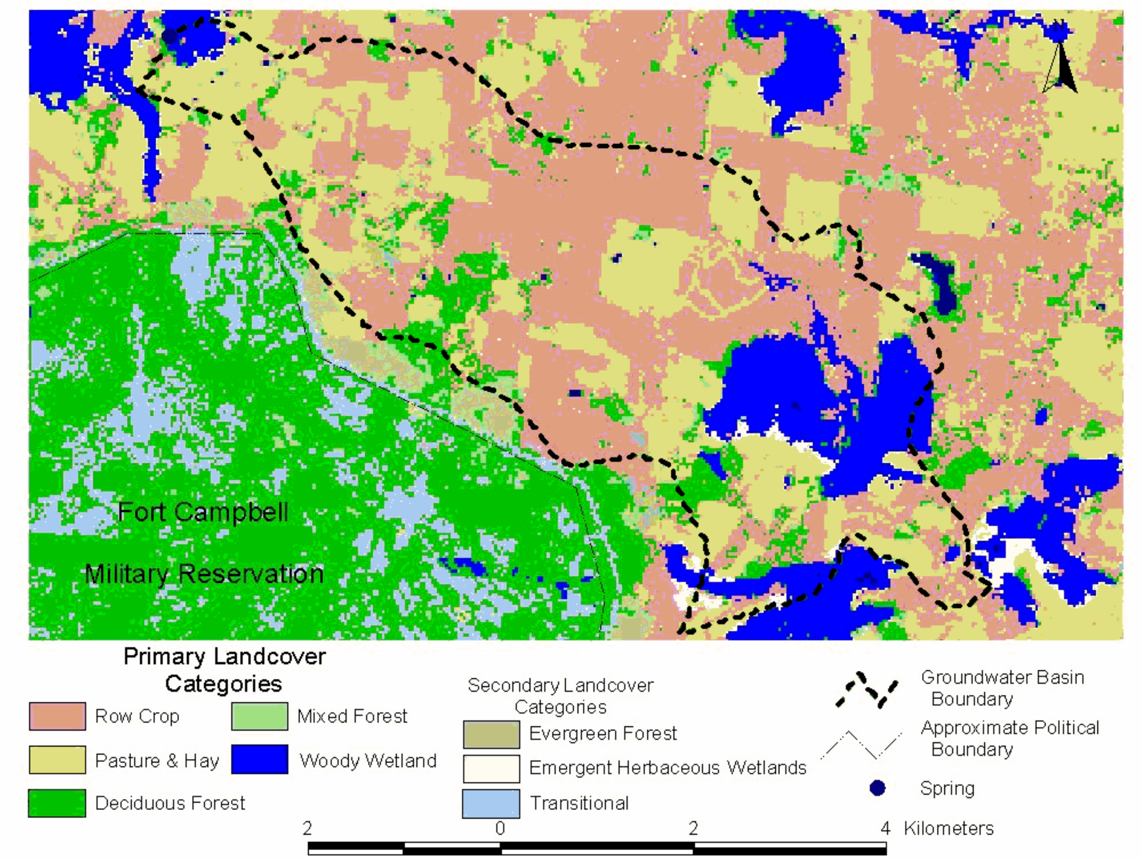

Figure 37: Walton Spring Basin Land Cover

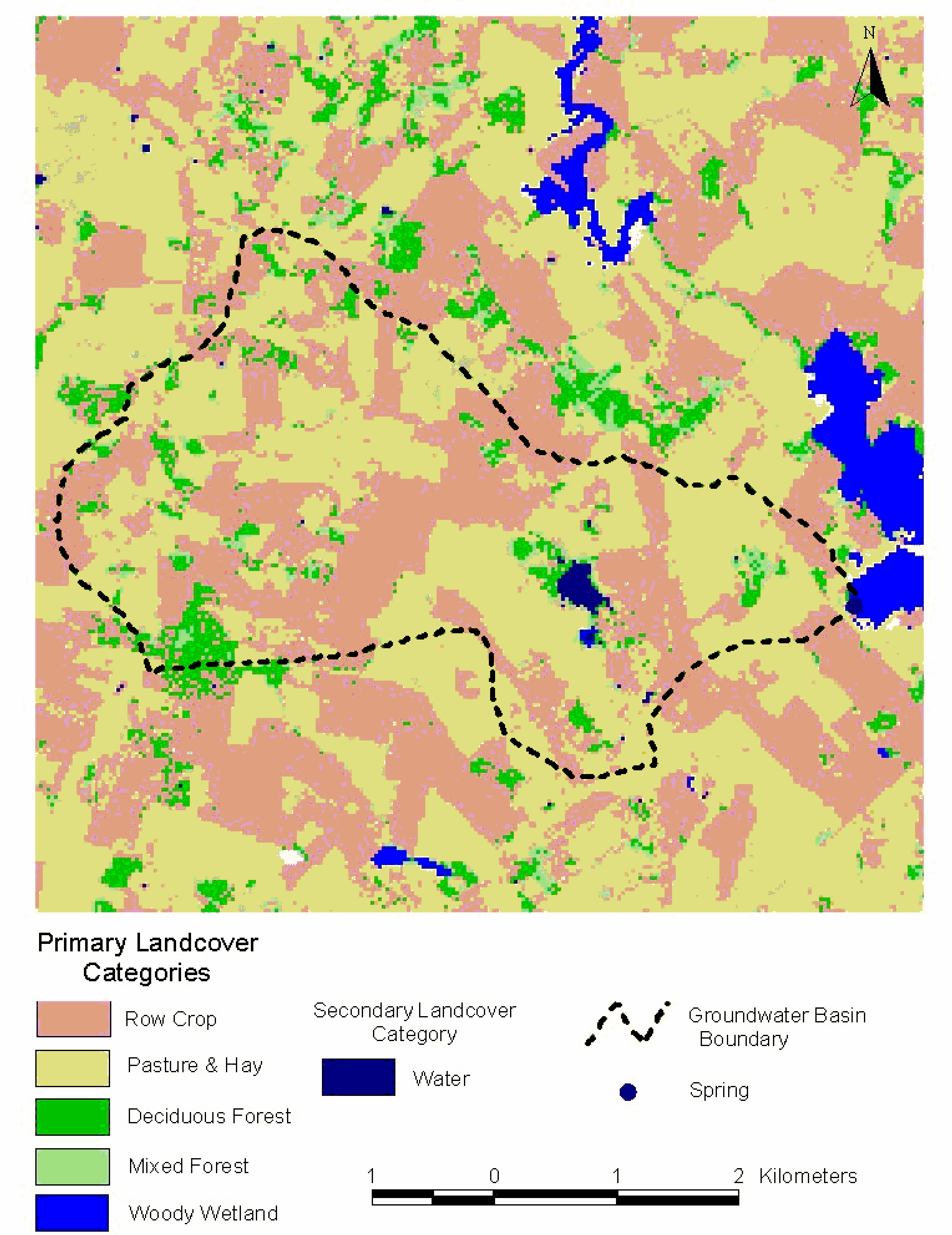

Figure 38: Wright Spring Basin Land Cover

EVALUATION OF SPRING-WATER CHEMISTRY DATA

Forty-four percent of Kentuckians rely on groundwater as a source of drinking water, either from public or private systems. In addition, many Kentuckians use groundwater for industrial, agricultural, and commercial purposes. Groundwater provides the baseflow to Kentucky streams. In fact, groundwater constitutes greater than 90% of Kentucky's freshwater resources. Consequently, groundwater is an important resource and needs to be managed and protected. The collection of physical and chemical data from the regional springs sampled during this study helps to address the need for base-line information. These data are especially important in Kentucky's karst regions where surface and groundwater function as conjunctive systems.

Some of the parameters assessed in this study have limits established by the EPA for treated drinking water supplied to the public. The EPA (2000) defines the following three types of drinking water standards: Maximum Contaminant Levels, Secondary Drinking Water Regulations, and Health Advisories:

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

Secondary Drinking Water Regulations are defined as "non-enforceable Federal guidelines regarding cosmetic effects (such as tooth or skin discoloration) or aesthetic effects (such as taste, odor, or color) of drinking water." In common usage, this is often referred to as Secondary Maximum Contaminant Level (SMCL).

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

Most of the information provided about various chemical parameters is cited from EPA (1998, 1999, 2000) and World Health Organization (1996) publications.

Boxplots

Boxplots are used to graphically depict the sample results of all twelve springs on one diagram so that comparisons can be made. Data from four springs in the NE study area are illustrated in the top third of the graph, and data from eight springs in the SW study area are shown in the lower two-thirds of the graph. The springs are arranged from largest to smallest volume in each group.

Boxplots were used to assess skewed datasets, such as water quality data containing numerous non-detect values. Skewed datasets are more appropriately described by the 5-Number Summary and Interquartile Range (IQR) than the mean and standard deviation. The 5-Number Summary consists of quartiles: Q_0 (minimum value), Q_1 (first quartile, or median of the lower half of the dataset), Q_2 (median), Q_3 (third quartile, or median of the upper half of the dataset), and Q_4 (maximum value). The Interquartile Range is calculated as the difference between Q_3 and Q_1 and represents 50% of the data values in a set.

Boxplots graphically depict the central tendency (location about which data values cluster) and scatter of values in a dataset utilizing the 5-Number Summary. The "box" in a boxplot extends from Q_1 to Q_3, representing the Interquartile Range. The median is represented by a vertical line inside this box. Horizontal lines ("whiskers") are extended from Q_1 down to the lowest value within 1.5 IQR of Q_1 and from Q_3 up to the highest value within 1.5 IQR of Q_3; a small vertical bar ("fence") on the end of each line indicates the location of these two values. Outliers, values more than 1.5 IQR from the quartiles, are denoted by an open square. Extreme outliers, values more than 3.0 IQR from the quartiles, are denoted by a red cross within a square.

Outliers are significant because they represent distinct deviations from the bulk of the data values in a set. In water quality data, values are generally skewed to the right, or positively skewed, due to the presence of a few high outliers. Most of the values in this type of data set cluster at or near 0, or some laboratory-defined detection limit (represented on a boxplot by a left-truncated appearance).

Nutrients

Nutrients are widespread nonpoint source contaminants in karst groundwater, which are commonly related to agricultural practices. Nutrient sources include fertilizers and manure applied to the land surface for crop production, feedlots, pastures, dairy, poultry, and swine operations (Berryhill, 1989). Nutrients are particularly important in surface water, where eutrophication may be caused by excessive nutrient enrichment of water. This enrichment can cause an overabundance of some plant life, such as algal blooms and may also have adverse effects on animal life, because excessive oxygen consumption by plants leaves little available for animal use. Nutrients included in this report are nitrate-nitrogen, nitrite-nitrogen, ammonia, orthophosphate and total phosphorous.

Nitrate

Nitrate (NO_3-N) occurs in the environment from a variety of anthropogenic and natural sources: nitrogen-fixing plants such as alfalfa and other legumes, nitrogen fertilizers, decomposing organic debris, atmospheric deposition from combustion and human and animal waste. Nitrate is reported either as the complex ion NO_3, or as the equivalent molecular weight of nitrogen-N. Since 1 mg/L of nitrogen equals 4.5 mg/L nitrate, the drinking water MCL of 10 mg/L nitrate-N equals 45 mg/L nitrogen. In this report, results are reported as "nitrate-N." In infants, excess nitrate consumption can cause methemoglobinemia or "blue-baby" syndrome (Lambert, 1976; EPA, 1999). In adults, possible adverse health effects of nitrate ingestion are under study and much debated. Because nitrate is difficult to remove through ordinary water treatment, its occurrence at levels above the MCL in drinking water sources is a problem. High nitrate levels also encourage the growth of algae and other organisms in streams. The unnatural accelerated growth of these organisms depletes the available oxygen in water and creates an oxygen deficient environment uninhabitable by many other organisms. Thus, streams high in nitrate content will have a smaller diversity and population of organisms.

Table 4 shows nitrate-N values in mg/L from the twelve sampled springs over 8 quarters. None of the values are above MCL. However, compared to a typical reference value of less than 2 mg/L for a relatively pristine karst spring, nitrate-N levels are moderately high in most intensively farmed karst basins, especially the SW study area. Figure 39 shows the overall median value of nitrate in the SW study area to be about 2.4 times higher than the NE study area.

Flow Condition	Moderate	Moderate	Low	Low	Moderate	Low	Low	Moderate	-
Sample Date (SW)	**1/19/99 & 1/20/99**	**5/17/99 & 5/18/99**	**8/24/99 & 8/25/99**	**12/08/99 & 12/09/99**	**4/26/00 & 4/27/00**	**8/22/00 & 8/23/00**	**1/09/01 & 1/10/01**	**5/15/01 & 5/16/01**	
Spring (SW)									MEDIAN
River Bend	6.24	5.6	5.74	5.24	5.38	5.63	6.28	6.85	5.69
Barkers Mill	5.45	5.79	5.04	4.54	6.19	5.18	5.02	5.45	5.32
Wright	6.85	4.75	3.66	3.1	5.81	4.18	7.05	4.9	4.83
Mill Stream	4.84	6.08	4.02	3.46	3.64	3.84	6.73	6.28	4.43
King	4.72	3.5	3.8	3.46	4.72	3.82	4.23	4.81	4.03
Cook	3.62	4	3.86	3.32	4.59	4	5.49	4.93	4
Walton	3.93	3.23	3.66	3.39	6.24	3.8	4.61	4.61	3.87
Brelsford	2.64	1.74	1.38	1.15	2.35	1.38	2.49	1.9	1.82
Sample Date (NE)	**1/27/1999**	**5/11/1999**	**8/25/1999**	**12/1/1999**	**4/26/2000**	**8/23/2000**	**1/10/2001**	**5/15/2001**	
Spring (NE)									
French Creek	2.58	2.62	2.76	2.49	2.98	2.51	3.59	2.96	2.69
Boiling	2.42	1.31	1.92	1.2	2.1	2.06	3.03	2.53	2.08
Buttermilk Falls	1.94	1.79	1.7	1.72	1.83	1.83	2.21	2.06	1.83
Head of Wolf	0.88	0.88	0.72	0.68	0.81	0.68	1.04	0.59	0.77

Table 4: Nitrate – N Concentration (mg/L) in Springs, 1999 - 2001

Comparing land use of the two areas, the SW area has a combined agricultural land-use area of approximately 80% as opposed to 45% for the NE area; in fact the area under row crop cultivation (a process that uses more fertilizer) is approximately equal to the total agricultural area of the NE (Figure 40). A higher nitrate concentration in runoff and groundwater from the SW area is to be expected (Boyer and Alloush, 2001). Also, the basin with the lowest median value in each area (Brelsford in SW, Head of Wolf in NE) is the basin with the greatest amount of *Forest* (either deciduous, mixed, or woody wetlands), indicating that, although nitrate is present naturally, the elevated nitrate numbers in the other areas result primarily from agricultural land use. High and low median values of nitrate-N in each study area are listed below along with percentages of agricultural land use. These figures reinforce the contention that elevated nitrate-N is due to more intensive agriculture.

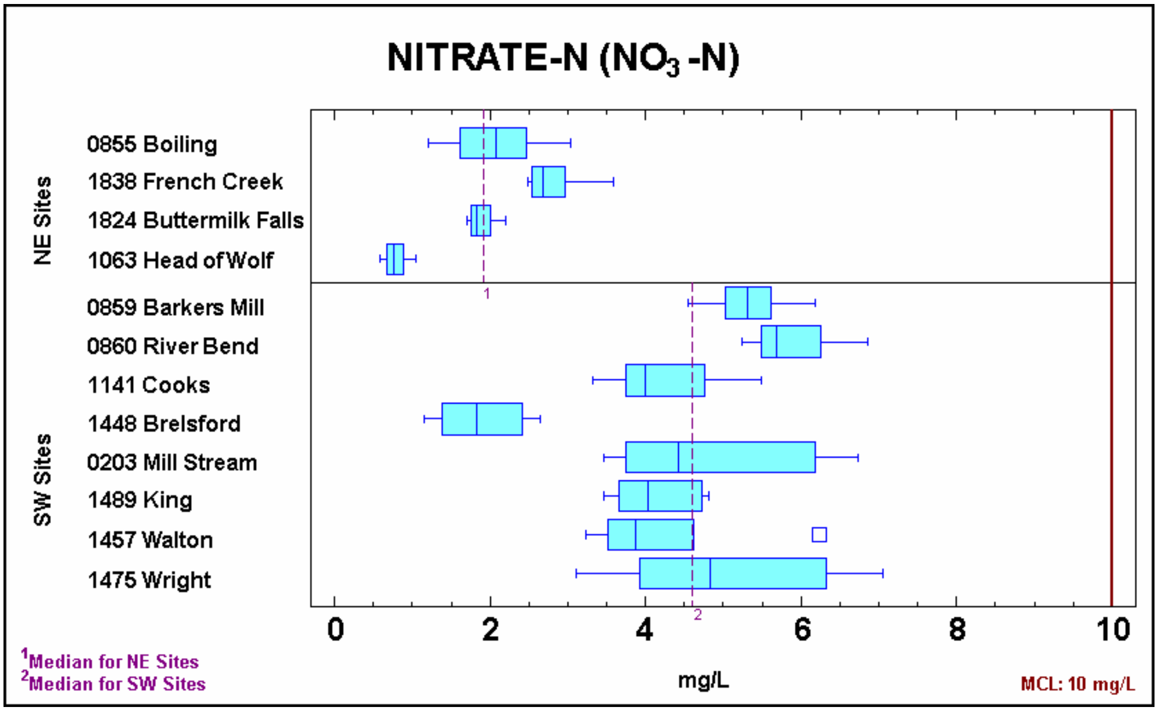

Figure 39: Boxplots of Nitrate-N Concentration in Springs; MCL equals 10 mg/L

Median Nitrate-N in SW:
Low: 1.82 mg/L @ *Brelsford*
(Total Ag: 65.4% - 52.2% Pasture and Hay, 13.2% Row Crops)

High: 5.69 mg/L @ *River Bend*
(Total Ag: 87.7% - 44.3% Pasture and Hay, 43.4% Row Crops)

Median Nitrate-N in NE:
Low: 0.77 mg/L @ *Head of Wolf*
(Total Ag: 27.9% - 12.7% Pasture and Hay, 15.2% Row Crops)

High: 2.69 mg/L @ *French Creek*
(Total Ag: 67.9% - 43.9% Pasture and Hay, 24.0% Row Crops)

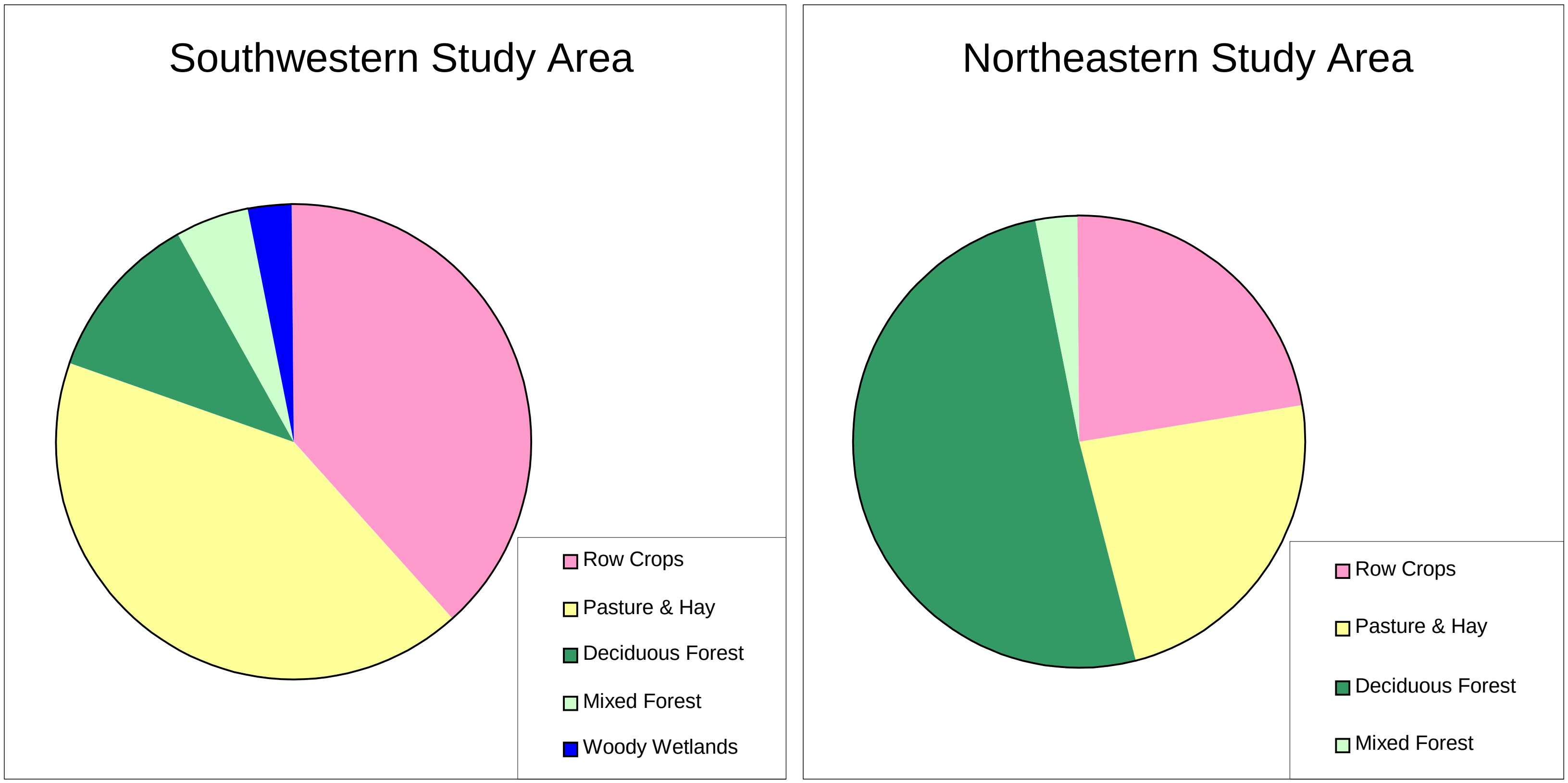

Figure 40: Pie-Chart Comparison of Primary Land Cover Types within the two Study Areas

Nitrite

Nitrite (NO_2-N) also occurs naturally from many of the same sources as nitrate. Nitrite, however, is an unstable ion and is quickly converted to nitrate in the presence of free oxygen. Nitrite is reported either as the complex ion NO_2, or as the equivalent molecular nitrogen-N. The MCL for nitrite-N is 1 mg/L. Nitrite is not a significant nonpoint source pollutant, although it may contribute to high levels of nitrate. Within the study areas, only one spring basin (Wright) has consistent detections of nitrite and even those concentrations are low (Figure 41). The median values of both study areas are essentially identical which indicates that nitrite either is nearly nonexistent or that it does not persist in groundwater within these aquifers, but is rapidly converted to nitrate. The anomalous Wright Spring consists of nearly 90% agricultural land use and may have greater concentrations of nitrite simply because there is so much more available from runoff that conversion to nitrate cannot keep pace with the total amount coming into the water system.

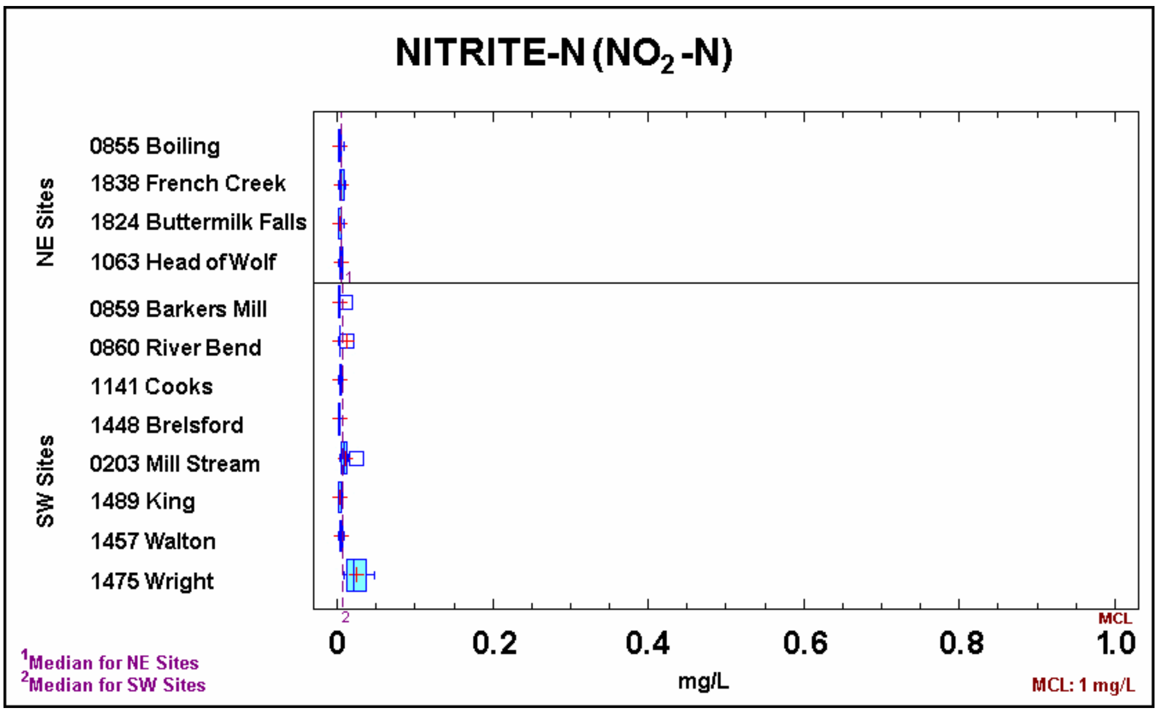

Figure 41: Boxplots of Nitrite-N Concentration in Springs

Ammonia

Ammonia (NH_3) occurs naturally in the environment, primarily from the decay of plants and animal waste. The principal source of man-made ammonia in groundwater is from ammonia-based fertilizers. No drinking water standards exist for ammonia, however, the risk-based number calculated by the Kentucky Department for Environmental Protection for tap water is

0.110 mg/L. Only three springs had any detections of ammonia during the course of the study (Figure 42), and only one (Mill Stream Spring) was near the DEP limit of 0.110 mg/L.

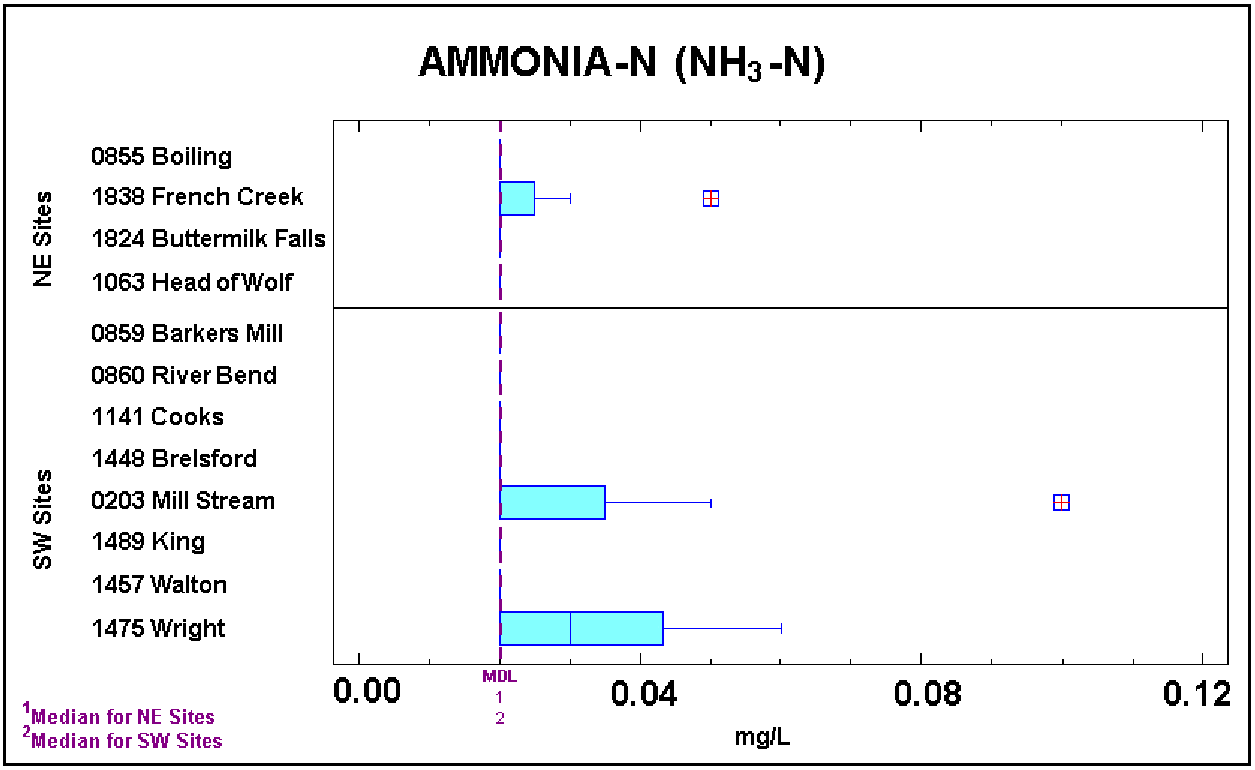

Figure 42: Boxplots of Ammonia Concentration in Springs

Phosphorus

Phosphorus (P) is a common constituent of rocks, especially the carbonate rocks of Kentucky. However, inorganic phosphorus has a low solubility and readily adsorbs onto soil particles, so availability in groundwater is limited. Phosphorus is a constituent in phosphate fertilizers, sewage, and animal waste. Phosphorus contributes to the eutrophication of surface water, by encouraging "algal blooms" and the subsequent reduction of dissolved oxygen. This problem can especially affect lakes and sluggish streams, as well as conjunctive surface water/groundwater systems such as karst. Two forms of phosphorus are discussed in this report: orthophosphate and total phosphorus. Neither orthophosphate nor total phosphorus has a drinking water standard. For the purposes of this report, total phosphorus data are compared to the surface water limit of 0.1 mg/L recommended by the USGS.

Ortho-P

Orthophosphate-P (PO_4-P), or simply "orthophosphate," or "ortho-P," is the final product of the dissociation of phosphoric acid, H_3PO_4. It occurs naturally in the environment most often as the result of the oxidation of organic forms of phosphorus and is found in animal waste and detergents. In most pristine natural systems orthophosphate occurs at very low levels (<0.01 mg/L). Orthophosphate is the most abundant form of phosphorus, usually accounting for about 90% of the total available phosphorus.

Local geology controls some natural variation of total phosphorous in waters. Phosphate and nitrogen are limiting nutrients. An increased availability of the limiting nutrient (organic enrichment) results in eutrophic conditions in lakes and streams. Generally, total phosphorous above 0.1 mg/L has been considered a threshold at which deleterious effects occur, though in some areas (e.g. the mountainous regions of eastern Kentucky, the Outer Bluegrass, the Pennyroyal) this threshold is probably significantly lower.

Figure 43 shows that orthophosphate concentrations are generally higher in the more intense agricultural areas. However, land use alone may not account for the higher orthophosphate concentrations in Boiling and French Creek springs. Farmers in those areas may prefer and preferentially use phosphate-based fertilizers, however, other factors unknown to the authors may also affect orthophosphate levels.

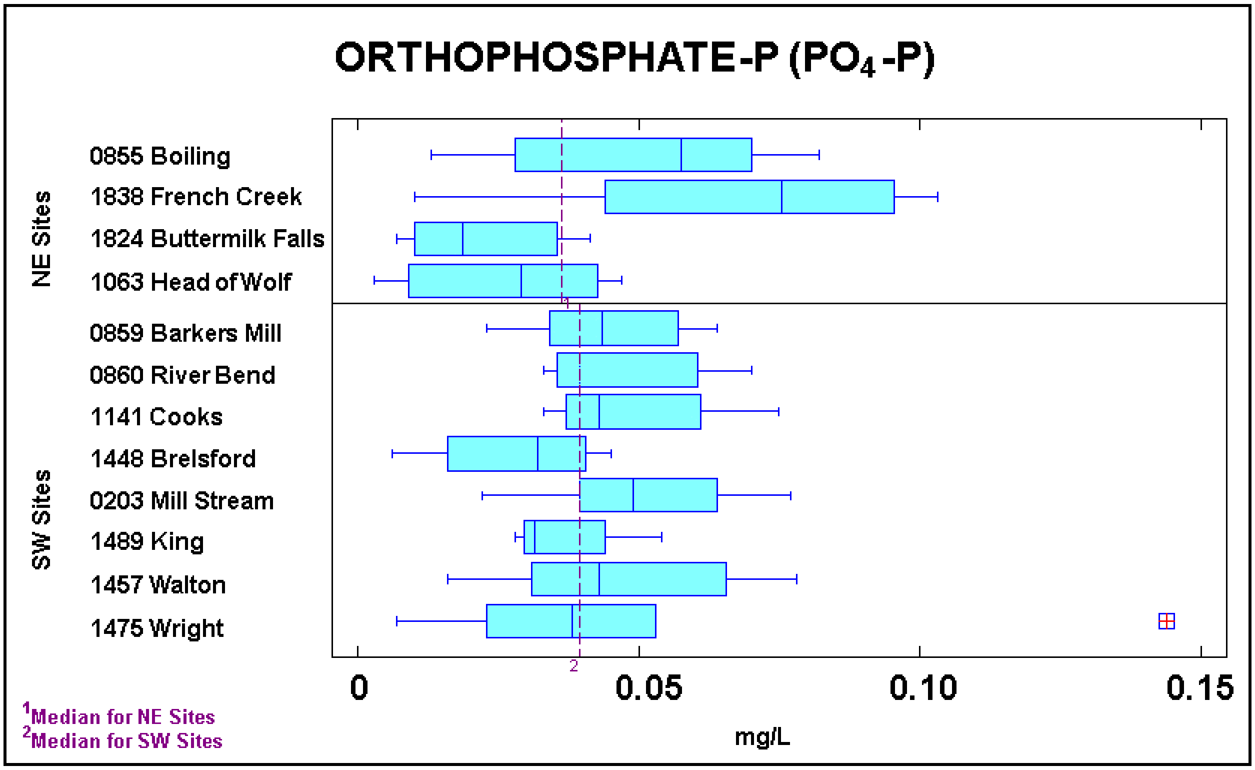

Figure 43: Boxplots of Orthophosphate-P Concentration in Springs

Total Phosphorus

Total phosphorus (P or Total-P) is the sum of organic and inorganic forms of phosphorus. During the course of this investigation, the MDL for P changed several times. Some of the MDLs were above the standard being used while some were below. Given the changes in MDL, the results are impossible to interpret in any meaningful fashion. Therefore no boxplot is shown. Total-P was detected at all sites, and only exceeded the 0.1 mg/L standard three times. Nevertheless, these data suggest that phosphorus may be entering these groundwater systems in enough quantity to be of concern from a human health standpoint. Further investigations, with newer methods of detection, are recommended for both areas.

Total Dissolved Solids

Total Dissolved Solids (TDS) measures the solids remaining in a water sample filtered through a 1.2 µm filter. According to the World Health Organization (WHO, 1996), the compounds and elements remaining after filtration are commonly calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulfate, silica and nitrate-n. High TDS affects the taste and odor of water and in general, levels above 300 mg/L become noticeable to consumers. As TDS increases, the water becomes increasingly unacceptable. Although the SMCL for TDS is 500 mg/L, levels above 1200 mg/L are unacceptable to most consumers. Because TDS measurements may include a variety of parameters, which can be naturally occurring or anthropogenic, its value as an indicator of nonpoint source pollution is limited. Median values of TDS were found below the SMCL of 500 mg/L and no value exceeded the SMCL (Figure 44).

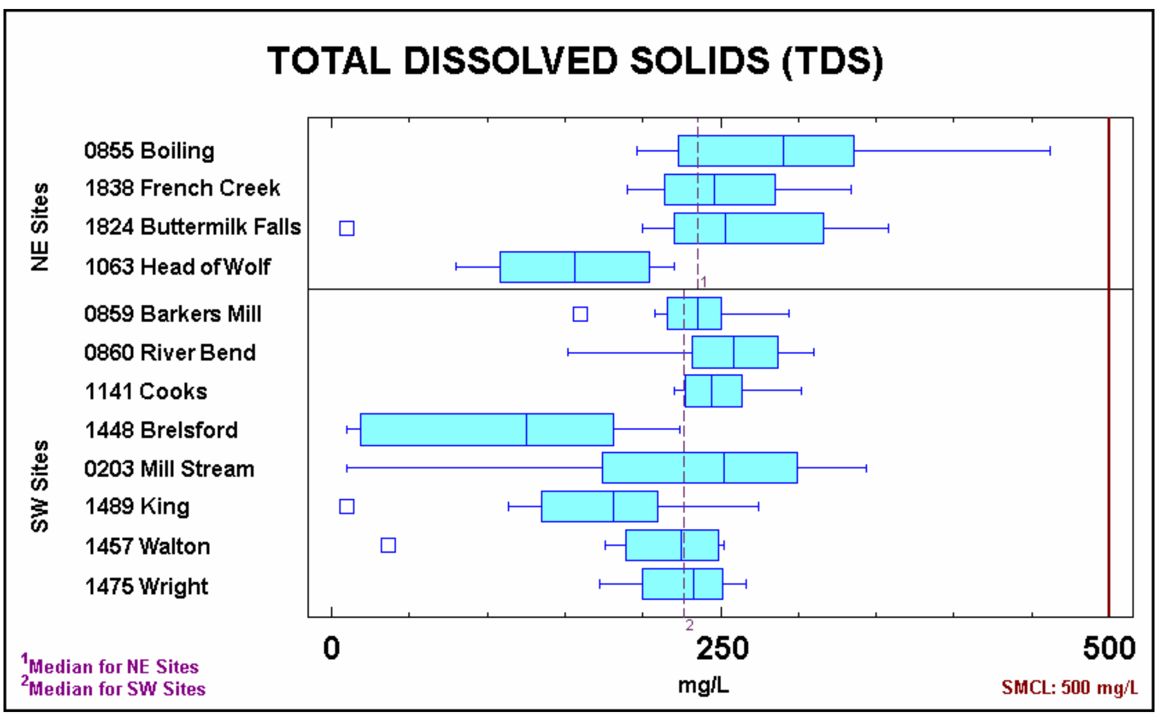

Figure 44: Boxplot of Total Dissolved Solids (TDS) in Springs

TDS was surprisingly low in the Mississippian Plateau, especially considering that this is soluble carbonate terrane. One possible explanation is that the quick flow characteristics of this region reduce the contact time between water and rock, thereby retarding dissolution. In general, TDS is not usually an important primary indicator of nonpoint source pollution of groundwater, although this parameter can serve as a surrogate indicative of general water quality. Because no probable sources for elevated TDS were noted adjacent to sampling sites, no nonpoint source impacts could be confirmed. Figure 44 shows higher values in the Boiling Springs Basin. These higher values are probably natural, perhaps resulting from longer residence times or dissolution of gypsum beds.

Total Suspended Solids

Total Suspended Solids (TSS), also known as non-filterable residue, are those solids (minerals and organic material) that remain trapped on a 1.2 μm filter (EPA, 1998). Suspended solids can enter groundwater through runoff from industrial, urban, or agricultural areas. Elevated TSS (MMSD, 2002) can ". . . reduce water clarity, degrade habitats, clog fish gills, decrease photosynthetic activity and cause an increase in water temperatures." TSS has no drinking water standard.

Most TSS values occurred within a narrow range, but three elevated measurements, above 45 mg/L, did occur (Figure 45). Within most karst systems, turbidity and TSS vary with change in flow. However, poor management practices associated with activities such as construction and agricultural tillage can remove vegetation cover and allow the quick influx of sediment into karst groundwater via overland flow and internal runoff. Therefore, outliers in the karst of the Mississippian Plateau may represent nonpoint source impacts. However, in the case of Boiling Spring, which generally contained the highest TSS levels, no significant correlation was found between land use and TSS. Although impacts from construction activities and agricultural tillage may be considered transient, cumulative sediment deposition within conduit systems and surface drainage networks is clearly a detriment to the aquatic system.

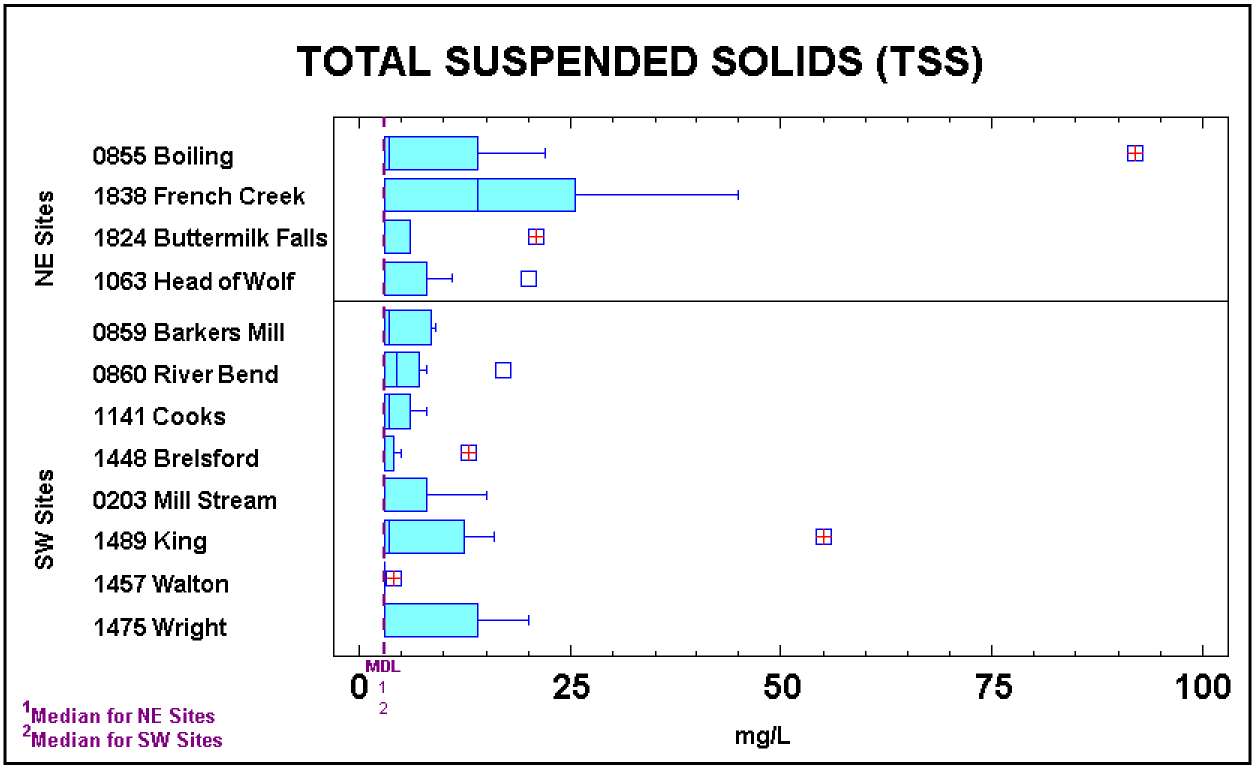

Figure 45: Boxplot of Total Suspended Solids (TSS) in Springs

pH

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

The greatest variability is in the southwest study area, with the median value at 7.35 and the outliers ranging from 6.75 to 8.15 pH units. The pH ranges tend to be slightly higher in the northeast study area, with a median value of 7.76. All values were within the SMCL range of 6.5-8.5 pH units (Figure 46). Buttermilk Falls precipitates tufa deposits, which indicate that the spring water is saturated with carbonate. This would account for the pH values at Buttermilk

Falls, which were generally higher than other sites. Consequently, no nonpoint source impacts can be interpreted from these pH data.

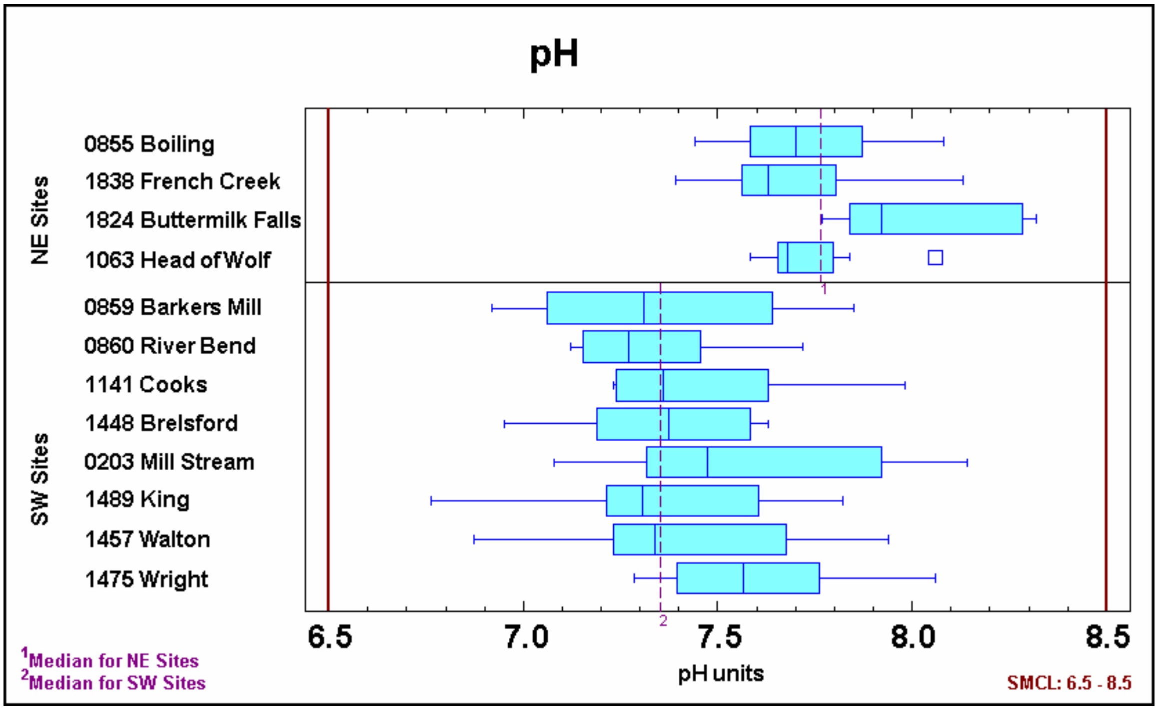

Figure 46: Boxplot of Spring-Water pH

Chloride

Chloride (Cl) is naturally occurring in most rocks and soils and is the primary constituent that makes water "salty". Chloride also occurs in sewage, industrial brines, and in urban runoff from the application of road de-icers. Chlorides may be associated with crude oil and are commonly produced as a by-product of oil production. For disposal, these brines are typically re-injected into very deep and already briny formations. However, chloride-rich brines can contaminate freshwater aquifers through improperly cased or abandoned oil-production wells. In general, the boxplots for chloride (Figure 47) shows low chloride values in the Mississippian Plateau Study areas. The SMCL for chloride is 250 mg/L and all the values for this study are 20 or more times less than the SMCL. Therefore, no apparent nonpoint source impacts can be interpreted from chloride data.

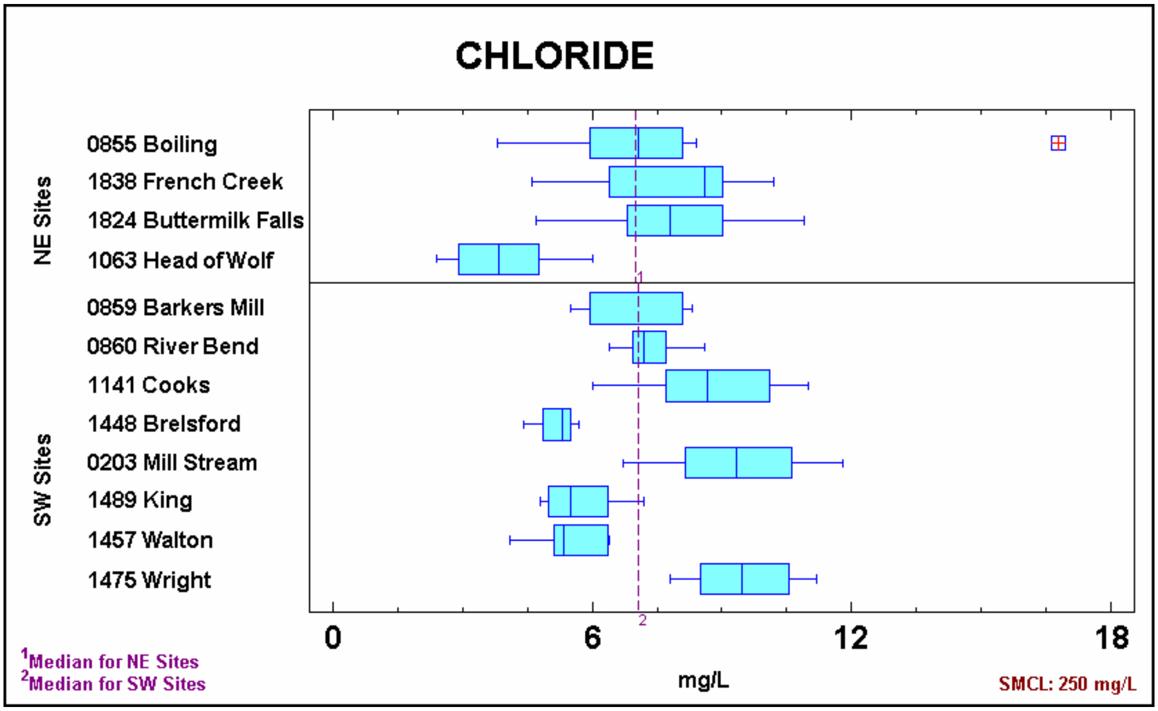

Figure 47: Boxplot of Chloride Concentration in Springs

Sulfate

Sulfate (SO_4) typically dissolves into groundwater from gypsum (hydrous calcium sulfate) and anhydrite (calcium sulfate), from the oxidation of iron sulfides, such as pyrite (FeS) and from other sulfur compounds. Sulfate has an SMCL of 250 mg/L and greater levels impart distasteful odor and taste to the water and commonly have a laxative effect. In the project area sulfate is common and naturally occurring, and therefore it is not easy to use as an indicator of nonpoint source pollution. In general, Figure 48 illustrates a narrow range of sulfate values, well under the SMCL.

The sulfate levels at Boiling Springs were the highest in this study but were still well below the SMCL. About 35% of Boiling Spring's basin includes sandstone caprocks, which may be a source of the relatively higher sulfate levels. Other springs with relatively higher sulfate include French Creek Spring and Head of Wolf Creek Spring in the NW, and Mill Stream Spring in the SW. Like Boiling Spring, these three springs also contain some sandstone rocks within their catchments.

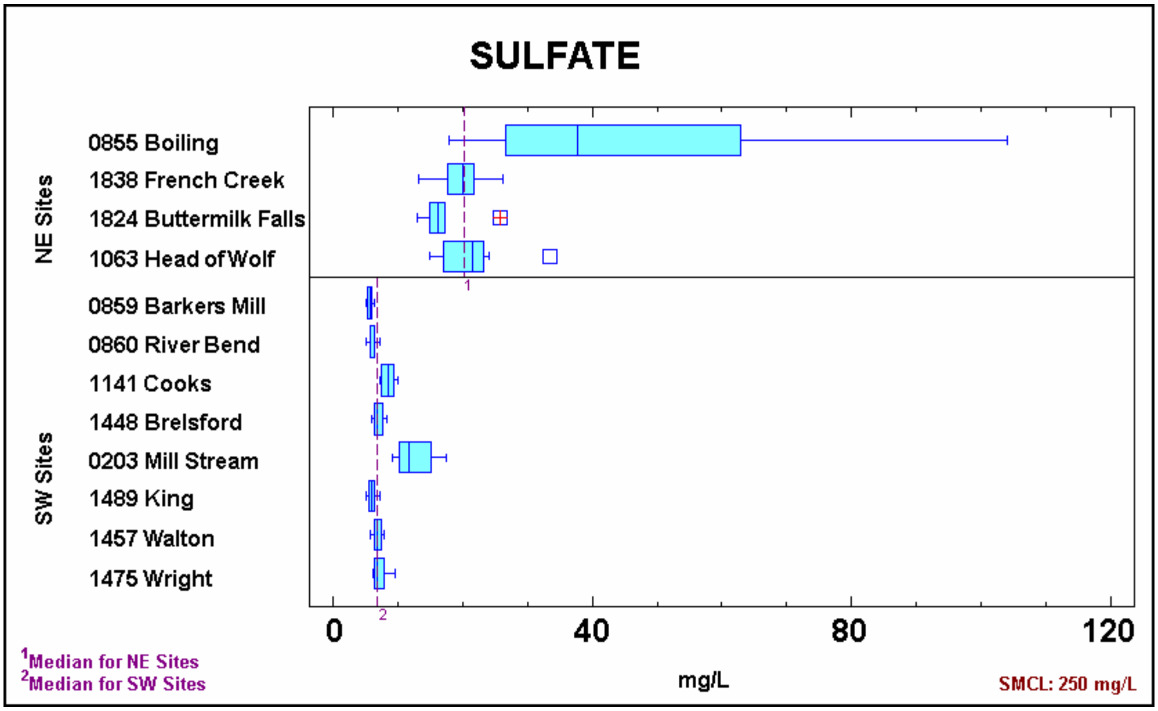

Figure 48: Boxplot of Sulfate Concentration in Springs

Total Organic Carbon

Total organic carbon (TOC) is the measure of organic material in water. Organic matter plays a major role in aquatic systems. Organic matter in water consists of thousands of components, including macroscopic particles, colloids, dissolved macromolecules, and specific compounds. It affects biogeochemical processes, nutrient cycling, biological availability, chemical transport, and interactions. It also has direct implications in the planning of wastewater treatment and drinking water treatment. Organic matter content is typically measured as TOC and dissolved organic carbon, which are essential components of the carbon cycle.

Public water supplies can form trihalomethanes and haloacetic acids at unacceptable levels when they use chlorine to disinfect source waters with TOC levels above 4.0 mg/L. Most sample values were below the 4.0 mg/L value (Figure 49). One outlier at Boiling Springs from May, 2001, exceeded 22 mg/L. The source of this anomaly is unknown. Runoff from a livestock feedlot or manure spreading is a possible source of this relatively high TOC value.

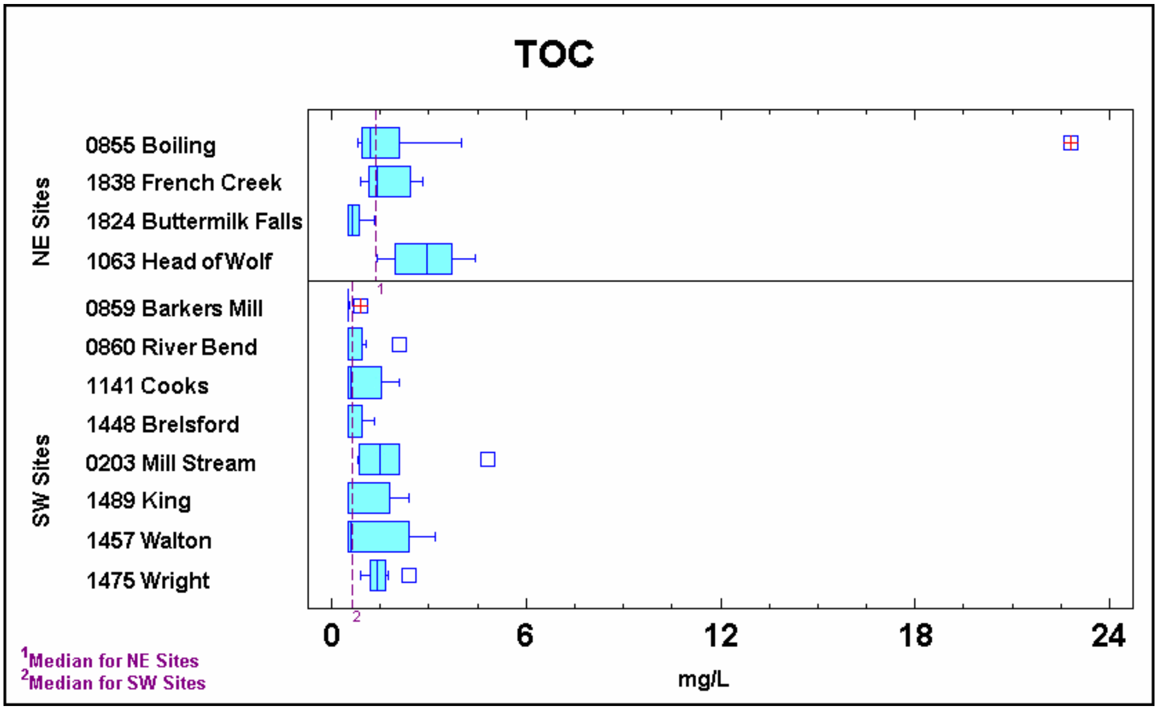

Figure 49: Boxplot of Total Organic Carbon (TOC) in Springs

Pesticides

Pesticides are not naturally occurring and are therefore good indicators of nonpoint source impacts to groundwater. The most common pesticide detected in spring waters of both study areas was atrazine. Low levels of acetochlor, metolachlor, simazine, alachlor, and metribuzin were occasionally detected as well. These are all agricultural herbicides and are briefly described below.

Atrazine

According to Division of Pesticides agriculture sales data for 1999 and 2000, approximately two million pounds of atrazine was purchased for use in Kentucky during each of those years. Atrazine was the number one pesticide sold (by weight) in both years. Although sales data does not translate directly into use data, a significant amount of that two million pounds was used during the study period.

Atrazine is an odorless, white powder made in a laboratory. Atrazine is not very volatile, reactive, or flammable, and is only moderately soluble in water. However, because atrazine does not adsorb strongly to soil particles and has a lengthy half-life (60 to >100 days), it has a high potential for groundwater contamination despite its moderate solubility in water. Atrazine is used on crops such as sugarcane, corn, sorghum, and on evergreen tree farms and for evergreen forest regrowth. It has also been used to keep weeds from growing on both highway and railroad rights-of-way. Atrazine can be sprayed on croplands as a pre-emergent before crops start growing, and after they have emerged from the soil. Some of the trade names of atrazine are Aatrex®, Aatram®, Atratol®, and Gesaprim®. The scientific name for atrazine is 6-chloro-N-ethyl-N'-(1-methylethyl)-triazine-2,4-diamine. Atrazine is a restricted-use pesticide, which means that it requires use by a certified pesticide applicator or under of the direct supervision of a certified applicator and strict records on its use and application are required (Ernest Collins, personal communication, 2002). The EPA has set an MCL value of 0.003 mg/L for atrazine in drinking water.

KGS analyzed for atrazine, using the nitrogen phosphorus detector (NPD) method, at a minimum detection limit (MDL) of 0.0003 mg/L. Atrazine was detected above the MDL in 26% of 95 samples. These detections only occurred in the April & May samples and are associated with infiltration and runoff recharge during the pesticide application season (Figure 50). Atrazine was detected above EPA's Maximum Contaminant Level (MCL) of 0.003 mg/L, seven times at six springs (8% of the samples). Values near the MCL at two additional springs ranged between 0.00294 and 0.00299 mg/L. The highest level of atrazine was from Walton Spring at **0.0119** mg/L, almost four times the MCL. This was the only spring to exceed the MCL on two separate dates, in the spring of 1999 and 2000 (Table 5 and Figure 51). The DEP uses a risk-based standard for atrazine of 0.00067 mg/L. Atrazine was detected above the risk-based standard in 20 of 95 samples or 21%.

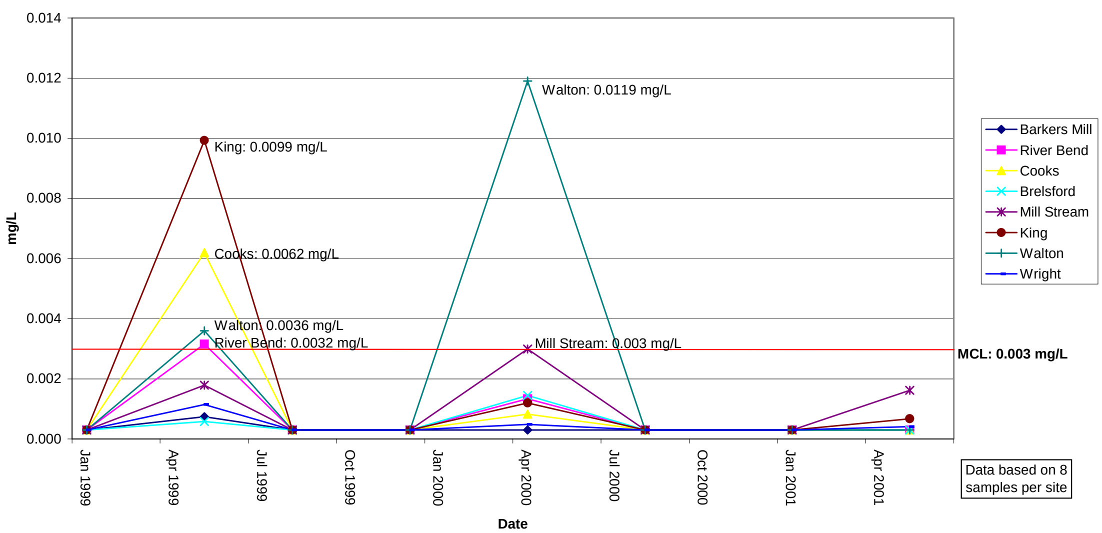

Figure 50: Atrazine Concentration (mg/L) at Springs in SW Study Area, Showing Detections during Spring-Time Application Season

Flow Condition	Moderate	Moderate	Low	Low	Moderate	Low	Low	Moderate
Sample Date (SW)	**1/19/99 & 1/20/99**	**5/17/99 & 5/18/99**	**8/24/99 & 8/25/99**	**12/08/99 & 12/09/99**	**4/26/00 & 4/27/00**	**8/22/00 & 8/23/00**	**1/09/01 & 1/10/01**	**5/15/01 & 5/16/01**
Spring (SW)								
River Bend	ND	**0.00315**	ND	ND	0.00134	ND	ND	ND
Barkers Mill	ND	0.00074	ND	ND	ND	ND	ND	ND
Wright	ND	0.00115	ND	ND	0.00048	ND	ND	0.00041
Mill Stream	ND	0.00179	ND	ND	0.00299	ND	ND	0.00162
King	ND	**0.00993**	ND	ND	0.0012	ND	ND	0.00067
Cook	ND	**0.00615**	ND	ND	0.00083	ND	ND	ND
Walton	ND	**0.00360**	ND	ND	0.0119	ND	ND	ND
Brelsford	ND	0.00059	ND	ND	0.00145	ND	ND	ND

Sample Date (NE)	**1/27/1999**	**5/11/1999**	**8/25/1999**	**12/1/1999**	**4/26/2000**	**8/23/2000**	**1/10/2001**	**5/15/2001**
Spring (NE)								
French Creek	ND	**0.00675**	ND	ND	ND	ND	ND	ND
Boiling	ND	0.00067	ND	ND	ND	ND	ND	0.00055*
Buttermilk Falls	ND	**0.00393**	ND	ND	-	ND	0.0012	0.00206
Head of Wolf	ND	0.00294	ND	ND	ND	ND	ND	ND

ND = Non-detection of atrazine (MDL = 0.0003 mg/L); **Corrected from 0.55 on 7/2/07*
Bold values are above MCL of 0.003 mg/L

Table 5: Atrazine Concentrations (mg/L) in Springs, 1999-2001

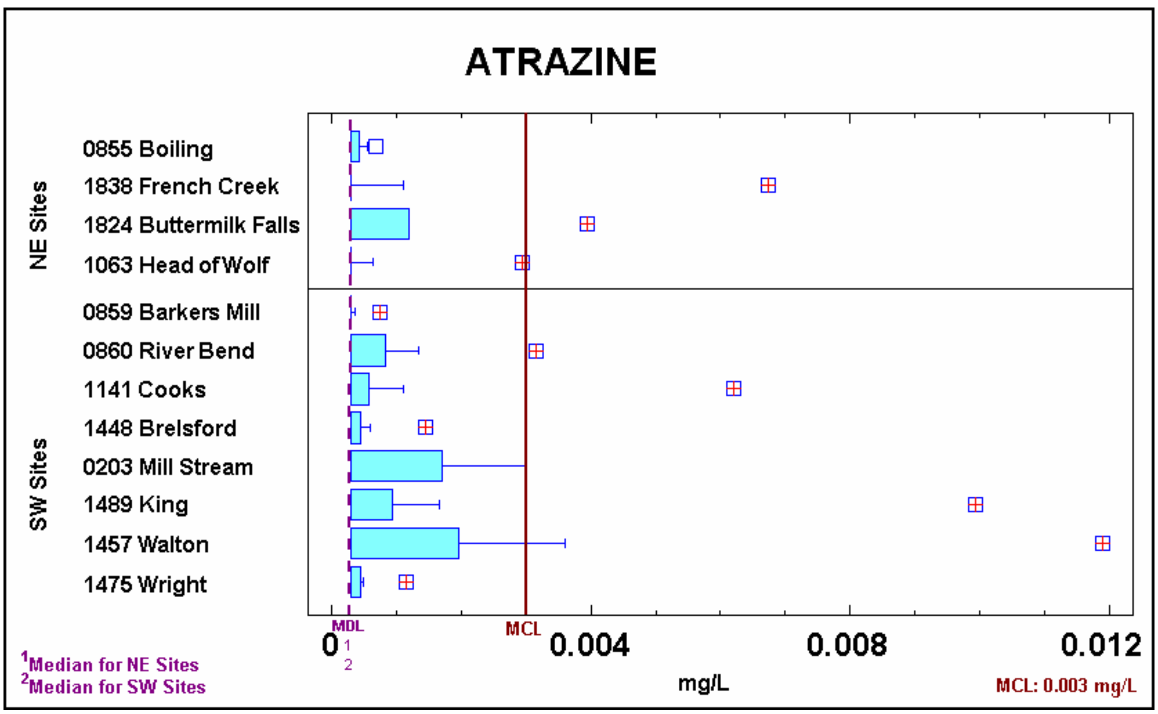

Figure 51: Boxplot of Atrazine Concentration in Springs

Pleasant Grove Spring in Logan County, Kentucky, which drains a hydrogeologic setting similar to the springs in the SW study area, was intensively sampled for nonpoint source contaminants during the early 1990's (Currens 1999). A low-level background of atrazine in the range of 0.00005-0.0003 mg/L was documented for this spring with the only non-detection occurring in February. Low levels of atrazine are likely to persist year-round in most karst springs draining agricultural basins where atrazine is applied (James Currens, personal communication, 2002). Halberg and others (1985), reported year-round levels of atrazine at or above 0.0002 mg/L at Big Spring in northeast Iowa.

A five-month study of eight karst springs in the Green River basin by the USGS (Crain, 2002) detected atrazine in 100% of 59 monthly samples at a low MDL of 0.000007 mg/L. Thirteen of 59 samples, or 22% of those samples were above the KGS laboratory MDL value of 0.0003 mg/L (Angela Crain, personal communication, 2002), which is similar to 26% detection above 0.0003 mg/L in this study).

Quarterly samples (the design frequency of this study) obviously do not reveal the range of variation of pesticide concentration discharged by a karst spring. Currens (1999) showed that with monthly and storm event sampling, higher levels of atrazine are periodically flushed from karst springs draining agricultural basins. The highest atrazine value recorded at Pleasant Grove Spring was 0.028 mg/L (5-4-93) "during a major high-flow event following an extended dry period during planting season" (Currens, 1999). Inferring that similar karst will act the same hydrologically, the two studies above indicate that all karst springs in this study are discharging significant levels of atrazine during spring floods, possibly up to an order of magnitude above MCL during those brief periods, and these same springs are most likely discharging currently undetectable levels of atrazine on a continuing basis.

Other Herbicides Detected

Acetochlor

Acetochlor is used for control of most annual grasses and certain broadleaf weeds. Crops include cabbage, corn (all types), cotton, green peas, onion, orchards, potatoes, rape, soybeans, sugarbeets, sugarcane, sunflower, and vineyards. Acetochlor is applied pre-emergence, pre-plant incorporated and is compatible with most other pesticides and fluid fertilizers when used at recommended rates. Usually 0.3-0.6 inches of rainfall will activate the product if it occurs within 7-10 days. Acetochlor, like atrazine, is a restricted-use pesticide.

Acetochlor was the number five best seller on the Division of Pesticides List of Pesticides Sold during 1999 and number six in 2000. However, it was only detected once at Buttermilk Falls in the NE area in January of 2000.

Metolachlor

Because of the slow microbial and anaerobic degradation rates of this chemical and its ability to leach through soil, metolachlor has the potential to contaminate groundwater. Trade names for products containing metolachlor include Bicep®, CGA-24705®, Dual®, Pennant®, and

Pimagram®. The compound may be used in formulations with other pesticides (often herbicides that control broad leaved weeds) including atrazine, cyanazine, and fluometuron.

Metolachlor was the number three best selling pesticide in Kentucky (by weight) in both 1999 and 2000. Approximately 800,000 pounds were sold in 1999 and approximately 650,000 pounds of the pesticide were sold during 2000. Although metolachlor was detected in 8.5% of the samples, none was detected at very high levels. Metolachlor does not have an MCL, but does have a HAL limit of 0.1 mg/L. None of the samples with metolachlor detections reached half of the HAL (0.05 mg/L). Only one sample from the NE study area contained metolachlor (Head of Wolf Spring during the May 1999 sampling event). The SW area, however, showed detections at five springs (River Bend, May '99; Cooks Spring, May '99; Mill Stream May '99 and May '01; King May '99; and Walton Spring May '99 and April '00) (Figure 51). The highest concentration detected was at Walton Spring in April of 2000 at 0.001901 mg/L.

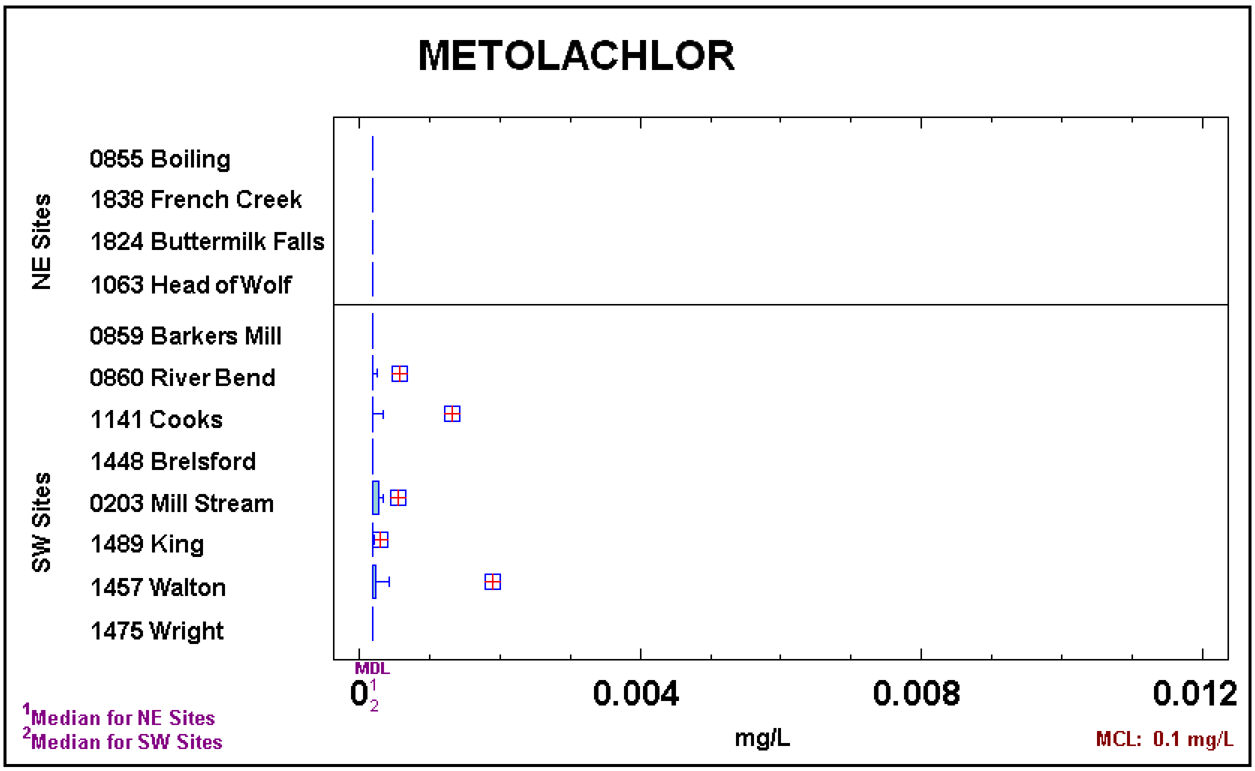

Figure 52: Boxplot of Metolachlor Concentration in Springs

Simazine

Simazine is an organic white solid, used as a pre-emergence herbicide used for control of broad-leaved and grassy weeds on a variety of deep-rooted crops such as artichokes, asparagus, berry crops, broad beans, citrus, etc., and on non-crop areas such as farm ponds and fish hatcheries. Its major use is on corn where it is commonly combined with Atrex® (which contains atrazine). The MCL for simazine is 0.0004 mg/L.

Simazine was detected in 11.5% of the samples, but none was detected above the MCL nor even above ½ the MCL. The highest concentration of simazine was detected at 0.0000016 mg/L in Mill Stream Spring in April of 2000 (it was also detected in May of 2001 at a lower concentration). Detections on more than one occasion occurred at other springs during the study period as well (Buttermilk Falls in May of ’99 and May of ’01; and River Bend in May ’99 and April ’00) (Figure 53). However, simazine was not detected in either study area as a persistent contaminant.

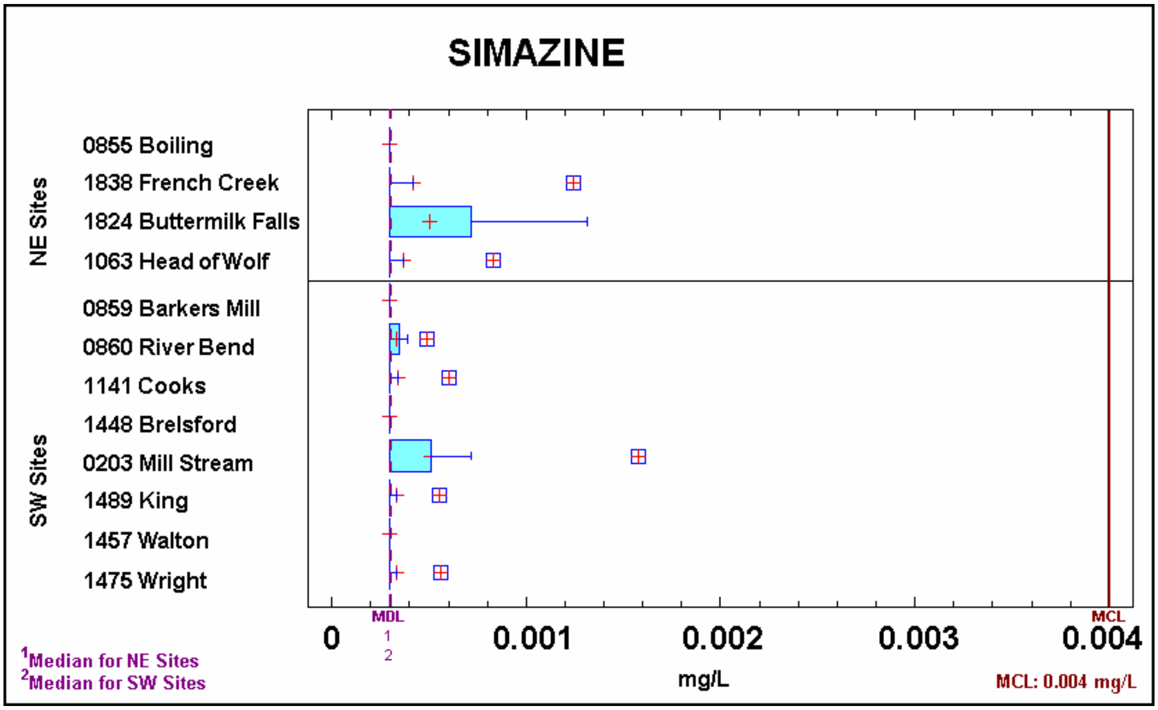

Figure 53: Boxplot of Simazine Concentration in Springs

Metribuzin

Metribuzin is a selective triazinone herbicide, which inhibits photosynthesis. It is used for control of annual grasses and numerous broadleaf weeds in field and vegetable crops, in turf grass, and on fallow lands. Metribuzin is highly soluble in water and has a low tendency to adsorb to most soils. Metribuzin is considered to be one of a group of pesticide compounds that has the greatest potential for leaching into, and contaminating, groundwater. Metribuzin was only detected once at Wright spring in the SW study area (5-18-99), just above the MDL. The high solubility of metribuzin and only a single detection in this study indicate that metribuzin is not likely to contaminate groundwater for long periods of time. Pulses of water coming through the system as a result of a rain event may wash some unmetabolized metribuzin into the groundwater, however.

Alachlor

Alachlor (trade names include Bullet® and Micro-Tech®) is used for corn and soybean production for pre-emergent weed control. Alachlor has an MCL of 0.002 mg/L. Alachlor has been associated with cancer in humans and has also been linked with noncancerous effects in the liver, spleen and kidneys. Alachlor occurred at only one site in this study and it was well below the MCL. Alachlor was found at Buttermilk Falls in the NE study area. Based upon its limited occurrence, alachlor has apparently had minor impacts on groundwater in this area.

Summary Statistics

A tabular summary of water quality analyses is provided in Appendix C. The initial table lists 16 *parameters* with *applicable water quality standards*. This table also provides *Total Number of Samples, Samples <MDL, Samples With Detects, Detects >Standard,* and *Detects >1/2 Standard.* For each parameter *Minimum, Median, Maximum,* and *Interquartile Range* are provided for individual springs, including study totals. Also, totals are separately provided for the NE and SW study areas.

RANKING OF NONPOINT SOURCE POLLUTION IN SPRING BASINS

We propose that the following approach be used to address NPS issues in karst systems. The twelve sampled karst springs were ranked and prioritized based on water quality and land use. These rankings were based on twelve weighted parameters. A weighted average was calculated by assigning weights to each parameter according to its relative importance in generating nonpoint source pollution. Since metolachlor, simazine, and alachlor were detected minimally during the study, their combined importance was considered equivalent to that of the other water quality parameters. Thus, they were assigned 1/8th (or 5/40) of the importance, divided among the three (or 2/40, 2/40, and 1/40). The other five water quality parameters were assigned ranks of relative importance equivalent to 1/8th. The eight water quality components included: atrazine (5/40), metolachlor (2/40), simazine (2/40), alachlor (1/40), nitrate-N (5/40), orthophosphate (5/40), total organic carbon (5/40), and total suspended solids (5/40).

Four land use components included: row crops (6/40), pasture and hay (4/40), urban (2/40), and forest (-2/40). Because both nutrients and pesticides may be applied to row crops, it was considered the highest-rated land-use component, whereas pasture and hay could be considered a less intensive land use. Urban/residential land use is minimal in the predominantly rural study areas. The only basin to exceed 3% of this type land use was Buttermilk Falls Spring with 5.1%. Even though urban runoff can yield significant nonpoint source pollution, it was ranked low because of minimal spatial occurrence in the two study areas. Forest is the only land use to be expressed with a negative weighting, which lowers the priority rating relative to nonpoint source pollution. Karst basins with greater forested land cover typically exhibit the best water quality, Brelsford Spring for example. The above criteria are organized by class in Table 6.

Weight	*Class*	*Individual Parameter Weights*
10/40	Pesticides	Atrazine (5); Metolachlor (2); Simazine (2); Alachlor (1)
10/40	Nutrients	Nitrate-N (5); Ortho-P (5)
10/40	Other Parameters	Total Organic Carbon (5); Total Suspended Solids (5)
10/40	Land Use	Row Crop (6); Pasture & Hay (4); Urban (2); Forest (-2)

Table 6: Criteria for Karst Basin Priority Ranking

Average ranks yielded from the Kruskal-Wallis test (Hollander and Wolfe, 1973) were used to assign ranks for the springs from smallest to largest based on concentrations of the parameters considered as well as type and percentage of land use. These 12 average parameter ranks were then weighted and summed for each spring, and the sums ordered from highest to lowest. An overall ordinal ranking for water quality, based on concentration and land use, was assigned to each spring according to the spring's position in this ordering with **1** indicating the highest priority (poorest water quality), and **12** indicating the lowest priority (best water quality). The relative weighted-value scores are shown for each spring in Table 7.

Rank	*Spring*		*Weighted Value*
	Southwest	*Northeast*	
1	River Bend		9.15
2	Wright		8.83
3	Mill Stream		7.83
4	King		7.53
5	Cooks		7.10
6	Barkers Mill		6.88
7		French Creek	6.88
8	Walton		6.53
9		Boiling	5.68
10		Buttermilk Falls	4.05
11		Head of Wolf	4.00
12	Brelsford		3.58

Table 7: Nonpoint-Source Pollution Priority Ranking of Twelve Sampled Karst Springs

Correlation of Water Quality of Springs with Land Cover

Nitrate-N

The distribution of nitrate-N concentration was nearly normally distributed (Shapiro-Wilk (w) = 0.97, p = 0.0272). The strong positive correlation between nitrate-N concentration and percentage of agricultural land was significant (Pearson correlation coefficient (r) = 0.81, p <

0.0001). The relationship between nitrate-N concentration and percentage of row crop land use ($r = 0.80$, $p < 0.0001$) was stronger than that between nitrate-N concentration and percentage of pasture land ($r = 0.55$, $p < 0.0001$). The strong inverse relationship between nitrate-N concentration and percentage of forested land was also significant ($r = -0.81$, $p < 0.0001$). Regionally, stronger positive correlations between nitrate-N concentration and percentage of agricultural land were observed in the NE region ($r = 0.74$, $p < 0.0001$) than in the SW region ($r = 0.64$, $p < 0.0001$).

In the NE region, correlation between nitrate-N concentration and percentage of pasture land ($r = 0.71$, $p < 0.0001$) was stronger than that between nitrate-N concentration and percentage of row crop land use ($r = 0.61$, $p = 0.0002$). A strong inverse relationship between nitrate-N concentration and forested land ($r = -0.81$, $p < 0.0001$) was also observed.

In the SW region, a moderate positive correlation was observed between nitrate-N concentration and agricultural land ($r = 0.64$, $p < 0.0001$), while a moderate inverse relationship was observed between nitrate-N concentration and forested land ($r = -0.63$, $p < 0.0001$). A moderate positive correlation between row crop land use ($r = 0.64$, $p < 0.0001$) was observed, but no significant correlation between nitrate-N concentration and pasture land existed in this region.

Regression analysis showed that 65% of the variability in nitrate-N concentration in the entire study area (NE and SW combined) could be attributed to agricultural land use ($R^2 = 0.65$, $p < 0.0001$), 64% attributed to row crop usage ($R^2 = 0.64$, $p < 0.0001$), and 67% to forested land ($R^2 = 0.67$, $p < 0.0001$). Regionally, 55% of the variability in nitrate-N concentration in the NE region could be attributed to agricultural land use ($R^2 = 0.55$, $p < 0.0001$), 50% attributed to pasture land ($R^2 = 0.50$, $p < 0.0001$), and 65% to forested land ($R^2 = 0.65$, $p < 0.0001$). 41% of the variability in nitrate-N concentration in the SW region could be attributed to agricultural land use ($R^2 = 0.41$, $p < 0.0001$), and 41% attributable to row crop land use ($R^2 = 0.41$, $p < 0.0001$).

Ortho-P

The distribution of ortho-P concentration was nearly normally distributed (Shapiro-Wilk (w) = 0.93, $p = 0.0346$). The strong positive correlation between ortho-P concentration and percentage of agricultural land was significant (Pearson correlation coefficient (r) = 0.64, $p < 0.0001$). The relationship between ortho-P concentration and percentage of pasture land ($r = 0.63$, $p = 0.0000$) was stronger than that between ortho-P concentration and percentage of row crop land use ($r = 0.48$, $p = 0.0051$). The strong inverse relationship between ortho-P concentration and percentage of forested land was also significant ($r = -0.63$, $p = 0.0001$). Regionally, stronger positive correlations between ortho-P concentration and percentage of agricultural land were observed in the NE region ($r = 0.74$, $p < 0.0001$); no significant correlation between ortho-P concentration and agricultural land existed in the SW region.

Because of the numerous non-detections of atrazine, it could not be correlated with land use.

Use of Agricultural Best Management Practices to Limit and Reduce Nonpoint Source Pollution

This study has shown that karst groundwater drainage is especially sensitive to agricultural nonpoint-source pollution. However, Kentucky's Agricultural Water Quality Plan (1996) describes numerous best management practices (BMPs) that have been developed to help limit and reduce soil erosion and the rapid leaching or runoff of nutrients and pesticides. Below is a list of key BMPs:

- Avoid applying pesticides when heavy rain is forecasted. Runoff of chemicals reduces their usefulness and is expensive, as well as polluting to groundwater and streams.
- Read application instructions before using any pesticide and review each season. Follow setbacks and required buffers under "Environmental Hazards" section.
- Employ soil-testing on row-crop acreage and apply only the nutrients required (precision farming). Analyze animal waste prior to land application to formulate application rates.
- Utilize conservation cropping systems that include crop rotations, cover crops, conservation tillage technologies, and buffer strips. Cover crops are especially effective on sloping land to control soil erosion and promote filtering of sediment and soil-borne pollutants.
- Limit manure spreading to the growing season when it is most effectively exploited by crops to avoid polluted runoff during winter rains. Avoid spreading manure on frozen or snow-covered land.
- Seek and test alternative pesticides that are less harmful to desirable plants, animals, and aquatic organisms.
- Maintain and expand grassed buffer strips along drainage-ways and around sinkhole drains. Maintain sod in swales and shallow drainage channels within row-crop fields.
- Whenever possible, fence livestock from waterways and open sinkhole drains and use improved stream-crossing methods and stock-activated watering pumps.
- Locate livestock water troughs, mineral blocks, cattle rubs, and shade loafing areas away from sinkhole drains and waterways.
- Encourage maintenance and expansion of forested land cover and vegetated fence-row belts. Limit disturbance of swamps, marshes, and riparian areas.
- Consider seeding marginal areas in native vegetation to encourage wildlife and expand vegetated buffers.

Conclusions

Karst landscapes located in Kentucky's Mississippian-aged rocks are especially sensitive to nonpoint pollution from agriculture, urban development, and transportation corridors. The region's karst drainage is vulnerable to pollution because of rapid preferential drainage via soil macropores, sinkholes, and solution conduits. Also, the hidden underground nature of karst drainage tends to impede research and knowledge about this important resource. The Pennyroyal Plateau of western and central Kentucky is primarily an intensive agricultural region. These important economic activities can generate serious nonpoint-source (NPS) pollution of the vital groundwater resources of the region.

In order to identify, evaluate, and help mitigate impacts from nonpoint source pollution in the region's water systems, this five-year field study investigated twelve karst springs in two study areas within the Pennyroyal Plateau. The research methodology included:

(a) Extensive hydrogeologic field reconnaissance, literature and research survey, and numerous professional and landowner contacts were completed.

(b) A total of 42 groundwater tracer tests were conducted in both areas and 261 km (162 mi) of subsurface flow routes within nineteen groundwater basins were mapped for the first time or replicated. These basins represent total land areas of 670 km^2 (258 mi^2) and base-flow water supply of 850 L/s (30 ft^3/s).

(c) Discharge of 32 large springs was measured during dry-season base flow conditions in order to assess aquifer yield and evaluate basin delineations through unit base flow calculations.

(d) Ninety-six quarterly groundwater samples were collected at 12 representative springs from January 1999, through May 2001, to determine water chemistry and water quality.

(e) Based on the delineated spring basins, digital land-cover data were evaluated in order to quantify agricultural land use.

(f) Based on analysis of water-quality results and land use, springs (and their identified basins) were ranked and prioritized so that NPS resources could be applied to watersheds with the greatest needs.

Results of this research generated the following major conclusions about the study areas:

(1) Groundwater tracer testing is the only practical method to delineate karst drainage basins. This information is essential in order to attribute nonpoint-source pollutants within a landscape to the correct receiving spring. Topographic divides and potentiometric surface maps can also be used to estimate recharge areas of springs; however, estimates derived by these methods should be verified by tracer testing.

(2) Assessing the aquifer yield (base flow per unit area) is useful to understand hydrogeologic variations and support basin delineations. Springs were gaged in both study areas, from 1997-2001, resulting in the following conclusions:

   (a) A direct relationship exists between base-flow discharge and basin area, within uniform hydrogeologic settings. However, UBF in the SW study area is 25-30% greater than in comparable areas of the NE. This is likely due to slightly higher rainfall and increased groundwater storage within thicker soils of the SW study area.

   (b) Within the NE study area, basins typified by sinkhole-plain topography yielded twice the UBF as did basins draining dissected sandstone caprock. This is a consequence of greater sustained groundwater storage in soil-mantled limestone than in sandstone-capped plateaus.

(3) Most springs in the study areas are moderately contaminated by nitrate-N from agriculture, with medians ranging from about 1-6 mg/L. The highest concentrations were recorded at Wright Spring (7.05 mg/L) and River Bend Spring (6.85 mg/L). These concentrations approached but did not exceed the MCL of 10 mg/L.

(4) The herbicide atrazine is a persistent contaminant in karst groundwater, especially in the spring application season. Atrazine was detected above the MDL of 0.0003 mg/L in 26% of 95 samples. Atrazine was detected above the MCL of 0.003 mg/L, seven times at six springs (7% of the samples). The highest concentrations were recorded at Walton Spring (0.0119 mg/L) and King Spring (0.00993 mg/L). Water samples were collected quarterly; continuous monitoring would certainly have revealed much higher maximum levels of atrazine in springs.

(5) The SW study area exhibits greater NPS pollution from agriculture than does the NE study area. This difference is primarily due to the intense agriculture in the more arable SW and greater forested land in the more dissected NE. Consequently, the higher priority ranking of springs tended to include most of the basins in the SW study area.

ID #	Spring	Discharge L/s*	Basin Area km^2	% Agri.	% Forest	Maximum Nitrate-N mg/L	Maximum Atrazine mg/L[B]	Weighted Score	Priority Rank
0860	River Bend	158.6	69.9[m]	87.7	8.7	6.19	**0.00315**	9.15	**1**
1475	Wright	25.5	14.2	89.7	6.2	7.05	0.00115	8.83	**2**
0203	Mill Stream	82.1	182.1[m]	73.8	21.9	6.73	0.00299	7.83	**3**
1489	King	59.5	28.2	85.2	11.5	4.81	**0.00993**	7.53	**4**
1141	Cook	93.4	41.7[m]	75.3	17.1	5.49	**0.00615**	7.10	**5**
0859	Barkers Mill	169.9	69.2[m]	93.0	3.0	6.19	0.00074	6.88	**6**
1838	French Creek	45.3	54.4	67.9	27.2	3.59	**0.00675**	6.88	**7**
1457	Walton	48.1	25.1	77.4	19.0	6.24	**0.0119**	6.53	**8**
0855	Boiling	277.5	327.6	52.7	45.6	3.03	0.00067	5.68	**9**
1824	Buttermilk Falls	22.7	12.7*est*	26.8	65.1	2.21	**0.00393**	4.05	**10**
1063	Head of Wolf Cr	14 *est*	42.5	27.9	70.1	1.04	0.00294	4.00	**11**
1448	Brelsford	85 *est*	32.9	65.4	31.1	2.64	0.00145	3.58	**12**

Table 8: Summary of Numerical Data Derived by this Investigation.
(*Discharge during dry-season base-flow conditions; [m] Basin areas have been modified by subsequent research; [B] Bold font indicates atrazine concentration above MCL)

REFERENCES CITED

Aley, T.J., and Thomson, K.C., 1981, Hydrogeologic mapping of unincorporated Greene County, Missouri, to identify areas where sinkhole flooding and serious groundwater contamination could result from land development. Contract report by the Ozark Underground Laboratory for Greene County, Missouri, 11 pages and 5 maps.

Aley, T.J., 1999, Ozark Underground Laboratory's Groundwater Tracing Handbook. Ozark Underground Laboratory, Protem, Missouri, 35 p.

Amos, D.H., 1972, Geologic Map of the New Amsterdam Quadrangle, Kentucky-Indiana and part of the Mauckport Quadrange, Kentucky: USGS GQ-990.

Amos, D.H., 1975, Geologic Map of the Hardinsburg Quadrangle, Breckinridge County, Kentucky: USGS GQ-1232.

Bell, Howard K., Consulting Engineers, Inc., 1976, 201 Facilities Plan for Wastewater Treatment Work, Irvington, Kentucky, 216 p.

Berryhill Jr., W.S., 1989, The impact of agricultural practices on water quality in karst regions. *in* Proceedings of the Third Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, B.F. Beck, (ed.), Balkma, Rotterdam, p. 159-164.

Boyer, D.G., and Alloush, G.A., 2001, Spatial distribution of nitrogen on grazed karst landscapes. *in* Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proceedings of the 2nd International Nitrogen Conference on Science and Policy, The Scientific World, 1, 5 p.

Brahana, J.V., 1997, Rationale and methodology for approximating spring-basin boundaries in the mantled karst terrane of the Springfield Plateau, northwestern Arkansas. In Beck & Stephenson, eds., The Engineering Geology and Hydrogeology of Karst Terranes, Balkema, Rotterdam, p. 77-82.

Campbell, C.W., and Mike Singer, 2001, Application of thermography to groundwater monitoring at Arnold Air Force base, Tennessee. *in* Geotechnical and Environmental Applications of Karst Geology and Hydrology, B.F. Beck & J.G. Herring, (eds.), Swets & Geitlinger, Lisse, p. 353-358.

Carey, D.I., Currens, J.C., Dinger, J.S., Kipp, J.A., Wunsch, D.R., and Conrad, P.G., 1994. Groundwater in the Kentucky River Basin. Information Circular 52, Series XI, Kentucky Geological Survey, Lexington, Kentucky. 67 p.

Carey, M.S., 1985, The delineation of karst drainage to identify possible contaminant migration routes from the Campbell Army Airfield, Fort Campbell, Kentucky. MS thesis (geology) Eastern Kentucky University, Richmond, 61 p.

Crain, A.S., 2002, Pesticides and nutrients in karst springs in the Green River basin, Kentucky, May-September 2001, U.S. Geological Survey Fact Sheet 133-01, Louisville, Kentucky, 4 p.

Crain, A.S., 2002, The loads of selected herbicides in the Ohio River basin, 1997-2000, U.S. Geological Survey Fact Sheet 089-02, Louisville, Kentucky, 4 p.

Crawford, N.C., 1984, Sinkhole flooding associated with urban development upon karst terrain: Bowling Green, Kentucky. *in* Sinkholes: Their Geology, Engineering, and Environmental Impact, B.F. Beck, (ed.), Balkma, Rotterdam. p. 283-292.

Crawford, N.C., 1987, Groundwater flow in the vicinity of a gasoline spill near Gracey, Trigg County, Kentucky, Consultant Report, 18 p.

Crawford, N.C., and Mylroie, J.E., (unpublished manuscript) Groundwater flow in the vicinity of Gracey, eastern Trigg County, Kentucky, 8 p.

Currens, J.C., and Graham, C.D.R., 1993, Flooding of the Sinking Creek karst area in Jessamine and Woodford counties, Kentucky. Kentucky Geological Survey, Report of Investigations 7, Series XI, 33 p.

Currens, J.C., 1999, Mass flux of agricultural nonpoint-source pollutants in a conduit-flow-dominated karst aquifer, Logan County, Kentucky. Kentucky Geological Survey, Report of Investigations 1, Series XII, 151 p.

Dyas, M.D., 1979, Belford Spring Caves- Trigg County, Kentucky: Western Kentucky Speleological Report, 4 p.

Environmental Quality Commission, Commonwealth of Kentucky, 1992, State of Kentucky's Environment: A Report of Progress and Problems.

Ettensohn, F.R., and Dever, G.R., Jr., eds., 1979, Carboniferous geology from the Appalachian basin to the Illinois basin through eastern Ohio and Kentucky, Field trip no. 4, 9th International Congress of Carboniferous Stratigraphy and Geology: Lexington, Ky., University of Kentucky, 293 p.

Ewers, R.O., Carey, M.J., and Green, D.L., 1989, Fort Campbell groundwater study final report: Consultants Report, 8 p.

Ewers, R.O. and Idstein, P.J., 1991, Groundwater Flow in the vicinity of the Trigg County Landfill, Trigg County, Kentucky, Consultants Report, 16 p.

Ewers, R.O., DeFosset, B.S., and Idstein, P.J., 2001, Dye tracing study: Cadiz Spring groundwater basin delineation, Phase One, Cadiz, Kentucky, Consultants Report, 27 p.

Field, M.S., Wilhelm, R.G., Quinlan, J.F., and Aley, T.J., 1995, An assessment of the potential adverse properties of fluorescent tracer dyes used for groundwater tracing: Environmental Monitoring and Assessment, v. 38, p. 75-96.

Fox, Jr., K.F., 1965, Geology of the Cadiz Quadrangle, Trigg County, Kentucky: USGS GQ-412.

George, A.I., 1978, Caves and karst of the lower and middle portion of Sinking Creek, Breckinridge County, Kentucky. Guidebook to the 1978 Kentucky Speleofest; p. 4-1 to 4-6.

George, A.I., 1976, Karst and cave distribution in north-central Kentucky. Natl. Speleol. Soc. Bull., v. 38, no. 4, p. 93-98.

Hallberg, G.R., Libra, R.D., and Hoyer, B.E., 1985, Nonpoint source contamination of ground water in karst-carbonate aquifers in Iowa. *in* Perspectives in Nonpoint Source Pollution. W.S. Environmental Protection Agency, EPA 440/5-85-001, p. 109-114.

Hileman, G.E., 1997, Potentiometric surface of the bedrock aquifer in the Campbell Army Airfield area, Kentucky and Tennessee, November 1996. US Geological Survey Administrative Report, 18 p.

Hileman, G.E., and Ladd, D.E., 1998, Potentiometric surface of the bedrock aquifer in the Campbell Army Airfield area, Kentucky and Tennessee, September 1997. US Geological Survey Administrative Report, 22 p.

Hoffer, R., 1991, National assessment of contaminated groundwater discharge to surface water: USEPA, Office of Water, Ground-Water Protection Division, 26 p.

Hollander, M. and Wolfe, D.A., 1973, *Nonparametric Statistical Methods*. New York: John Wiley & Sons, 788 p.

Jillson, W.R., 1927, *The Topography of Kentucky*: Kentucky Geological Survey, ser. 6, v. 30, Frankfort, Kentucky, 60 p.

Jones, W.K., 1997. Karst Hydrology Atlas of West Virginia: Karst Waters Institute, Special Publication 4, 111 p.

Kastning, K.M., and Kastning, E.H., 1981, Fracture control of dolines, caves, and surface drainage: Mississippian Plateau, Western Kentucky, U.S.A., *in* B.F. Beck, (ed.), Proceedings, Eighth International Congress of Speleology, Bowling Green, Kentucky, July 18-24: National Speleological Society, Huntsville, Alabama, vol. 2, p. 696-698.

Kentucky Risk Assessment Guidance, June 8, 2003.

Kentucky Agricultural Water Quality Plan, 1996, B.L. Zalph, ed.

Klemic, Harry, 1966, Geologic Map of the Allensville Quadrangle, Kentucky-Tennessee: USGS GQ-502.

Klemic, Harry, 1966, Geologic Map of the Hammacksville Quadrangle, Kentucky-Tennessee: USGS GQ-540.

Klemic, Harry, 1966, Geologic Map of the Herndon Quadrangle, Kentucky-Tennessee: USGS GQ-572.

Klemic, Harry, and Ulrich, G.E., 1967, Geologic Map of the Roaring Spring Quadrangle, Kentucky-Tennessee: USGS GQ-658.

Lambert, T.W., 1976, Water in a limestone terrane in the Bowling Green area, Warren County, Kentucky: Kentucky Geological Survey: Report of Investigations #17, 43 p.

Mason, Don, 1982, Glovers Cave area geology: The Petroglyph, 18: no. 1, 3-5

McDowell, Dan, 1983, Meander cutoffs on Big West Fork Creek, Christian County, Kentucky: The Michiana Caver, 10: no.6, 217-221.

Milwaukee Metropolitan Sewerage District (MMSD), 2002, Environmental Performance Report-2002, cited December 2002, http:// www.mmsd.com/envper2001/page3.asp

Moody, J.R., Ray, J.A., and Leo, D.P., 2000, Waterworks Spring groundwater basin Nonpoint Source study, Warren County, Kentucky: Kentucky Division of Water, Frankfort, Kentucky, 36 p.

Moore, F.M., and Mylroie, J.E., 1979, Influence of master stream incision on cave development, Trigg County, Kentucky, *in* Mylroie, J.E. (ed), Western Kentucky Speleological Survey Annual Report, Murray State University, p. 47-68.

Mull, D.S., Alexander, A.G., and Schultz, P.E., 1989, Geohydrology and ground-water quality at selected sites in Meade County, Kentucky, 1987-88. U.S. Geological Survey, Water-Resources Investigations Report 89-4108, 67 p.

Mylroie, J.E., and Mylroie, J.R., 1991, Meander cutoff caves and self piracy: The consequences of meander incision into soluble rocks: National Speleological Society Bulletin, 52: 33-44.

Palmer, A.N., 1990, Origin and morphology of limestone caves. Geol. Soc. Am., Bull., vol. 103, p. 1-21.

Paylor, R.L., and Currens, J.C., 2001, Mapping karst groundwater basins in the Inner Bluegrass as a nonpoint-source management tool, *in* Beck, B.F. and Herring, J.G., eds: Proceedings of the Eight Multidisciplinary Conference on Sinkhole and the Engineering and Environmental Impact of Karst; Swets & Zeitlinger, Lisse, The Netherlands, pp. 229-234.

Plebuch, R.O., Faust, R.J., and Townsend, M.A., 1985, Potentiometric surface and water quality in the principal aquifer, Mississippian Plateaus Region, Kentucky. Water-Resources Investigations Report 84-4102, U.S. Geological Survey, Louisville, Kentucky. 45 p.

Quinlan, J.F., and Ray, J.A., 1995, Normalized base-flow discharge of groundwater basins: A useful parameter for estimating recharge area of springs and for recognizing drainage anomalies in karst terranes. In Beck, B.F., ed., Karst GeoHazards, Balkema, Rotterdam. p. 149-164.

Quinlan, J.F., and Ewers, R.O., 1981, Hydrogeology of the Mammoth Cave region, Kentucky, *in GSA Cincinnati '81 Field Trip Guidebook 3*, T.G. Roberts, ed., Falls Church, Va.: American Geological Institute, p. 457-506.

Ray, J.A., and O'dell, P.W., 1993, DIVERSITY: A new method for evaluating sensitivity of groundwater to contamination. Environmental Geology, vol. 22, no. 4, p. 345-352.

Ray, J.A., Webb, J.S., and O'dell, P.W., 1994, Groundwater Sensitivity Regions of Kentucky. Kentucky Department for Environmental Protection, Frankfort, Kentucky; [1:500,000 map sheet].

Ray, J.A., & Stapleton, B.B., 1996, Delineation of the Meriwether Spring groundwater basin, sole water-supply spring source of Guthrie, Kentucky: Kentucky Natural Resources and Environmental Protection Cabinet, Department for Environmental Protection, Division of Water, Frankfort, Kentucky, 14 p.

Ray, J.A., and Joe Meiman, 1998, Unit base flow of karst drainage basins: A useful groundwater-tracing tool, *Extended Abstract*, Friends of Karst-IGCP 379, Western Kentucky University, Bowling Green, Kentucky, Sept. 23-25, *Abstract,* p. 27-28

Ray, J.A., 1997, Overflow conduit systems in Kentucky: A consequence of limited underflow capacity, *in* Beck, B.F, & Stephenson, J. B., eds: Proceedings of the Sixth Multidisciplinary Conference of Sinkholes and the Engineering and Environmental Impacts of Karst; A.A. Balkema, Rotterdam/Brookfield, pp. 153-156

Ray, J.A., 2001, Spatial interpretation of karst drainage basins, *in* Beck, B.F., and Herring, J.G., eds: Proceedings of the Eighth Multidisciplinary Conference on Sinkhole and the Engineering and Environmental Impacts of Karst; Swets & Zeitlinger, Lisse, The Netherlands, pp. 235-244.

Ray, J.A., 2002, Cryptic artesian flow of Bull Spring: A karst rarity, *oral presentation*: Geological Society of America, Southeastern Section Annual Meeting, Lexington, Kentucky, March, 2002.

Sable, E.G., and Dever, G.R., Jr., 1990, Mississippian Rocks in Kentucky: U.S. Geological Survey Professional Paper 1503, Washington, D.C., 125 p.

Schaffer, K., and Miller, G., 2002, Pesticides in Kentucky Streams, *Abstract & Poster:* 2002 Kentucky Nonpoint Source Conference, Lake Barkley State Resort Park, September 23, p. 80-81.

Schindel, G.M., Quinlan, J.F., and Ray, J.A., 1994, Determination of the recharge area for the Rio Springs groundwater basin, near Munfordville, Kentucky: An application of dye tracing and potentiometric mapping for delineation of springhead and wellhead protection area in carbonate aquifers and karst terranes. Project Completion Report, Groundwater Branch, USEPA, Region IV, Atlanta, GA. 27 p.

Seeland, D.A., 1968, Geologic Map of the Cobb Quadrangle, Trigg and Caldwell Counties, Kentucky: USGS GQ-710.

Taylor, C.J., 1996, Results of dye-tracing tests in the Little West Fork basin, Fort Campbell Military Reservation, Tennessee and Kentucky, 1994 and 1995, US Geological Survey, Administrative Report, 13 p.

Taylor, C.J., and McCombs, G.K., 1998, Recharge-area delineation and hydrology, McCraken Springs, Fort Knox Military Reservation, Meade County, Kentucky. U.S. Geological Survey, Water-Resources Investigations Report 98-4196, 12 p.

Ulrich, G.E., and Klemic, Harry, 1966, Geologic Map of the Caledonia Quadrangle, Trigg and Christian Counties, Kentucky: USGS GQ-604.

U.S. Environmental Protection Agency, 1999, Children and drinking water standards: Washington, D.C., Office of Water, EPA 815-K-99-001, 15 p.

U.S. Environmental Protection Agency, 1998, Total Suspended Solids Laboratory Method 160.2, cited August 2002: http://www.epa.gov/region09/lab/sop

U.S. Environmental Protection Agency, 2000, Drinking Water Standards and Health Advisories, cited June 2002, http://www.epa.gov/ost/drinking/standards/dwstandards.pdf.

Van Couvering, 1962, Characteristics of large springs in Kentucky: Kentucky Geological Survey, Information Circular 8, Series X, 37 p.

Vogelmann, J.E., Howard, S.M., Yang, L., Larson, C.R., Wylie, B.K., and Van Driel, N., 2001, Completion of the 1990's national land cover data set for the conterminous Unites States from Landsat thematic mapper data and ancillary data sources, Photogrammetric Engineering and Remote Sensing, 67: 650-652.

Wellner, J., and Fister, G. 1989, Dye Tracing Study for the City of Irvington, Kentucky: Commonwealth Technology, Inc., Lexington, Kentucky, 7 p.

White, W.B., 1988, *Geomorphology and Hydrology of Karst Terrains:* Oxford University Press, New York, 464 p.

Whitesides, D.V., 1965, Graham and Lost River Springs, a potential source of industrial water supply: Kentucky Department of Commerce and U.S. Geological Survey, 8 p.

World Health Organization, 1996, Guidelines for drinking water quality, 2nd edition, cited August 2002, http://www.who.int/water_sanitation_health/.

Worthington, S.R.H., Davies, G.J., and Quinlan, J.F., 1992, Geochemistry of springs in temperate carbonate aquifers: recharge type explains most of the variation. Colloque d'Hydrogeologie en Pays Calcaire et en Millieu Fissure (5th, Neuchatel, Switzerland), Proceedings, Annales Scientifiques de l'Universite de Besancon. Geologie - Memoires Hors Serie, No. 11, vol. 2, p. 341-347.

APPENDIX A: FINANCIAL AND ADMINISTRATIVE CLOSEOUT

1. Work Plan Outputs

Milestones

1.	Preliminary work	Completed
2.	Initial spring reconnaissance, discharge measurements, and 1st quarter monitoring	Completed
3.	2nd quarter monitoring	Completed
4.	3rd quarter monitoring	Completed
5.	4th quarter monitoring	Completed
6.	5th quarter monitoring	Completed
7.	6th quarter monitoring	Completed
8.	7th quarter monitoring	Completed
9.	Basin delineations completed	Completed
10.	8th quarter monitoring	Completed
11.	Karst education agriculture outreach	Continuing
12.	Land use analyses completed	Completed
13.	Develop karst groundwater basin nonpoint source ranking scheme	Completed
14.	Prepare Ranking and Monitoring Report	Completed

2. Budget

Budget Categories	Section 319(h)	Non-Federal Match	Total	Final Expenditures
Personnel	$11,216	$40,480	$51,696	$51,696
Supplies				
Equipment				
Travel				
Contractual	$49,504		$49,504	$49,504
Operating Costs				
Other				
TOTAL	$60,720	$40,480	$101,200	$101,200
	60%	40%	100%	

The Groundwater Branch of the Kentucky Division of Water was reimbursed $60,720. All dollars were spent; there were no excess project funds to reallocate.

3. Equipment Purchased.

No equipment was purchased for this project.

4. Special Grant Conditions.

No special grant conditions were placed on this project.

This project did involve contractual activity which included a contract with the Kentucky Geological Survey for sample analysis. The DOW/KGS contract is attached.

MEMORANDUM OF AGREEMENT

between the

COMMONWEALTH OF KENTUCKY

NATURAL RESOURCES AND ENVIRONMENTAL PROTECTION CABINET

DEPARTMENT FOR ENVIRONMENTAL PROTECTION

DIVISION OF WATER

and the

UNIVERSITY OF KENTUCKY RESEARCH FOUNDATION

for the

KENTUCKY GEOLOGICAL SURVEY

SUBJECT: IDENTIFICATION AND PRIORITIZATION OF KARST GROUNDWATER BASINS IN KENTUCKY FOR TARGETING RESOURCES FOR NONPOINT SOURCE POLLUTION PREVENTION AND ABATEMENT - ANALYTICAL SERVICES

Kentucky Nonpoint Source Management Program

July 1, 1998

This Memorandum of Agreement, made and entered into by and between the Commonwealth of Kentucky, Natural Resources and Environmental Protection Cabinet, Department for Environmental Protection, Division of Water, (hereinafter "Division of Water" or "DOW"), and the University of Kentucky Research Foundation for the Kentucky Geological Survey (hereinafter "recipient").

WITNESSETH:

WHEREAS, the Commonwealth of Kentucky is charged with the implementation of the Kentucky Nonpoint Source Management Program as required by Section 319 of the federal Clean Water Act Amendments of 1987; and

WHEREAS, control of nonpoint source pollution through water quality assessment is an important component of the Kentucky Nonpoint Source Management Program; and

WHEREAS, the Division of Water, as the lead oversight agency for the Kentucky Nonpoint Source Pollution Control Program, implements the Program primarily through the activities of cooperating agencies, institutions, and organizations; and

WHEREAS, part of the mission of the recipient is activities involving water quality assessment; and

NOW, THEREFORE, in consideration of the mutual covenants expressed herein, DOW and the recipient hereby AGREE as follows:

I. INTRODUCTION

The Division of Water, as the lead oversight agency for the Kentucky Nonpoint Source Pollution Control Program, developed a Section 319(h) Kentucky Nonpoint Source Implementation Grant Workplan for Federal Fiscal Year (FFY) 1997. The Workplan describes projects that will partially implement the Kentucky Nonpoint Source Management Program. Subsequently, the U.S. Environmental Protection Agency (EPA) approved the Workplan and, to enable implementation of the projects described therein, awarded a grant to the Division of Water through the Section 319(h) Nonpoint Source Implementation Program Cooperative Agreement (#C9994861-97) for FFY 1997, which is subject to the terms and conditions of the approved Workplan. This Memorandum of Agreement assigns implementation of one of the Workplan projects, "Identification And Prioritization Of Karst Groundwater Basins In Kentucky For Targeting Resources For Nonpoint Source Pollution Prevention And Abatement - Analytical Services" to the recipient.

Introduction to the Project:

The objectives of this study are as follows: (1) spring monitoring samples will be delivered to the recipient laboratory for analysis. Analytical results will be delivered to the Groundwater Branch by the recipient laboratory on a quarterly basis.; (2) produce additional water quality assessment data that will augment groundwater monitoring efforts conducted by the Division of Water, the Division of Pesticides, the Kentucky Geological Survey, the U.S. Geological Survey and the Departments of Agriculture and Agronomy at the University of Kentucky

II. SCOPE OF SERVICES

The recipient shall comply with the terms and conditions as follows:

Section A. Identification And Prioritization Of Karst Groundwater Basins In Kentucky For Targeting Resources For Nonpoint Source Pollution Prevention And Abatement - Analytical Services

Plan of Work:

The recipient shall conduct this plan of work as follows:

1. Receive samples delivered by the DOW at a maximum of twelve (12) samples per quarter. Each sample will be accompanied by a Chain-of-Custody (COC) form completed by the DOW which shall serve as the instructions for the analyses required. The recipient shall maintain the custody and integrity of each of the samples at all times and shall store the unused portion of each sample for a period of three (3) months after the sample collection date.

2. The recipient shall perform one or more of the following tasks as defined by the COC for each sample. These tasks include:

a. The preparation of water samples for all laboratory analyses.
b. Analyze the prepared samples for the constituents listed in Attachment I.

Section B. Outputs

The recipient shall:

1. Report the analytical data to the DOW in a format suitable for electronically loading into the DOW's Consolidated Groundwater Database, and in hard copy to include the completed analyses together with the documentation necessary to validate the results. Reports shall be submitted to the DOW within sixty (60) days of receipt of each sample.

2. Provide quarterly invoices for personnel costs and all completed samples that have been analyzed during the quarter.

Section C. Quality Assurance/Quality Control Plan

The recipient shall ensure that all water quality monitoring activities in this Agreement shall be conducted in accordance with the approved Quality Assurance/Quality Control Plan. The approved Quality Assurance/Quality Control Plan shall be incorporated into this Agreement by reference.

Section D. Reporting Requirements

Records Retention Requirement: The recipient shall retain all financial records, supporting documents, accounting books and other evidence of assisted activities including federal and non-federal matching funds until December 31, 2009. If any litigation, claim or audit is started prior to this expiration date, the recipient must maintain all appropriate records until these actions have been completed and all issues have been resolved.

III. METHOD OF PAYMENT

This Agreement shall be funded by an award from EPA to the Division of Water through 319(h) Nonpoint Source Implementation Program Cooperative Agreement #C9994861-97, CFDA 66.460. The total project cost shall not exceed forty nine thousand five hundred four and dollars ($49,504).

Under this cost reimbursement contract, the recipient shall invoice DOW for all costs associated with the project on a quarterly basis. DOW shall reimburse the federally funded portion, one hundred percent (100.00%), of the total project cost. The total reimbursement is not to exceed forty nine thousand five hundred and four dollars ($49,504) in accordance with this Agreement. The recipient shall submit quarterly invoices with an attached NPS Project Progress Report to the Division of Water, Nonpoint Source Section. The recipient shall submit the final invoice with attached Final Report, Project Close Out Report, and project documentation to the Division of Water, Nonpoint Source Section. Payment of the final invoice is subject to Environmental Protection Agency approval.

IV. ASSURANCES

A. The recipient shall comply with: (1) Office of Management and Budget Circular Nos. A-21, A-110, and A-133; and (2) applicable provisions of Standard Form 424B, Assurances - Non-construction Programs, all of which are incorporated into this Agreement by reference.

B. The recipient shall comply with the following award conditions specified in 319(h) Nonpoint Source Implementation Program Cooperative Agreement #C9994861-97, CFDA #66.460: (1) The recipient must ensure to the fullest extent possible that at least an 8% minimum MBE/WBE (minority business enterprises/women's business enterprises) goal of Federal funds for prime or subcontracts for supplies, construction, equipment, or services are made available to organizations owned or controlled by socially and economically disadvantaged individuals, women, and historically black colleges and universities. The recipient agrees to include in its bid documents this 8% minimum goal and require all of its prime contractors to include in their bid documents for subcontracts the negotiated "Fair Share" percentage. To evaluate compliance with the "Fair Share" policy, the recipient agrees to comply with P.L. 102-389, the six affirmative steps stated in 40 CFR 33.44(b), 31.36(e), or 35.6580(a) as appropriate. (2) In accordance with Section 129 of Public Law 100-590, the Small Business Administration Reauthorization and Amendment Act of 1988, the recipient is encouraged to utilize small businesses located in rural areas to the maximum extent possible. The recipient agrees to follow the six affirmative steps stated in 40 CFR 33.44(b), 31.36, or 35.6580 as appropriate. (3) Pursuant to Environmental Protection Agency Order 1000.25, dated January 24, 1990, the recipient agrees to use recycled paper for all reports which are prepared as a part of this Agreement and delivered to EPA. This requirement does not apply to reports which are prepared on forms supplied by EPA. This requirement applies even when the cost of recycled paper is higher than that of virgin paper. (4) The recipient agrees to ensure that all conference, meeting, convention, or training space funded in whole or in part with Federal funds, complies with The Hotel and Motel Fire Safety Act of 1990. (5) Pursuant to the Lobbying Disclosure Act of 1995, the recipient agrees to refrain from entering into any subagreement or contract under this Agreement with any organization described in Section 501(c)(4) of the Internal Revenue Code of 1986, unless such organization warrants that it does not, and will not, engage in lobbying activities prohibited by the Act as a special condition of the subagreement or contract. (6) The recipient agrees to provide the Cabinet with a copy of the recipient's current Title VI of the 1964 Civil Rights Act Plan. If the recipient does not have an existing plan, the recipient shall agree to use the Cabinet's current Title VI Plan. (7) By signing this contract, the recipient agrees to certify that all state taxes have been paid in accordance with Senate Bill 258 of the 1994 General Assembly (KRS Chapter 45A.485).

V. CHOICE OF FORUM

Any legal action brought on the basis of this Agreement shall be filed in the Franklin County Circuit Court of the Commonwealth of Kentucky.

VI. TERM OF CONTRACT

This Agreement is entered into and effective for the period beginning July 1, 1998 and ending on June 31, 2001. This Agreement may be further extended by written agreement of the parties hereto for an additional period.

VII. CANCELLATION CLAUSE

Either party shall have the right to terminate and cancel this Agreement for cause at any time or upon thirty (30) days written notice to the other party.

VIII. AMENDMENTS

This Agreement shall not be modified except by written agreement of both parties.

IX. MISCELLANEOUS

The parties certify, by the signatures of duly authorized representatives hereinafter affixed, that they are legally entitled to enter into this Agreement, and that they shall not be violating, either directly or indirectly, any conflict of interest statute of the Commonwealth of Kentucky by performance of this Agreement. Further, the parties covenant that they presently have no conflict of interest, in any manner or degree, with the performance of services required to be performed under this Agreement. The parties further covenant that in the performance of this Agreement no persons having any such conflict of interest shall be employed. The signatures below signify acceptance and approval of this AGREEMENT.

Memorandum of Agreement, Natural Resources and Environmental Protection Cabinet and the University of Kentucky Research Foundation for the Kentucky Geological Survey.

UNIVERSITY OF KENTUCKY

RECOMMENDED FOR APPROVAL:

____
Director, Kentucky Geological Survey — Date

APPROVED:

____
Director, University of Kentucky Research Foundation — Date

NATURAL RESOURCES AND ENVIRONMENTAL PROTECTION CABINET

RECOMMENDED FOR APPROVAL:

____
Director, Division of Water — Date

____
Commissioner, Department for Environmental Protection — Date

____
Director, Division of Administrative Services — Date

EXAMINED AS TO LEGALITY AND FORM:

____

General Counsel, Office of Legal Services — Date

APPROVED:

____

Secretary, Natural Resources and Environmental Protection Cabinet — Date

FINANCE AND ADMINISTRATION CABINET

EXAMINED AS TO LEGALITY AND FORM:

____

Attorney, Finance and Administration Cabinet — Date

RECOMMENDED FOR APPROVAL:

____

Commissioner, Department for Administration — Date

APPROVED:

____

Secretary, Finance and Administration Cabinet — Date

ATTACHMENT I
KENTUCKY GEOLOGICAL SURVEY
Computer and Laboratory Services Section

Analysis Parameters

INORGANIC-NONMETAL	Method	Cost
Alkalinity	EPA 310.1	
Chloride	EPA 300.0 (IC)	
Conductance	EPA 120.1	
Fluoride	EPA 340.2	
pH	EPA 150.1	
Sulfate	EPA 300.0 (IC)	
		$30.00
NUTRIENT		
Ammonia-Nitrogen	EPA 350.3	
Kjeldahl-Nitrogen	EPA 351.4	
Nitrate-Nitrogen	EPA 300.0 (IC)	
Nitrite-Nitrogen	EPA 354.1	
Orthophosphate	EPA 365.3	
		$37.00
RESIDUE		
Suspended Solids	EPA 160.2	
Dissolved Solids	EPA 160.1	
		$14.00
DEMAND		
CBOD	EPA 405.1	
		$14.00

ORGANIC EPA 507-508 (GC-ECD)

Herbicide	Insecticide
Butylate	Malathion
Trifluralin	Chlorpyrifos
Atrazine	Endosulfan
Alachlor	Permethrin
Linuron	Diazinon
Metolachlor	
Pendimethalin	Fungicide
Simazine	Chorothalonil

$67.00

ATTACHMENT I (Continued)

INORGANIC METALS EPA 200.7a (ICP)

Aluminum	Magnesium
Antimony	Manganese
Arsenic	Nickel
Barium	Phosphorous
Beryllium	Potassium
Boron	Selenium
Cadmium	Silicon
Calcium	Silver
Chromium	Sodium
Cobalt	Strontium
Copper	Sulfur
Gold	Thallium
Iron	Tin
Lead	Vanadium
Lithium	Zinc

$36.00

EPA 200.9 GFAA Methods

Arsenic
Chromium
Lead

$36.00

TOTAL ANALYTICAL: $234.00

BUDGET

Budget Summary:

Budget Categories	**Project Activity Categories**						
	BMP Imple-mentation	**Project Management**	**Public Education**	**Monitoring**	**Technical Assistance**	**Other**	**Total**
Personnel							
Supplies							
Equipment							
Travel							
Contractual				$49,504			$49,504
Operating Costs							
Other							
TOTAL				$49,504			$49,504

Detailed Budget:

Budget Categories	**Section 319(h)**	**Non-Federal Match**	**Total**
Personnel			
Supplies			
Equipment			
Travel			
Contractual	$49,504		$49,504
Operating Costs			
Other			
TOTAL	$49,504		$49,504
	100%		100%

Budget Narrative

The total project budget is $49,504. This ($49,504) includes contractual sample analysis costs through a MOA with the Kentucky Geological Survey laboratory.

APPENDIX B: QA/QC FOR WATER MONITORING

TITLE SECTION

Project Name

"IDENTIFICATION AND PRIORITIZATION OF KARST GROUNDWATER BASINS IN KENTUCKY FOR TARGETING RESOURCES FOR NONPOINT SOURCE POLLUTION PREVENTION AND ABATEMENT"

B. QA/QC Plan Preparers

David P. Leo, Geologist Supervisor – Registered

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

(502) 564-3410

Date

August 9, 1996

Project Description

This project is intended to identify karst groundwater basins in selected areas of the Mississippian Plateau physiographic province of west-central and south-west Kentucky that have potential or demonstrated nonpoint source pollution problems. Once identified, these basins will be prioritized based on the presence of, and the susceptibility to, nonpoint source pollution, land use within the basin and related threats posed by land use, use of the water in the basin, and the need for or application of best management practices within the basin. This priority scheme will help to appropriately target future nonpoint source resource, such as BMP implementation and modification, public education, and technical assistance at karst groundwater basins that have been established to have the most critical need.

Anticipated nonpoint source pollutants include: pesticides, primarily from agricultural use, secondarily from urban uses; and bacterial and nutrients from agriculture and onsite sewage disposal.

2. WATERBODY INFORMATION

A. **1. Stream Names**

Determining which of the lower order karst groundwater basins (spring basins) to be studied is part of the proposed study. All of the karst groundwater basins to be studied will be in the basins of one of the following streams:

Ohio River
Sinking Creek
Rough River
Little River
Sinking Fork
Lower Cumberland River

2. Major River Basin

Ohio River
Lower Cumberland River

3. Water Body Number

To our knowledge, water body numbers have not been assigned to any of Kentucky's karst groundwater basins. However, every karst groundwater basin will be a tributary to one of the following streams:

Ohio River
Sinking Creek
Rough River
Little River
Sinking Fork
Lower Cumberland River

4. USGS Hydrologic Unit Number

U.S.G.S. Hydrologic Unit numbers have not been assigned to the karst groundwater basins that are to be delineated, assessed, and ranked. Additionally, individual basins to be delineated have not yet been identified as that is part of the function of the study. However, every karst groundwater basin will be a tributary to one of the following streams:

Ohio River
Sinking Creek
Rough River
Little River
Sinking Fork
Lower Cumberland River

5. Stream Order

Individual basins to be delineated have not yet been identified as that is part of the function of the study. Steam orders for these basins have traditionally not been assigned. Rather, tracer testing and unit base-flow measurements are used to approximate the size of karst groundwater basins. The areas of recharge for karst groundwater basins in the Pennyroyal of Kentucky correspond to surface stream watershed areas up to fourth-order streams. Every karst groundwater basin will be a tributary to one of the following streams:

Ohio River
Sinking Creek
Rough River
Little River
Sinking Fork
Lower Cumberland River

6. Counties in Which Study Area is Located

Breckinridge, Christian, Hardin, Meade, Todd, and Trigg.

7. USGS 7.5-minute Topographic Quadrangles Containing Project Area

Northeast Study Area – New Amsterdam, Mauckport, Lodiburg, Irvington, Guston, Rock Haven, Hardinsburg, Garfield, Big Spring, Kingswood, Custer, and Constantine

Southwest Study Area – Cobb, Gracey, Cadiz, Caledonia, Church Hill, Johnson Hollow, Roaring Spring, Herndon, Oak Grove, Trenton, Guthrie, and Allensville.

3. Monitoring Schedule

Initial monitoring will be conducted along with spring surveys and spring discharge measurements. Monitoring of each spring will continue throughout the study on a quarterly, or an as-needed basis. For example, springs that demonstrate highly variable water quality or that have a significant level of pollution may be monitored more frequently than non-impacted springs or spring with consistent water quality.

4. Monitoring Objectives

Gage base-flow discharge of selected springs;

Estimate groundwater recharge areas;

Evaluate land use within each delineated karst groundwater basin;

Determine actual or potential impacts of nonpoint source pollution to selected springs.

5. Study Area Description

The Mississippian Plateau physiographic province of Kentucky extends from the Jackson purchase Region on the west, south of the Western Coal Field, southwest of the Bluegrass Region, with the Eastern Coal Field serving as a boundary on the East. Three northern extensions, one between the Jackson Purchase and the Western Coal Field, one between the Bluegrass Region and the Western Coal Field and one between the Bluegrass Region and the Eastern Kentucky Coal Field extend north to the Ohio River.

A. Most of the karst basins that will be studied are located in rural settings, with only a few proximal to the urban center of Hopkinsville. Several areas within this province will be studied in this project, with the concentration of the work being done in the NE and SW study areas shown on figure 1.

B. A general description is offered which is applicable to most of the Mississippian Plateau. Site-specific information is not available as sites have not yet been identified per the nature of the study. The topography is generally gently rolling plains and flat regions containing dolines, karst windows, sinking streams, springs, and other karst features. Soils are predominantly clay or clayey loam soils with minor sandy loam soils. The geology dominantly consist of massively bedded carbonates of mid-Mississippian age. These carbonates are predominated by limestones with minor, but important, interbeds of calcareous shales, dolomites and cherts. These carbonates are locally capped by quartzitic sandstones. The study will be conducted in the Mississippian Plateau physiographic region. The ecoregion as applies to the Mississippian Plateau in Kentucky.

C. 1. Watershed acreages are to be approximated as part of the study using unit base-flow methods and further delineation will be conducted using traditional groundwater tracing techniques.

2. This study will be evaluating karst groundwater basins with recharge areas equilivent to 1^{st}-order through fourth-order streams. Flow patterns within these karst groundwater basins are dominated by conduit flow, but contain elements of diffuse flow and fracture flow. Karst topographic features that occur within the study area are dolines, sinking streams, springs, karst windows, along with other less common karst features. This project is designed to estimate and delineate numerous karst groundwater systems. All the systems being delineated and assessed are dominated by karst groundwater drainage systems.

D. Land use in this region varies widely from relatively undisturbed land to areas of urbanization. Most of the rural land is dedicated to agriculture and is used for row cropping of corn, soy beans, tobacco, oats, and wheat. Both dairy and beef cattle are raised in this region, and the area includes both hog farms and poultry farms. Sewage treatment varies from a predomination of rural on-site waste disposal systems (approved methods and otherwise) to urban sewer districts, as well as smaller package-plant facilities. Local quarrying of limestone occurs throughout the area, and historical niter mining has occurred in some areas. Numerous landfills, both permitted and non-permitted, occur through the Mississippian Plateau. Many major industries occur in the area, including automobile parts manufacturing, and others. The area is largely rural and this study is targeted to focus on agricultural nonpoint sources of pollution.

E. Site-specific maps are not available due to the nature of the study. A general regional map is presented to indicate areas where new karst groundwater basin delineations and assessments are planned, as well as areas where substantial historical data exists. The areas will be used to collect information sufficient to prioritize individual karst basins for further nonpoint source efforts and resource expenditures.

F. The project monitoring areas have not yet been identified to site-specific locations. It is an aspect of this project to provide geographic and land-use features as a part of the study.

6. Project Organization and Responsibility

The supervisor of the Technical Services Section of the Kentucky Division of Water's Groundwater Branch will coordinate this project. Individual staff members will be selected based on staff work loads at the time of the project. The laboratory analyses will be conducted by the Kentucky Geological Survey (KGS) laboratory. All data generated will be stored in the Kentucky Department for Environmental Protection's consolidated Groundwater Database and will be forwarded electronically to the Kentucky Geological Survey's Groundwater Data Repository.

7. Monitoring Program/Technical Design

A. Monitoring strategies include obtaining samples from springs during field reconnaissance and spring flow gaging. Thereafter, springs will be monitored on a quarterly basis as an attempt to assess seasonal/temporal variations in water quality parameters. Springs that demonstrate highly variable water quality may be sampled more frequently to determine the nature of the variation. Additionally, storm event sampling may be attempted at some locations with an automated sampler to determine variation due to storm events.

B. All monitoring station locations are to determined as part of the study, unless they are otherwise specifically identified in another study. All monitoring sites will be karst groundwater basin springs.

C. Refer to Table I – Sample Parameters and Methods, and to Table II – Sample Parameters, Containerization, Preservation and Holding Times.

Table II outlines the constituents that will be sampled as the monitoring/assessment effort of this study. Consistent with other monitoring efforts samples will be collected at each spring and samples analyzed for bulk parameters, nutrients, chemical and biological demand, pesticides, including most commonly used herbicides, insecticides, and fungicide. Samples may be analyzed for the major metals as part of an ongoing ambient monitoring program. Metals analyses will not be funded by this 310(h) project. See Table below for individual analytical methods used for each parameter.

Analysis of all samples are conducted by a contract lab according to methods approved by the Division of Environmental Services.

TABLE I. SAMPLE PARAMETERS AND METHODS

PARAMETER	EPA WATER METHOD
Alkalinity	310
Fluoride	340
Chloride	300
Nitrite	354.1
Nitrate	300
TDS	160.1
TSS	160.2
Sulfate	300
Conductance	120.1
Orthophosphate	365.2
BOD	405.1
Pesticides	507-508
NH3	350
TKN	351
Metals	200 Series/200.7

D. Refer to Table II. Samples are taken as grab samples using properly decontaminated sampling devices and containers.

E. Sampling will begin with initial spring base-flow gaging and will be conducted quarterly for two years. More frequent sampling may occur if the water quality of a spring varies greatly from one sampling event to the next. Storm event sampling will be conducted on some springs, if possible, to determine the effective variations in spring water quality related to rain events. Storm-event sampling will proceed through the entire event if possible. Automatic sampling will not be conducted in such a manner as to exceed the methods holding time for any parameter being sampled.

8. Chain-of-Custody Procedures

A. 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 KGS laboratory, for each sample. The KGS 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.

B. Name: David P. Leo
Position: Geologist Supervisor - Registered
Agency: Groundwater Branch
Address: Kentucky Division of Water
14 Reilly Road
Frankfort, KY 40601
Phone: 502/564-3410

9. Quality Assurance/Quality Control Procedures

A. Field Reconnaissance

Field Reconnaissance will be conducted prior to groundwater sampling to assess the suitability and accessibility of each site. A Spring Inventory Record will be completed for each spring gaged. 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.

1. 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

Sample collection equipment such as bailers and buckets will consist of Teflon. Disposable bailers are preferable. 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. If oily substances or films are encountered during sampling a pesticide grade acetone or xylene rinse will be used as the first rinse of the decontamination procedure on reusable sampling equipment.

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.

2. Equipment Calibration

Field meters will be calibrated in accordance with the manufacturer's specifications, using standard buffer solutions or zero adjust (for flow meters). Meter probes will be decontaminated according to the manufacture's decontamination protocols for field meters and stored according to the manufacture's recommendations.

3. Sample Collection and Preservation/Contamination Prevention

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

Sample containers will be obtained from the Kentucky Division of Environmental Services, and will be new or laboratory-decontaminated in accordance with Division of Environmental Services accepted procedures. Sample containerization, preservation, and holding time requirements are presented in Table II. 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 contract 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 (form DEP 5005A or equivalent) for each sample. The contract 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.

Samples will be collected as near 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.

4. 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. Dissolved oxygen and Eh meter readings may be taken at problem spring sites to help better define the water chemistry. 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.

Flow meter measurements will follow the manufactures recommendations as well as USGS protocols for stream flow measurements to ensure consistent and accurate flow measurements in the field.

b. Name: David P. Leo
Position: Geologist Supervisor - Registered
Agency: Groundwater Branch
Address: Kentucky Division of Water
14 Reilly Road
Frankfort, KY 40601
Phone: 502/564-3410

Table II. SAMPLE PARAMETER, CONTAINERIZATION, PRESERVATION AND HOLDING TIMES

Parameter	Container	Preservative	Holding Time
Bulk Parameters Alkalinity Chloride Conductance Fluoride pH Sulfate Nitrate Nitrogen Nitrite Nitrogen Total Suspended Solids Total Dissolved Solids	1000 ml plastic	Cool to 4°C	 14 days 28 days 28 days 28 days 2 hours 28 days 48 hours 48 hours 7 days 7 days
Nutrients Ammonia-Nitrogen Total Kjeldahl-Nitrogen	1000 ml plastic	H_2SO_4 to pH <2 Cool to 4°C	28 days
Orthophosphate	1000 ml plastic	Cool to 4°C	48 hours
Pesticides *Herbicides:* Alachlor, Atrazine, Butylate, Cyanazine, Linuron, Metolachlor, Pendimethalin, Simazine, Trilfluralin *Insecticides:* Chlorpyrifos, Diazinon, Endosulfan, Malathion, Permethrin, Acetochlor *Fungicides:* Chlorothalonil	950 ml glass	Cool to 4°C	7 days prior to extraction. 40 days after extraction.
Metals Aluminum, Antimony, Arsenic, Barium, Beryllium, Boron, Cadmium, Calcium, Chromium, Cobalt, Copper, Gold, Iron, Lead, Lithium, Magnesium, Manganese, Nickel, Sodium, Phosphorus, Potassium, Selenium, Silicon, Silver, Strontium, Sulfur, Thallium, Tin, Vanadium, Zinc	1000 ml plastic	Filter on site HNO_3 to pH <2 Cool to 4°C	6 months

Appendix C: SUMMARY OF WATER QUALITY ANALYSES

	PARAMETER	WATER QUALITY STANDARD	TOTAL NUMBER OF SAMPLES	SAMPLES < 6.5	SAMPLES 6.5 - 8.5	SAMPLES > 8.5
GENERAL PARAMETERS	pH	6.5 - 8.5 pH units[2]	96	0	96	0

	PARAMETER	WATER QUALITY STANDARD	TOTAL NUMBER OF SAMPLES	SAMPLES < MDL	SAMPLES W/DETECTS	DETECTS > STANDARD	DETECTS > 1/2 STANDARD
GENERAL PARAMETERS	TOC	-	96	28	68	-	-
INORGANICS	Chloride	250 mg/L [2]	96	0	96	0	0
	Sulfate	250 mg/L [2]	96	1	95	0	0
NUTRIENTS	Ammonia-N	0.110 mg/L [4]	96	86	10	0	2
	Nitrate-N	10 mg/L [1]	96	0	96	0	23
	Nitrite-N	1 mg/L [1]	96	5	91	0	0
	Orthophosphate-P	0.04 mg/L [7]	96	1	95	44	80
	Total Phosphorus	0.1 mg/L [6]	96	43	53	4	17
PESTICIDES	Alachlor	0.002 mg/L [1]	95	94	1	0	0
	Atrazine	0.003 mg/L [1]	95	71	24	8	11
	Atrazine	***0.00067 mg/L [4]***	***95***	***71***	***24***	***20***	***24***
	Metolachlor	0.1 mg/L [3]	95	87	8	0	0
	Simazine	0.004 mg/L [1]	95	84	11	0	0
RESIDUES	TDS	500 mg/L [2]	96	5	91	0	33
	TSS	35 mg/L [5]	96	54	42	3	8

* Pesticides sample for Buttermilk Falls on 4/26/00 was destroyed.

Standards:
[1] MCL (Maximum Contaminant Level)
[2] SMCL (Secondary Maximum Contaminant Level)
[3] HAL (Health Advisory Level)
[4] DEP (Kentucky Department for Environmental Protection risk-based number)
[5] KPDES (Kentucky Pollutant Discharge Elimination System)
[6] NAWQA (National Water-Quality Assessment Program (USGS))
[7] TXSW (Texas Surface Water Standard)

Summary Statistics - pH

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	7.44	7.70	8.08	0.286
FRENCH CREEK	#1838	8	7.39	7.63	8.13	0.242
BUTTERMILK FALLS	#1824	8	7.77	7.92	8.32	0.447
HEAD OF WOLF CR.	#1063	8	7.59	7.68	8.06	0.140
BARKERS MILL	#0859	8	6.92	7.31	7.85	0.580
RIVER BEND	#0860	8	7.12	7.27	7.72	0.302
COOK'S	#1141	8	7.23	7.36	7.98	0.391
BRELSFORD	#1448	8	6.95	7.38	7.63	0.395
MILL STREAM	#0203	8	7.08	7.48	8.14	0.603
KING	#1489	8	6.76	7.31	7.82	0.390
WALTON	#1457	8	6.87	7.34	7.94	0.445
WRIGHT	#1475	8	7.28	7.57	8.06	0.365
Total		96	6.76	7.58	8.32	0.486
Total NE Springs		32	7.39	7.76	8.32	0.300
Total SW Springs		64	6.76	7.35	8.14	0.380

Summary Statistics – TOC

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	0.8	1.185	22.8	1.15
FRENCH CREEK	#1838	8	0.9	1.4	2.8	1.27
BUTTERMILK FALLS	#1824	8	< 0.5	0.65	1.3	0.345
HEAD OF WOLF CR.	#1063	8	1.4	2.95	4.44	1.75
BARKERS MILL	#0859	8	< 0.5	< 0.5	0.9	0
RIVER BEND	#0860	8	< 0.5	< 0.5	2.1	0.435
COOK'S	#1141	8	< 0.5	0.6	2.1	1.02
BRELSFORD	#1448	8	< 0.5	< 0.5	1.3	0.415
MILL STREAM	#0203	8	0.8	1.5	4.8	1.27
KING	#1489	8	< 0.5	< 0.5	2.4	1.28
WALTON	#1457	8	< 0.5	0.6	3.2	1.87
WRIGHT	#1475	8	0.9	1.4	2.4	0.465
Total		96	< 0.5	0.9	22.8	1.215
Total NE Springs		32	< 0.5	1.335	22.8	1.7
Total SW Springs		64	< 0.5	0.665	4.8	1.05

Summary Statistics - Chloride

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	3.8	7.1	16.8	2.2
FRENCH CREEK	#1838	8	4.6	8.6	10.2	2.6
BUTTERMILK FALLS	#1824	8	4.7	7.8	10.9	2.2
HEAD OF WOLF CR.	#1063	8	2.4	3.9	6.0	1.9
BARKERS MILL	#0859	8	5.5	7.1	8.3	2.2
RIVER BEND	#0860	8	6.4	7.2	8.6	0.8
COOK'S	#1141	8	6.0	8.7	11.0	2.4
BRELSFORD	#1448	8	4.4	5.3	5.7	0.7
MILL STREAM	#0203	8	6.7	9.4	11.8	2.5
KING	#1489	8	4.8	5.5	7.2	1.4
WALTON	#1457	8	4.1	5.4	6.4	1.3
WRIGHT	#1475	8	7.8	9.5	11.2	2.1
Total		96	2.4	7.1	16.8	3.1
NE Total Springs		32	2.4	7.0	16.8	3.7
SW Total Springs		64	4.1	7.1	11.8	2.9

Summary Statistics - Sulfate

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	17.8	37.8	104	36.3
FRENCH CREEK	#1838	8	13.2	20.05	26.3	4.05
BUTTERMILK FALLS	#1824	8	12.9	16.25	25.7	2.3
HEAD OF WOLF CR.	#1063	8	15	21.6	33.4	6.15
BARKERS MILL	#0859	8	< 5	5.65	6.3	0.6
RIVER BEND	#0860	8	5.2	5.75	7.2	0.65
COOK'S	#1141	8	7.2	8.4	10.1	1.8
BRELSFORD	#1448	8	6	6.85	8.2	1.3
MILL STREAM	#0203	8	9.1	11.6	17.4	4.8
KING	#1489	8	5.2	5.95	7.3	0.9
WALTON	#1457	8	5.7	6.8	7.9	1.05
WRIGHT	#1475	8	6.2	6.75	9.6	1.5
Total		96	< 5	8	104	10.45
NE Total Springs		32	12.9	20.3	104	9.75
SW Total Springs		64	< 5	6.7	17.4	2.05

Summary Statistics - Ammonia (NH_3-N)

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	< 0.02	< 0.02	< 0.02	0
FRENCH CREEK	#1838	8	< 0.02	< 0.02	0.05	0.005
BUTTERMILK FALLS	#1824	8	< 0.02	< 0.02	< 0.02	0
HEAD OF WOLF CR.	#1063	8	< 0.02	< 0.02	< 0.02	0
BARKERS MILL	#0859	8	< 0.02	< 0.02	< 0.02	0
RIVER BEND	#0860	8	< 0.02	< 0.02	< 0.02	0
COOK'S	#1141	8	< 0.02	< 0.02	< 0.02	0
BRELSFORD	#1448	8	< 0.02	< 0.02	< 0.02	0
MILL STREAM	#0203	8	< 0.02	< 0.02	0.1	0.015
KING	#1489	8	< 0.02	< 0.02	< 0.02	0
WALTON	#1457	8	< 0.02	< 0.02	< 0.02	0
WRIGHT	#1475	8	< 0.02	0.03	0.06	0.02318
Total		96	< 0.02	< 0.02	0.1	0
NE Total Springs		32	< 0.02	< 0.02	0.05	0
SW Total Springs		64	< 0.02	< 0.02	0.1	0

Summary Statistics - Nitrate (NO_3-N)

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	1.2	2.08	3.03	0.86
FRENCH CREEK	#1838	8	2.49	2.69	3.59	0.425
BUTTERMILK FALLS	#1824	8	1.7	1.83	2.21	0.245
HEAD OF WOLF CR.	#1063	8	0.588	0.767	1.04	0.202
BARKERS MILL	#0859	8	4.54	5.315	6.19	0.59
RIVER BEND	#0860	8	5.24	5.685	6.85	0.77
COOK'S	#1141	8	3.32	4	5.49	1.02
BRELSFORD	#1448	8	1.15	1.82	2.64	1.04
MILL STREAM	#0203	8	3.46	4.43	6.73	2.44
KING	#1489	8	3.46	4.025	4.81	1.07
WALTON	#1457	8	3.23	3.865	6.24	1.085
WRIGHT	#1475	8	3.1	4.825	7.05	2.41
Total		96	0.588	3.63	7.05	2.835
NE Total Springs		32	0.588	1.93	3.59	1.4
SW Total Springs		64	1.15	4.6	7.05	1.84

Summary Statistics - Nitrite (NO_2-N)

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	0.001	0.0025	0.008	0.003
FRENCH CREEK	#1838	8	0.002	0.005	0.01	0.005
BUTTERMILK FALLS	#1824	8	< 0.001	0.002	0.009	0.004
HEAD OF WOLF CR.	#1063	8	0.002	0.0045	0.007	0.0045
BARKERS MILL	#0859	8	0.001	0.0025	0.011	0.0025
RIVER BEND	#0860	8	0.001	0.0035	0.012	0.0015
COOK'S	#1141	8	< 0.001	0.0035	0.007	0.0035
BRELSFORD	#1448	8	< 0.001	0.0025	0.007	0.0025
MILL STREAM	#0203	8	0.004	0.008	0.025	0.0075
KING	#1489	8	< 0.001	0.002	0.007	0.004
WALTON	#1457	8	< 0.001	0.0045	0.009	0.005
WRIGHT	#1475	8	0.009	0.0205	0.047	0.0245
Total		96	< 0.001	0.004	0.047	0.005
NE Total Springs		32	< 0.001	0.003	0.01	0.0045
SW Total Springs		64	< 0.001	0.004	0.047	0.006

Summary Statistics - Orthophosphate (PO_4-P)

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	0.013	0.0575	0.082	0.042
FRENCH CREEK	#1838	8	0.01	0.0755	0.103	0.0515
BUTTERMILK FALLS	#1824	8	0.007	0.0185	0.041	0.0255
HEAD OF WOLF CR.	#1063	8	< 0.003	0.029	0.047	0.0335
BARKERS MILL	#0859	8	0.023	0.0435	0.064	0.023
RIVER BEND	#0860	8	0.033	0.0395	0.07	0.025
COOK'S	#1141	8	0.033	0.043	0.075	0.024
BRELSFORD	#1448	8	0.006	0.032	0.045	0.0245
MILL STREAM	#0203	8	0.022	0.049	0.077	0.0245
KING	#1489	8	0.028	0.0315	0.054	0.0145
WALTON	#1457	8	0.016	0.043	0.078	0.0345
WRIGHT	#1475	8	0.007	0.038	0.144	0.03
Total		96	< 0.003	0.0385	0.144	0.0265
NE Total Springs		32	< 0.003	0.0365	0.103	0.0465
SW Total Springs		64	0.006	0.0395	0.144	0.023

Summary Statistics - Total Phosphorus

Spring		Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	< 0.005	< 0.054	0.117	-
FRENCH CREEK	#1838	8	0.03	0.057	0.16	-
BUTTERMILK FALLS	#1824	8	< 0.006	< 0.054	< 0.054	-
HEAD OF WOLF CR.	#1063	8	< 0.005	< 0.054	< 0.054	-
BARKERS MILL	#0859	8	< 0.006	< 0.054	0.06	-
RIVER BEND	#0860	8	< 0.005	< 0.054	0.099	-
COOK'S	#1141	8	< 0.006	< 0.054	0.06	-
BRELSFORD	#1448	8	< 0.005	< 0.054	< 0.054	-
MILL STREAM	#0203	8	< 0.006	< 0.054	0.06	-
KING	#1489	8	< 0.006	< 0.054	0.13	-
WALTON	#1457	8	< 0.006	< 0.054	0.06	-
WRIGHT	#1475	8	< 0.006	< 0.054	< 0.054	-
Total		96	< 0.005	< 0.054	0.16	-
NE Total Springs		32	< 0.005	< 0.054	0.16	-
SW Total Springs		64	< 0.005	< 0.054	0.13	-

Summary Statistics – Alachlor

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	< 0.00002	< 0.00002	< 0.00002	0
FRENCH CREEK	#1838	8	< 0.00002	< 0.00002	< 0.00002	0
BUTTERMILK FALLS	#1824	7	< 0.00002	< 0.00002	0.000046	0
HEAD OF WOLF CR.	#1063	8	< 0.00002	< 0.00002	< 0.00002	0
BARKERS MILL	#0859	8	< 0.00002	< 0.00002	< 0.00002	0
RIVER BEND	#0860	8	< 0.00002	< 0.00002	< 0.00002	0
COOK'S	#1141	8	< 0.00002	< 0.00002	< 0.00002	0
BRELSFORD	#1448	8	< 0.00002	< 0.00002	< 0.00002	0
MILL STREAM	#0203	8	< 0.00002	< 0.00002	< 0.00002	0
KING	#1489	8	< 0.00002	< 0.00002	< 0.00002	0
WALTON	#1457	8	< 0.00002	< 0.00002	< 0.00002	0
WRIGHT	#1475	8	< 0.00002	< 0.00002	< 0.00002	0
Total		95	< 0.00002	< 0.00002	0.000046	0
NE Total Springs		31	< 0.00002	< 0.00002	0.000046	0
SW Total Springs		64	< 0.00002	< 0.00002	< 0.00002	0

Summary Statistics - Atrazine

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	< 0.0003	< 0.0003	0.000674	0.000124
FRENCH CREEK	#1838	8	< 0.0003	< 0.0003	0.006746	0
BUTTERMILK FALLS	#1824	7	< 0.0003	< 0.0003	0.003934	0.000901
HEAD OF WOLF CR.	#1063	8	< 0.0003	< 0.0003	0.002942	0
BARKERS MILL	#0859	8	< 0.0003	< 0.0003	0.00074	0
RIVER BEND	#0860	8	< 0.0003	< 0.0003	0.003154	0.000519
COOK'S	#1141	8	< 0.0003	< 0.0003	0.0062	0.0002645
BRELSFORD	#1448	8	< 0.0003	< 0.0003	0.001448	0.0001425
MILL STREAM	#0203	8	< 0.0003	< 0.0003	0.002993	0.001403
KING	#1489	8	< 0.0003	< 0.0003	0.009929	0.0006355
WALTON	#1457	8	< 0.0003	< 0.0003	0.011903	0.0016505
WRIGHT	#1475	8	< 0.0003	< 0.0003	0.001146	0.0001455
Total		95	< 0.0003	< 0.0003	0.011903	0.000109
NE Total Springs		31	< 0.0003	< 0.0003	0.006746	0
SW Total Springs		64	< 0.0003	< 0.0003	0.011903	0.0002335

Summary Statistics - Metolachlor

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	< 0.0002	< 0.0002	< 0.0002	0
FRENCH CREEK	#1838	8	< 0.0002	< 0.0002	< 0.0002	0
BUTTERMILK FALLS	#1824	7	< 0.0002	< 0.0002	< 0.0002	0
HEAD OF WOLF CR.	#1063	8	< 0.0002	< 0.0002	0.0002	0
BARKERS MILL	#0859	8	< 0.0002	< 0.0002	< 0.0002	0
RIVER BEND	#0860	8	< 0.0002	< 0.0002	0.000567	0
COOK'S	#1141	8	< 0.0002	< 0.0002	0.00133	0
BRELSFORD	#1448	8	< 0.0002	< 0.0002	< 0.0002	0
MILL STREAM	#0203	8	< 0.0002	< 0.0002	0.00055	0.0000685
KING	#1489	8	< 0.0002	< 0.0002	0.000302	0
WALTON	#1457	8	< 0.0002	< 0.0002	0.001901	0.0000245
WRIGHT	#1475	8	< 0.0002	< 0.0002	< 0.0002	0
Total		95	< 0.0002	< 0.0002	0.001901	0
NE Total Springs		31	< 0.0002	< 0.0002	0.0002	0
SW Total Springs		64	< 0.0002	< 0.0002	0.001901	0

Summary Statistics - Simazine

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	< 0.0003	< 0.0003	< 0.0003	0
FRENCH CREEK	#1838	8	< 0.0003	< 0.0003	0.001243	0
BUTTERMILK FALLS	#1824	7	< 0.0003	< 0.0003	0.001311	0.000415
HEAD OF WOLF CR.	#1063	8	< 0.0003	< 0.0003	0.00083	0
BARKERS MILL	#0859	8	< 0.0003	< 0.0003	< 0.0003	0
RIVER BEND	#0860	8	< 0.0003	< 0.0003	0.000487	0.000046
COOK'S	#1141	8	< 0.0003	< 0.0003	0.000602	0
BRELSFORD	#1448	8	< 0.0003	< 0.0003	< 0.0003	0
MILL STREAM	#0203	8	< 0.0003	< 0.0003	0.001579	0.0002075
KING	#1489	8	< 0.0003	< 0.0003	0.000556	0
WALTON	#1457	8	< 0.0003	< 0.0003	< 0.0003	0
WRIGHT	#1475	8	< 0.0003	< 0.0003	0.000561	0
Total		95	< 0.0003	< 0.0003	0.001579	0
NE Total Springs		31	< 0.0003	< 0.0003	0.001311	0
SW Total Springs		64	< 0.0003	< 0.0003	0.001579	0

Summary Statistics - TDS

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	196	290	462	113
FRENCH CREEK	#1838	8	190	246	334	71
BUTTERMILK FALLS	#1824	8	< 10	253	358	96
HEAD OF WOLF CR.	#1063	8	80	156	220	96
BARKERS MILL	#0859	8	160	235	294	34
RIVER BEND	#0860	8	152	258	310	55
COOK'S	#1141	8	220	244	302	37
BRELSFORD	#1448	8	< 10	125	224	162
MILL STREAM	#0203	8	< 10	252	344	125
KING	#1489	8	< 10	181	274	75
WALTON	#1457	8	36	225	252	60
WRIGHT	#1475	8	172	233	266	51
Total		96	< 10	232	462	73
NE Total Springs		32	10	235	462	110
SW Total Springs		64	< 10	226	344	74

Summary Statistics - TSS

Spring	ID #	Count	Minimum	Median	Maximum	Interquartile Range
BOILING	#0855	8	< 3	3.5	92	11
FRENCH CREEK	#1838	8	< 3	14	45	22.5
BUTTERMILK FALLS	#1824	8	< 3	< 3	21	3
HEAD OF WOLF CR.	#1063	8	< 3	< 3	20	5
BARKERS MILL	#0859	8	< 3	3.5	9	5.5
RIVER BEND	#0860	8	< 3	4.5	17	4
COOK'S	#1141	8	< 3	3.5	8	3
BRELSFORD	#1448	8	< 3	< 3	13	1
MILL STREAM	#0203	8	< 3	< 3	15	5
KING	#1489	8	< 3	3.5	55	9.5
WALTON	#1457	8	< 3	< 3	4	0
WRIGHT	#1475	8	< 3	< 3	20	11
Total		96	< 3	< 3	92	4.5
NE Total Springs		32	< 3	< 3	92	12.5
SW Total Springs		64	< 3	< 3	55	3.5

APPENDIX D: INDIVIDUAL DYE-TRACE RECORDS

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** ~~Kangy~~ Kanagy Sink   # 95 - 10 - JAR (Year – Trace # – Initials)
2. **Date of Injection:** 11 / 30 / 95 (Month / Day / Year)   **Time:** 3:50 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Melvin Kangy   **Phone:** ( )
4. **Quadrangle/County:** Guthrie / Todd
5. **Elevation:** 620' (✓) map ( ) measured   6. **Latitude:**   **Longitude:**
7. **Description of Injection Site:**
   - ( ) sinking stream   (✓) sinkhole   ( ) water well   ( ) injection well
   - ( ) losing stream   ( ) karst window   ( ) monitoring well   ( ) septic system
   - ( ) lagoon   ( ) cave stream   ( ) other

   Remarks
8. **Formation Receiving Tracer Injection:** Ste. Genevieve LS.
9. **Flow Conditions:** (✓) low ( ) moderate ( ) high
10. **Induced Flow?** ( ) no (✓) yes   100 gal (Pre-injection) / 50 gal (Post-injection)   30 (Elapsed Time) minutes
11. **Tracing Agent:** Amt 3.0 lb   ( ) Fluor. ( ) Rhod. WT ( ) OB (✓) DY96 ( ) other

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray   **Field Personnel** Bill Stapleton

Precipitation before & during trace

ID	Location of Dye Receptors	Background	Results				
	Date	11-20	11-30	12-6	12-13	12-19	12-29
	Duration	4d					
1	Guthrie Trib-TN	–	/	/	–		
2	Merriweather E	~	L	–	L	N	
4	Spillway Sp.	–	–	–	–	–	
5	Sadler Sp.	–	–	–Dry	D	–	
7	Downer Sp.	Dry	D	D	D	D	
8	Sp. Cr. @ Downer	–	–	–	–	–	
9	Yodell Sp.	Dry	D	D	D	N	
10	Sp. Cr. @ Lester	–	–	–	–	/	
14	Sp. Cr. @ 181	–	–	–	–	/	
20	Franks BH	–	–	+	+	/	+
21	Franks Stream	–	–	–	+	/	–
22	Cain Sp.	–	–	–	~	/	
23	Stooksbury Sp.	–	–	–	–	?	
3	Merriweather W		N	L	L	N	
24	Wright Sp.		N	–	–	–	
25	Short Run Sp. (Duck Sp)		N	–	–	–	

go to 95-13-JAR

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks TT = 3.7 Km in 139 hr = 27 M/hr. (Franks BH)

Interpretation

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): ______________________ # 95-10-JAR (cont.)
   Year -- Trace # -- Initials

2. Date of Injection: ________ / ________ / ________ Time: __________ ( ) a.m. ( ) p.m.
   Month / Day / Year

3. Owner of Injection Site: ______________________ Phone: ( ) __________

4. Quadrangle/County: ______________________ / ______________________

5. Elevation: ________ ( ) map ( ) measured 6. Latitude: __________ Longitude: __________

7. Description of Injection Site:
   - ( ) sinking stream
   - ( ) losing stream
   - ( ) lagoon
   - ( ) sinkhole
   - ( ) karst window
   - ( ) cave stream
   - ( ) water well
   - ( ) monitoring well
   - ( ) other
   - ( ) injection well
   - ( ) septic system

   Remarks ______________________

8. Formation Receiving Tracer Injection: ______________________

9. Flow Conditions: ( ) low ( ) moderate ( ) high

10. Induced Flow? ( ) no ( ) yes ________ / ________ (Pre-injection / Post-injection) ________ (Elapsed Time) minutes

11. Tracing Agent: Amt ________ ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ________

RECORD OF DYE TRACE

Principal Investigator ______________________ Field Personnel ______________________

Precipitation before & during trace ______________________

		Date	11-30	12-6	12-13	12-19	12-28									
		Duration														
ID	Location of Dye Receptors	Background	Results													
26	Culvert Sp (Gorby Sp)			N	—	—										
27	Herman Win.		N	—	—	/	—	R								
28	Mouth of Merriwether Run		N	—	—	—										
29	Robertson Window			N	—	—										

Go to 95-13-JAR

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- — Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______________________

Interpretation ______________________

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Wright Swallet **#** 96 – 2 – JAR (Year – Trace # – Initials)
2. **Date of Injection:** 1 / 17 / 96 (Month / Day / Year) **Time:** ____ ( ) a.m. ( ) p.m.
3. **Owner of Injection Site:** Wright **Phone:** ( ) ____
4. **Quadrangle/County:** Allensville / Todd
5. **Elevation:** 535' (✓) map ( ) measured **6. Latitude:** ____ **Longitude:** ____
7. **Description of Injection Site:**
   - ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream (✓) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ____
8. **Formation Receiving Tracer Injection:** Ste. Genevieve Limestone
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ____ / ____ (Pre-injection / Post-injection) ____ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 0.2 gal. ( ) Fluor. (✓) Rhod. WT ( ) OB ( ) DY96 ( ) other ____

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** Bill Stapleton

Precipitation before & during trace ____

ID	Location of Dye Receptors	Background (Date 1-17)	1-22 (Duration 5d)	1-29 (Duration 12)	2-6	Results
25	Duck Sp.	–	–	–	/	
26	Gorby. Sp.	–	–	–	/	
29	Robertson Win.	–	–	–	/	go to 96-2(rep.)-JAR
32	Barton Sp.	N	–	/	/	

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ____

Interpretation ____

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Wright Swallet # 96-2(rep) JAR (Year – Trace # – Initials)

2. Date of Injection: 2 / 14 / 96 (Month / Day / Year) Time: 1:50 ( ) a.m. (✓) p.m.

3. Owner of Injection Site: Wright Phone: ( )

4. Quadrangle/County: Allensville / Todd

5. Elevation: 535 (✓) map ( ) measured 6. Latitude: Longitude:

7. Description of Injection Site:
   - ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream (✓) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks

8. Formation Receiving Tracer Injection: Ste. Genevieve Ls.

9. Flow Conditions: ( ) low (✓) moderate ( ) high

10. Induced Flow? (✓) no ( ) yes ____ / ____ (Pre-injection / Post-injection) ____ minutes (Elapsed Time)

11. Tracing Agent: Amt 1.5 lb ( ) Fluor. ( ) Rhod. WT ( ) OB (✓) DY96 ( ) other

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray Field Personnel Bill Stapleton

Precipitation before & during trace

ID	Location of Dye Receptors	Background (Date 2-14)	2-20	2-27	3-4	
	Duration					
25	Duck Sp	—	—	—	—R	
26	Gorby Sp	—	—	—	—R	
29	Robertson Win.	—	—	—R		END TRACE
35	Underflow Sp (up)	—	+	/		
36	Underflow Sp (down)	N	++	/		
37	Elk Fork @ Railroad	/	/	?	R	
38	Elk Fork @ Bridge	—	+	—	R	
39	Gorby Sp #2	N	—	—	—R	
42	Cave Sp	N	L	—	—R	
43	Elk Fork @ Gorby	N	/	?	R	
44	Rum Sp. Cr.	—	/	—	R	
45	Emancipation Sp	—	—	—	R	
46	Gate Sp	N	—	—	—R	

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- — Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks

Interpretation

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Thomas Pools # 97-27-JAR (Year – Trace # – Initials)
2. **Date of Injection:** 12 / 4 / 97 (Month / Day / Year) **Time:** 11:00 (✓) a.m. ( ) p.m.
3. **Owner of Injection Site:** Thomas Estates **Phone:** ( )
4. **Quadrangle/County:** Herndon / Christian
5. **Elevation:** 520' (✓) map ( ) measured 6. **Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   - ( ) sinking stream
   - (✓) losing stream
   - ( ) lagoon
   - ( ) sinkhole
   - ( ) karst window
   - ( ) cave stream
   - ( ) water well
   - ( ) monitoring well
   - ( ) other
   - ( ) injection well
   - ( ) septic system

   Remarks: Infiltration through gravel
8. **Formation Receiving Tracer Injection:** ______
9. **Flow Conditions:** (✓) low ( ) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 9 oz. (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** ______

Precipitation before & during trace ______

	Date	12-4	12-12	12-17	1-13	1-22	1-29	2-6	2-20						
	Duration														
ID	**Location of Dye Receptors**	**Back-ground**	**Results**												
1	King Sp up	—	+++	++	++	+	/	+	+						
2	King Sp Middle	N	+++	/	+R										
3	King Sp Down	—	++	++	+	+	/	+	B+						
4	King Sp Middle overflow	N	+	/	+R										
5	King Sp Bluehole	N	+	/	/	/	/	/	/						
6	McCraw Sp	N	—	—	—	—	P?	—	—						
7	Buchanan Sp	N	/	/	/	/	/	/	/						
8	Little River up from King Sp		N	B+	B+R (↘ From Hopkinsville STP)										
9	Jones Mill Sp					N	—	—	—						
1	Walton Sp (changed to 11)				N	—	—	—	go to 98-5-JAR						
12	Head of Casey Cr (12)				N	—	—	—							
12	Casey Cr above Head (13)				N	—	—	—							

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- — Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- P Poor Circulation

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Smithson Insurgence # 98 - 2 - JAR (Rep) 4·20 (Year – Trace # – Initials)
2. Date of Injection: 1 (Rep) 4 / 13 9 / 98 98 (Month / Day / Year) Time: 4:22 ( ) a.m. (✓) p.m.
3. Owner of Injection Site: Douglas Smithson Phone: (502) 271-2528
4. Quadrangle/County: Herndon / Christian
5. Elevation: 535' (✓) map ( ) measured 6. Latitude: ______ Longitude: ______
7. Description of Injection Site:
   - (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ______
8. Formation Receiving Tracer Injection: ______
9. Flow Conditions: ( ) low (✓) moderate ( ) high
10. Induced Flow? (✓) no ( ) yes ______ Pre-injection / ______ Post-injection ______ Elapsed Time minutes
11. Tracing Agent: Amt 0.5– 0.75 lb (Rep) 1.0 oz ( ) Fluor. ( ) Rhod. WT ( ) OB (✓) DY96 ( ) other Fluor

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray Field Personnel ______

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background					
	Date	1-14	1-22	4-9	5-15		
	Duration						
			Results				
1	King Sp, ~~down~~ up		?	–	+	R	
3	King Sp. Down	–	+	–	+	R	
6	McCraw Sp		–				
9	Jones Mill Sp		N				
11	Walton Sp		–				
12	Head of Casey Cr		–				
13	Casey Cr above #9		–				

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______

Interpretation Perennial distributary

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Roaring Spring Sink # 98 - 4 - JAR (Year – Trace # – Initials)
2. Date of Injection: 1 / 29 / 98 (Month / Day / Year) Time: 1:00 ( ) a.m. (✓) p.m.
3. Owner of Injection Site: Jeff Choate Phone: (502) 271-2150
4. Quadrangle/County: Roaring Spring / Trigg
5. Elevation: 483 (✓) map ( ) measured 6. Latitude: ______ Longitude: ______
7. Description of Injection Site:
   - ( ) sinking stream (✓) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks: dye injected into trickle
8. Formation Receiving Tracer Injection: ______
9. Flow Conditions: (✓) low ( ) moderate ( ) high
10. Induced Flow? (✓) no ( ) yes ____ / ____ (Pre-Injection / Post-Injection) ____ (Elapsed Time) minutes
11. Tracing Agent: Amt 1.5 gal ( ) Fluor. ( ) Rhod. WT (✓) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator ______ Field Personnel ______

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background (Date 1-29)	Results 2-6	Results 2-20	Results 3-4
	Duration				
1	King Sp Up	/	–	–	–
3	King Sp Down	/	–	–	–
6	McCraw Sp	–	–	–	–
9	Jones Mill Sp	–	–	–	–
10	Big Sulphur Cave Sp	N	–	–	–
11	Walton Sp	–	++	+	–
12	Head of Casey Cr	–	–	–	–
13	Casey Cr above Head	–	–	–	–
14	Jones Window		N	+	R
15	Moore Window		N	+	R

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Garnett ~~losing~~ Sinking Cr. **#** 98 - 5 - JAR
   Year – Trace # – Initials

2. **Date of Injection:** 1 / 29 / 98 (Month / Day / Year) **Time:** 2:00 ( ) a.m. (✓) p.m.

3. **Owner of Injection Site:** William Garnett (c Phillips) **Phone:** (502) 886-6821 (shop)

4. **Quadrangle/County:** ______ / ______

5. **Elevation:** ______ ( ) map ( ) measured **6. Latitude:** ______ **Longitude:** ______

7. **Description of Injection Site:**
   - ( ) sinking stream
   - (✓) losing stream
   - ( ) lagoon
   - ( ) sinkhole
   - ( ) karst window
   - ( ) cave stream
   - ( ) water well
   - ( ) monitoring well
   - ( ) other
   - ( ) injection well
   - ( ) septic system

   Remarks ______

8. **Formation Receiving Tracer Injection:** ______

9. **Flow Conditions:** (✓) low ( ) moderate ( ) high

10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)

11. **Tracing Agent: Amt** 0.75 lb (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator ______ **Field Personnel** ______

Precipitation before & during trace ______

[redacted]	Date		1-29	2-6	2-20	3-4
	Duration					
ID	**Location of Dye Receptors**	**Back-ground**	**Results**			
1	King Sp Up		/	B*	B	—
3	King Sp Down		/	B	B	—
6	McCraw Sp		P?	—	—	
9	Jones Mill Sp		—	—	—	—
10	Big Sulphur Cave Sp		N	—	—	—
11	Walton Sp		—	—	+++	+
12	Head of Casey Cr		—	—	—	—
13	Casey Cr above Head		—	—	—	—
14	Jones Window			N	+++	R
15	Moore Window			N	+++	R

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- — Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- P Poor Circulation

Remarks B* from test #97-27-JAR

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Walker Swallet # 98 - 8 - JAR (Year – Trace # – Initials)

2. Date of Injection: 3 / 17 / 98 (Month / Day / Year) Time: 2:30 ( ) a.m. (✓) p.m.

3. Owner of Injection Site: Doug Walker Phone: (502) 886-2742

4. Quadrangle/County: Caledonia / Christian

5. Elevation: 495' (✓) map ( ) measured 6. Latitude: ____ Longitude: ____

7. Description of Injection Site:
   - (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ____

8. Formation Receiving Tracer Injection: ____

9. Flow Conditions: (✓) low ( ) moderate ( ) high

10. Induced Flow? (✓) no ( ) yes ____ / ____ (Pre-injection / Post-injection) ____ minutes (Elapsed Time)

11. Tracing Agent: Amt 3/8 gal ( ) Fluor. (✓) Rhod. WT ( ) OB ( ) DY96 ( ) other ____

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray Field Personnel ____

Precipitation before & during trace ____

ID	Location of Dye Receptors	Background	Results					
	Date	3-17	3-26	4-9	4-15	4-23	4-29	6-2
	Duration							6-3
1	River Bend Sp	–	++	+	+	–	?	–
2	Caledonia BH	–	–	–	–	–	–	–
3	Cane Overflow	–	–	–	–	–	/	–
4	Little River up from RiverBend Sp	N	–	–	–	–R		
5	Sinking Fork up from #3	N	P	–R				
6	Baker Sp	N	–	/	–	/	/	/
7	Cane Sp	N	–	–	/	/	/	/
8	Brellsford Sp	N	–	–	–	–	–	/
9	Lawrence Boil	N	–	–	–	/	–	–
10	Mill Stream Sp	N	–	–	/	–	/	–
11	Stream @ Julien	N	–	/	–R			
12	Hardy Sp	N	–	/	/	/	/	/

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- P Poor Circulation

Remarks ____

Interpretation ____

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Bradey Lane Swallet # 98 - 9 - JAR (Year - Trace # - Initials)
2. **Date of Injection:** 3 / 17 / 98 (Month / Day / Year) **Time:** 3:30 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Billy Williams **Phone:** (502) 886-4566
4. **Quadrangle/County:** Church Hill / Christian
5. **Elevation:** 485' (✓) map ( ) measured 6. **Latitude:** ____ **Longitude:** ____
7. **Description of Injection Site:**
   - (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ____
8. **Formation Receiving Tracer Injection:** ____
9. **Flow Conditions:** (✓) low ( ) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ____ / ____ (Pre-injection / Post-injection) ____ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 12 oz (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ____

RECORD OF DYE TRACE

Principal Investigator Joseph Ray **Field Personnel** Phil O'dell

Precipitation before & during trace ____

ID	Location of Dye Receptors	Background (Date 3-17)	3-26	4-9	4-15	4-23	4-29	6-2 (Duration 6-3)
1	River Bend Sp	—	—	—	—	—	—	—
2	Caledonia BH	—	—	—	—	—	—	—
3	Cane Overflow	—	—	—	—	—	/	—
4	Little River up from RiverBend Sp	N	—	—	B	B R		
5	Sinking Fork up from #3	N	P	— R				
6	Baker Sp	N	—	/	—	/	/	/
7	Cane Sp	N	+	—	/	/	/	/
8	Brellsford Sp	N	—	—	—	—	—	—
9	Lawrence Boil	N	—	—	—	/	—	—
10	Mill Stream Sp	N	+++	+	/	+	/	?
11	Stream @ Julien	N	—	/	— R			
12	Hardy Sp	N	—	/	/	/	/	/

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- — Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- P Poor Circulation

Remarks ____

Interpretation ____

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Sholar Swallet # 98-20-JAR (Year – Trace # – Initials)
2. **Date of Injection:** 4 (Month) / 8 (Day) / 98 (Year) **Time:** 2:30 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** ______ **Phone:** ( ) ______
4. **Quadrangle/County:** ______ / ______
5. **Elevation:** ______ ( ) map ( ) measured 6. **Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   - (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ______
8. **Formation Receiving Tracer Injection:** ______
9. **Flow Conditions:** (✓) low ( ) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 1 pint ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (✓) other Eocene

RECORD OF DYE TRACE

Principal Investigator ______ **Field Personnel** ______

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background (Date 4-9)	4-15	4-23	4-29	5-15	
	Duration						
8	Brellsford Sp	–	–	–	–	–	
9	Lawrence Boils	–	–	/	–	/	
15	Garnett Sp	–	+++	/	+	?	end
17	Head of Casey Cr				N	–	

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Adams Swallet **#** 98-21-JAR (Year – Trace # – Initials)

2. **Date of Injection:** 4 / 8 / 98 (Month / Day / Year) **Time:** 4:40 ( ) a.m. (✓) p.m.

3. **Owner of Injection Site:** ______ **Phone:** ( ) ______

4. **Quadrangle/County:** ______ / ______

5. **Elevation:** ______ ( ) map ( ) measured **6. Latitude:** ______ **Longitude:** ______

7. **Description of Injection Site:**
   - ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ______

8. **Formation Receiving Tracer Injection:** ______

9. **Flow Conditions:** ( ) low ( ) moderate ( ) high

10. **Induced Flow?** ( ) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)

11. **Tracing Agent:** Amt 2 oz (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator ______ **Field Personnel** ______

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background	4-9	4-15	4-23	4-29	5-15										
	Duration																
8	Brellsford Sp	–	–	–	–	–											
9	Lawrence Boils	–	–	/	–	/											
15	Garnett Sp	–	–	/	–	–											

Legend:
- + Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks Losing reach of eastern Trib. of Bunge Creek, 2.6 Mi SW of Brelsford Sp.

Interpretation Not Recovered – Too little dye?

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Payneville Culvert **#** 98 - 25 - JAR (Year – Trace # – Initials)

2. **Date of Injection:** 4 / 22 / 98 (Month / Day / Year) **Time:** 3:40 ( ) a.m. (✓) p.m.

3. **Owner of Injection Site:** KY DOT **Phone:** ( )

4. **Quadrangle/County:** Irvington / Meade

5. **Elevation:** 790 (✓) map ( ) measured **6. Latitude:** ______ **Longitude:** ______

7. **Description of Injection Site:**
   - ( ) sinking stream
   - (✓) losing stream
   - ( ) lagoon
   - ( ) sinkhole
   - ( ) karst window
   - ( ) cave stream
   - ( ) water well
   - ( ) monitoring well
   - ( ) other
   - ( ) injection well
   - ( ) septic system

   Remarks ______

8. **Formation Receiving Tracer Injection:** ______

9. **Flow Conditions:** ( ) low (✓) moderate ( ) high

10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)

11. **Tracing Agent:** Amt 1 pint ( ) Fluor. (✓) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** Jack Moody

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background	4-28	5-6	5-14	5-21	5-28	6-4	6-11	6-25	7-9
	Duration										
			Results								
1	French Cr. Sp. West		–	–							
2	French Cr. Sp. East		–	–	–		/	–	–	–	–
3	French Cr. Overflow		–	/							
4	Sp @ Bridge		–	–							
5	Payneville Elem.		–	–	/	–	/	–	–	/	
7	Oolite Sp		–	–	–	/	/	/	/	/	
9	Head of Wolf Cr		–	?	?	/	+	?	–	–	–
10	Head of Sp. Cr.		/	/	/	–	/	/	–	/	–
~~11~~	~~Hamilton Hill BH~~		/	/	/	/					
12	Boiling Sp.		/	/	–	/	/	/	/	/	

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Mathews Swallet **#** 98-26-JAR (Year – Trace # – Initials)

2. **Date of Injection:** 4 (Month) / 22 (Day) / 98 (Year) **Time:** 3:50 ( ) a.m. (✓) p.m.

3. **Owner of Injection Site:** Mathews **Phone:** ( )

4. **Quadrangle/County:** Irvington / Meade

5. **Elevation:** 610 ( ) map ( ) measured **6. Latitude:** ____ **Longitude:** ____

7. **Description of Injection Site:**

(✓) sinking stream	( ) sinkhole	( ) water well	( ) injection well
( ) losing stream	( ) karst window	( ) monitoring well	( ) septic system
( ) lagoon	( ) cave stream	( ) other	

Remarks ____

8. **Formation Receiving Tracer Injection:** ____

9. **Flow Conditions:** ( ) low (✓) moderate ( ) high

10. **Induced Flow?** (✓) no ( ) yes ____ / ____ (Pre-injection / Post-injection) ____ (Elapsed Time) minutes

11. **Tracing Agent:** Amt 10 oz. (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ____

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** Jack Moody

Precipitation before & during trace ____

ID	Location of Dye Receptors	Background	4-28	5-6	5-14	5-21	5-28	6-4	6-11	6-25	7-9	7-16	7-23	7-28		
	Duration															
1	French Cr. Sp. West		–	–												
2	French Cr. Sp East		–	–	–		/	–B	–	–B	–B	–B	–	/		
3	French Cr. Overflow		–	/												
4	Sp @ Bridge		–	–												
5	Payneville Elem.		–	–	/	–	/	–	–	/	/	/	/	/		
7	Oolite Sp		B	–	–	/	/	/	/	/	/	/	/	/		
9	Head of Wolf Cr.		–	+	+	/	+	+	+	+?	–B	–B	–	–		
10	Head of Sp. Cr.		/	/	/	–	/	/	–	/	–	/	/	–		
~~11~~	~~Hamilton Hill BH~~		~~/~~	/												
12	Boiling Sp.		/	/	B	/	/	/	/	/	/	/	/	/		

Legend: + Positive; ++ Very Positive; +++ Extremely Positive; – Negative Results; B Perceptible Background (slight); B+ Significant Background (problematic); NR Not Recovered (high water, stolen receptor, etc); R Receptor removed; / Receptor Not Changed; L Receptor lost; N New Receptor Installed

Remarks 1 through 4 consolidated at culvert

Interpretation ____

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Skinner Creek Swallet # 98 - 32 - JAR (Year – Trace # – Initials)
2. **Date of Injection:** 5 (Month) / ~~19~~ 15 (Day) / 98 (Year) **Time:** ______ ( ) a.m. ( ) p.m.
3. **Owner of Injection Site:** ______ **Phone:** ( ) ______
4. **Quadrangle/County:** ______ / ______
5. **Elevation:** ______ ( ) map ( ) measured 6. **Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   - ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - (✓) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ______
8. **Formation Receiving Tracer Injection:** ______
9. **Flow Conditions:** ( ) low ( ) moderate ( ) high
10. **Induced Flow?** ( ) no ( ) yes ______ (Pre-injection) / ______ (Post-injection) ______ (Elapsed Time) minutes
11. **Tracing Agent:** Amt 6 oz (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator ______ **Field Personnel** ______

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background (Date 5-15)	5-19	6-2	6-9	7-1
	Duration					
8	Brellsford Sp	–	–	–	/	–
9	Lawrence Birds	/	/	–	/	–
15	Garnett Sp. Main	–	–	–	–	–
17	Head of Casey Cr	–	++	++	/	+
18	Garnett Sp. South	N	–	–	/	–
13	Casey Cr. above Head	N	/	/	/	–

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Brame Window # 98 - 22 - JAR (Rep)
   Year – Trace # – Initials
2. **Date of Injection:** 4 / 9 / 98 (Month / Day / Year) — 6 / 3 / 98 **Time:** 3:00 — 1:25 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** David Brame **Phone:** ( )
4. **Quadrangle/County:** Church Hill / Christian
5. **Elevation:** 510' (✓) map ( ) measured 6. **Latitude:** **Longitude:**
7. **Description of Injection Site:**
   ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   ( ) losing stream (✓) karst window ( ) monitoring well ( ) septic system
   ( ) lagoon ( ) cave stream ( ) other
   Remarks
8. **Formation Receiving Tracer Injection:**
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ____ / ____ (Pre-Injection / Post-Injection) ____ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 1/3 gal (Rep) ½oz (✓)Fluor ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (✓) other Eocene

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** Phil O'dell

Precipitation before & during trace

ID	Location of Dye Receptors	Background	Results													
	Date	4-9	4-15	4-23	4-29					5-19	6-3	6-9	7-14			
	Duration															
1	River Bend Sp	—	—	—	—						—					
2	Caledonia BH	—	—	—	—						—	—				
3	Cane Overflow	—	—	—	/						—					
4	Little River up from RiverBend Sp	—	—	—R.												
5	Sinking Fork up from #3	—R														
6	Baker Sp	/	—	/	/						/					
7	Cane Sp	—	/	/	/						/					
8	Brellsford Sp	—	—	—	—						—					
9	Lawrence Boil	—	—	/	—						—					
10	Mill Stream Sp	—	/	—	/						—					
11	Stream @ Julien	/	—R			19 Adams Sp				—	—	++	?			
12	Hardy Sp	/	/	/	/	20 Adams Sp Channel					N	/	+++R			
13	Zook Sp	—	/	—	/	21 Adams Bank					N	/	+++R			
14	Smith Sp	—	/	—	/	22 New House Sp					N	/	+++R			
16	Lilly Sp	N	/	—R												

Legend:
+ Positive
++ Very Positive
+++ Extremely Positive
— Negative Results
B Perceptible Background (slight)
B+ Significant Background (problematic)
NR Not Recovered (high water, stolen receptor, etc)
R Receptor removed
/ Receptor Not Changed
L Receptor lost
N New Receptor Installed

Remarks Eocene detected at I-24 in Little River – Pete Injection

Interpretation

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Kyler Tile Sink # 98 - 36 - JAR (Year -- Trace # -- Initials)
2. Date of Injection: 6 / 2 / 98 (Month / Day / Year) Time: 6:45 ( ) a.m. (✓) p.m.
3. Owner of Injection Site: ______ Phone: ( ) ______
4. Quadrangle/County: Cadiz / Trigg
5. Elevation: 485 (✓) map ( ) measured 6. Latitude: ______ Longitude: ______
7. Description of Injection Site:
   - ( ) sinking stream ( ) sinkhole ( ) water well (✓) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks 2 ft diameter concrete tile installed in sink which floods 15' deep
8. Formation Receiving Tracer Injection: ______
9. Flow Conditions: ( ) low (✓) moderate ( ) high
10. Induced Flow? ( ) no (✓) yes 20 gal / 180 gal (Pre-injection / Post-injection) 15 (Elapsed Time) minutes
11. Tracing Agent: Amt 0.25 gal ( ) Fluor. (✓) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray Field Personnel Phil O'dell

Precipitation before & during trace ______

ID	Location of Dye Receptors	Back-ground	6-2	6-9	6-17	7-1
	Duration					
8	Brellsford Sp	—	/	+	—	
9	Lawrence Boils	—	/	/	+R	
15	Garnett Sp Main	—	—	/	—	
17	Head Casey Cr.	—	/	/	—	
18	Garnett Sp South	/	/	/	—	
13	Casey Creek above Head	/	/	/	—	

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- — Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Franks Bluehole #98 - 38 - JAR (Year – Trace # – Initials)
2. **Date of Injection:** 7 / 1 / 98 (Month / Day / Year) **Time:** 3:45 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Allen Franks **Phone:** ( )
4. **Quadrangle/County:** Guthrie / Todd
5. **Elevation:** 575 (✓) map ( ) measured 6. **Latitude:** **Longitude:**
7. **Description of Injection Site:**
   - ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream (✓) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks
8. **Formation Receiving Tracer Injection:**
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ____ / ____ (Pre-injection / Post-injection) ____ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 1 oz (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** Phil O'dell

Precipitation before & during trace

ID	Location of Dye Receptors	Background	7-1	7-9	7-29	8-5
	Duration					
1	Coblentz Sp #1	N	+	R		
2	Coblentz Sp #2	N	+	R		
3	Cain Window	N	+	R		
4	Stooksbury Window	N	+	R		
5	Barton Spring	–	–	– R		
9	Oval Sp	/	/	/	– R	

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks

Interpretation

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Sinking Fork at Old Bridge # 98 - 41 - JAR (Year – Trace # – Initials)
2. **Date of Injection:** 7 / 22 / 98 (Month / Day / Year) **Time:** 10:00 (✓ a.m. ( ) p.m.
3. **Owner of Injection Site:** ______ **Phone:** ( ) ______
4. **Quadrangle/County:** Caledonia / Trigg
5. **Elevation:** 425' (✓) map ( ) measured **6. Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   ( ) lagoon ( ) cave stream ( ) other

   Remarks ______
8. **Formation Receiving Tracer Injection:** ______
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)
11. **Tracing Agent:** Amt ½ gal ( ) Fluor. (✓) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** Phil O'Dell

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background (Date 7-22)	Results 7-28	Results 8-12	Results 8-19
1	Mill Stream Sp	–	++	/	–
2	Boatwright Hole	–	+	–	/
3	Pipeline Cave	–	–	–	/
4	McReynolds Win.	–	++	–	/
5	Roaring Crack	N	– R		
6	Pool up from Roaring Crack	N	– R		
7	Caledonia BH	L	–	/	–
8	Cane Sp (Cutoff sp)		N	– R	
9	River Bend Sp	/	/	/	–

Legend:
+ Positive
++ Very Positive
+++ Extremely Positive
– Negative Results
B Perceptible Background (slight)
B+ Significant Background (problematic)
NR Not Recovered (high water, stolen receptor, etc)
R Receptor removed
/ Receptor Not Changed
L Receptor lost
N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Swallet down from Roaring Crack # 98 - 42 - JAR
   (Year – Trace # – Initials)

2. Date of Injection: 7 / 22 / 98 (Month / Day / Year) Time: 12:30 ( ) a.m. (✓) p.m.

3. Owner of Injection Site: ____ Phone: ( ) ____

4. Quadrangle/County: Caledonia / Christian

5. Elevation: 428' (✓) map ( ) measured 6. Latitude: ____ Longitude: ____

7. Description of Injection Site:
   - (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ____

8. Formation Receiving Tracer Injection: ____

9. Flow Conditions: ( ) low (✓) moderate ( ) high

10. Induced Flow? (✓) no ( ) yes ____ / ____ (Pre-injection / Post-injection) ____ minutes (Elapsed Time)

11. Tracing Agent: Amt 1/4 gal ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (✓) other Eocene

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray Field Personnel Phil Odell

Precipitation before & during trace ____

ID	Location of Dye Receptors	Background (Date 7-22)	7-28	8-12	8-19
	Duration				
1	Mill Stream Sp	—	+	/	—
2	Boatwright Hole	—	?	—	
3	Pipeline Cave	—	—	—	
4	McReynolds Win.	—	+	+	
5	Roaring Crack	N	—R		
6	Pool up from Roaring Crack	N	—R		
7	Caledonia BH	L	—	/	—
8	Cane Sp (Cutoff Sp)		N	—	

Legend:
- + Positive
- ++ Very Positive
- +++ Extremely Positive
- — Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ____

Interpretation ____

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Bradey Lane Swallet # 98 - 9-JAR- Rep
   (Year – Trace # – Initials)
2. **Date of Injection:** 7 / 22 / 98 (Month / Day / Year) **Time:** 1:00 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Billy Williams **Phone:** (502) 886-4566
4. **Quadrangle/County:** Church Hill / Christian
5. **Elevation:** 480' (✓) map ( ) measured 6. **Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   ( ) lagoon ( ) cave stream ( ) other

   Remarks ______
8. **Formation Receiving Tracer Injection:** ______
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ (Elapsed Time) minutes
11. **Tracing Agent:** Amt 10 oz (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** Phil O'dell

Precipitation before & during trace ______

	Date	7-22	7-28	8-12	8-19
	Duration				
ID	**Location of Dye Receptors**	**Background**	**Results**		
1	Mill Stream Sp	B	+++	/	+
2	Boatwright Hole	–	++	+	
3	Pipeline Cave	–	++	+	
4	McReynolds Win.	–	+++	+	
5	Roaring Crack	N	+++	R	
6	Pool up from Roaring Crack	N	++	R	
7	Caledonia BH	L	–	/	–
8	Cane Sp (cutoff)		N	–	

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** McCoy Sinkhole # 98 - 43 - JAR (Year -- Trace # -- Initials)
2. **Date of Injection:** 7 / 23 / 98 (Month / Day / Year) **Time:** 5:00 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Mrs McCoy **Phone:** ( )
4. **Quadrangle/County:** GUSTON / MEADE
5. **Elevation:** 670' (X) map ( ) measured **6. Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   - ( ) sinking stream (✓) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ______
8. **Formation Receiving Tracer Injection:** ______
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** ( ) no (✓) yes 50 gal (Pre-injection) / 350 gal (Post-injection) 180 (Elapsed Time) minutes
11. **Tracing Agent:** Amt 2 oz (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** Jack Moody + Pat Keefe

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background	Results													
	Date		7-28	8-5	8-13	8-20	8-27	9-3	9-10							
	Duration															
1	Ekron #1		–	–	–	–	–	–	–							
2	Ekron #2		–	–	–	–	–	–	–							
3	Ekron #3		–	–	–	–	–	–	–							
11	Hamilton Hill BH		–	+	L	L	N	/	B							

end trace ✓

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Vessels Spring # 98 - 44 - JAR (Year – Trace # – Initials)
2. **Date of Injection:** 7 / 28 / 98 (Month / Day / Year) **Time:** 3:48 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Mrs. Vessels **Phone:** ( )
4. **Quadrangle/County:** IRVINGTON / MEADE
5. **Elevation:** 660' (✓) map ( ) measured **6. Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   - (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ______
8. **Formation Receiving Tracer Injection:** ______
9. **Flow Conditions:** (✓) low ( ) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 4 gal ( ) Fluor. (✓) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** Jack Moody, Pat Keefe

Precipitation before & during trace /

ID	Location of Dye Receptors	Background (Date 7-28)	8-5	8-13	8-20	8-27	9-3	9-10	9-17	10-1	10-8			12-9	12-16	12-22	1-6	2-16
Duration																		
B5	PAYNEVILLE ELEM	—	—		—	—	—	—	—	—	—			—	—	—	—	/
B9	HEAD OF WOLF		—	—	—	—	—	/	/	—	—			++	+	+	+	—
B10	HEAD OF SPRING		—	/	—	/	—	/	/	/	—			/	—	/	/	/
B16	LAPLAND SP		—	—	/	—	/	/	/	—	/							

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- — Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks See 98-57 for possible recovery five months later

Interpretation – Recovery delayed by dry fall weather

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** EKRON Trailer Court # 98 - 55 - JAR
   (Year – Trace # – Initials)
2. **Date of Injection:** 10 / 1 / 98 (Month / Day / Year) **Time:** 13:59 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** City of EKRON **Phone:** ( )
4. **Quadrangle/County:** GUSTON / MEADE
5. **Elevation:** ______ ( ) map ( ) measured **6. Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   - ( ) sinking stream ( ) sinkhole ( ) water well (✓) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks: Modified Sinkhole
8. **Formation Receiving Tracer Injection:** ______
9. **Flow Conditions:** ( ) low ( ) moderate ( ) high
10. **Induced Flow?** ( ) no (✓) yes 13:54 (Pre-injection) / 14:05 (Post-injection) ± 210 GAL 9.0 (Elapsed Time) minutes
11. **Tracing Agent:** Amt 4.5 oz (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator JOE RAY **Field Personnel** Jack Moody / Bruce McKinney

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background (Date 10-1)	Results 10-8	Results 10-21	Results 11-4
	Duration				
E-1	EKRON #1	–	+	+	+
E-2	EKRON #2	–	++	+	+
E-3	EKRON #3	–	–	–	–
11	Hamilton Hill Blue Hole	/	–	+	/

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Lilly Sp Low Flow Swallet # 98 -56 -JAR (Year – Trace # – Initials)
2. Date of Injection: 12 / 1 / 98 (Month / Day / Year) Time: 3:00 ( ) a.m. (✓) p.m.
3. Owner of Injection Site: Billy Williams Phone: (502) 886-4566
4. Quadrangle/County: Church Hill / Christian
5. Elevation: 493 (✓) map ( ) measured 6. Latitude: ______ Longitude: ______
7. Description of Injection Site:
   (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   ( ) lagoon ( ) cave stream ( ) other

   Remarks ______
8. Formation Receiving Tracer Injection: ______
9. Flow Conditions: (✓) low ( ) moderate ( ) high
10. Induced Flow? (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)
11. Tracing Agent: Amt 1 lb (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray Field Personnel ______

Precipitation before & during trace Dry for 4 days

		Date	12-15 12-16	12-22											
		Duration													
ID	Location of Dye Receptors	Background	Results												
10	Mill Stream Sp	N	+	-?											
1	River Bend Sp	N	–	–											
3	Pipeline Cave	N	++	/											

Legend: + Positive; ++ Very Positive; +++ Extremely Positive; – Negative Results; B Perceptible Background (slight); B+ Significant Background (problematic); NR Not Recovered (high water, stolen receptor, etc); R Receptor removed; / Receptor Not Changed; L Receptor lost; N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Moore Swallet # 98-59-JAR (Year – Trace # – Initials)
2. Date of Injection: 12 / 16 / 98 (Month / Day / Year) Time: 11:00 (✓ a.m. ( ) p.m.
3. Owner of Injection Site: Dewayne Moore Phone: (502) 886-1637
4. Quadrangle/County: Church Hill / Christian
5. Elevation: 491' (✓) map ( ) measured 6. Latitude: ______ Longitude: ______
7. Description of Injection Site:
   - (✓) sinking stream
   - ( ) losing stream
   - ( ) lagoon
   - ( ) sinkhole
   - ( ) karst window
   - ( ) cave stream
   - ( ) water well
   - ( ) monitoring well
   - ( ) other
   - ( ) injection well
   - ( ) septic system

   Remarks ______
8. Formation Receiving Tracer Injection: ______
9. Flow Conditions: ( ) low (✓) moderate ( ) high
10. Induced Flow? (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)
11. Tracing Agent: Amt 11 oz ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (✓) other Sulphorhodamine B

RECORD OF DYE TRACE

Principal Investigator Joseph Ray Field Personnel ______

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background (Date 12-16)	12-22	1-19 + 1-20	3-2
1	River Bend Sp	–	–	?	–
3	Pipeline Cave	–	/	/	/
7	Caledonia BH	–	?	+	–
8	Cave Overflow	–	–	+	/
9	Boyd Lake	–	–	/	/
10	Mill Stream Sp	–	–	–	/

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Montgomery Cave # 99-14-JAR (Year – Trace # – Initials)
2. **Date of Injection:** 3 (Month) / 4 (Day) / 99 (Year) **Time:** 16:53 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Unknown **Phone:** ( )
4. **Quadrangle/County:** Irvington / Meade
5. **Elevation:** 760 (✓) map ( ) measured 6. **Latitude:** **Longitude:** --
7. **Description of Injection Site:**
   - ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream (✓) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon (✓) cave stream ( ) other

   Remarks 0.5 cfs in two shallow karst windows beside 30' deep sinkhole
8. **Formation Receiving Tracer Injection:**
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ____ Pre-injection / ____ Post-injection ____ Elapsed Time minutes
11. **Tracing Agent:** Amt 26.5 oz (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other

RECORD OF DYE TRACE

Principal Investigator Joe Ray **Field Personnel** Jack Moody & Pat Keefe

Precipitation before & during trace

	Date	3-4	3-9	3-11	3-16	3-19	3-25	
	Duration							
ID	Location of Dye Receptors	Background	Results					
2	French Creek	–	/	/	–	/	–	
9	Head Wolf Creek	–	/	–	/	/	–	
10	Head Spring Creek	–	/	/	++	–	L	
11	Hamilton Hill Bluehole	/	/	/	/	/	/	End
12	Boiling Spring	–	–	/	–	/	–	
17	Sugar Tree Spring	–	–	/	–	–	/	
18	Sinking Cr. above Boiling	N	–	/	–	/	–R	
19	Mystic Overflow			N	–	–	/	
20	Sugar Tree Run Overflow			N	–	/	/	
21	Yellow Bank Cr	N	/	/	/	L	R	

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks

Interpretation

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Cabin Swallet # 99 - 15 - JAR (Year – Trace # – Initials)
2. **Date of Injection:** 3 / 11 / 99 (Month / Day / Year) **Time:** 1:50 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Tim Smith **Phone:** (502) 422 - 2695
4. **Quadrangle/County:** Lodiburg / Breckinridge
5. **Elevation:** 540 (✓) map ( ) measured 6. **Latitude:** **Longitude:** --
7. **Description of Injection Site:**
   (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   ( ) lagoon ( ) cave stream ( ) other
   Remarks 0.01 cfs into gravel
8. **Formation Receiving Tracer Injection:**
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ____ / ____ (Pre-Injection / Post-Injection) ____ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 3 oz. ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (✓) other Eosine

RECORD OF DYE TRACE

Principal Investigator Joseph Ray **Field Personnel** Jack Moody

Precipitation before & during trace ½ in. 3 days later

	Date	3-4	3-9	3-11	3-16	3-19	3-25	3-30	
	Duration								
ID	**Location of Dye Receptors**	**Back-ground**	**Results**						
2	French Creek	—	/	/	—	/	—	—	
9	Head Wolf Creek	—	/	—	/	/	—	—	
10	Head Spring Creek	—	/	/	—	+	+	—	
11	Hamilton Hill Bluehole	/	/	/	/	/	/	/	
12	Boiling Spring	—	—	/	—	/	—	—	END
17	Sugar Tree Spring	—	—	/	—	—	/	/	
18	Sinking Cr. above Boiling	N	—	/	—	/	— R		
19	Mystic Overflow			N	—	—	/	/	
20	Sugar Tree Run Overflow			N	—	/	/	/	
21	Yellow Bank Cr.	N	/	/	/	L R			
22	Union Star Spring				N	—	/	/	
23	Sinking Creek				N	/	/	/	

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- — Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks

Interpretation

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Dutchke's Swallet # 99 - 16 - JAR
   Year – Trace # – Initials
2. **Date of Injection:** 3 / 11 / 99 (Month / Day / Year) **Time:** 3:30 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Jim Collins **Phone:** ( )
4. **Quadrangle/County:** Irvington /
5. **Elevation:** 655 (✓) map ( ) measured 6. **Latitude:** **Longitude:** --
7. **Description of Injection Site:**
   - ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream (✓) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks 0.15 cfs into swallet
8. **Formation Receiving Tracer Injection:**
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-Injection / Post-Injection) ______ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 5 oz. ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (✓) other SRB

RECORD OF DYE TRACE

Principal Investigator Joseph Ray **Field Personnel** Jack Moody
Precipitation before & during trace ½" 3days Later

	Date	3-4	3-9	3-11	3-16	3-19	3-25	3-30								
	Duration															
ID	Location of Dye Receptors	Background	Results													
2	French Creek	—	/	/	—	/	—	—								
9	Head Wolf Creek	—	/	—	/	/	—	—								
10	Head Spring Creek	—	/	/	—	—	L	—								
11	Hamilton Hill Bluehole	/	/	/	/	/	/	/								
12	Boiling Spring	—	—	/	—	/	—	—								
17	Sugar Tree Spring Burtons Hole		—	/	++	—	/	/								
18	Sinking Cr. above Boiling	N	—	/	—	/	—R		END							
19	Mystic Overflow			N	++	—	/	/								
20	Sugar Tree Run Overflow			N	—	/	/	/								
21	Yellow Bank Cr.	N	/	/	/	LR										
22	Union Star Spring				N	—	/	/								
23	Sinking Creek				N	/	/	/								

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- — Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks

Interpretation

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Millay Sinking Sp **#** 99-20-JAR (Year – Trace # – Initials)

2. **Date of Injection:** 3 / 25 / 99 (Month / Day / Year) **Time:** 16:00 ( ) a.m. (✓) p.m.

3. **Owner of Injection Site:** Harold Millay **Phone:** (502) 547-6341

4. **Quadrangle/County:** Irvington / Meade

5. **Elevation:** 840' (✓) map ( ) measured **6. Latitude:** ___ **Longitude:** --

7. **Description of Injection Site:**
   ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   ( ) lagoon ( ) cave stream ( ) other (✓) Sinking Spring

   Remarks ___

8. **Formation Receiving Tracer Injection:** Beech Cr. Limestone

9. **Flow Conditions:** ( ) low (✓) moderate ( ) high

10. **Induced Flow?** (✓) no ( ) yes ___ / ___ (Pre-injection / Post-injection) ___ (Elapsed Time) minutes

11. **Tracing Agent:** Amt 27 oz. (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ___

RECORD OF DYE TRACE

Principal Investigator Joseph Ray **Field Personnel** ___

Precipitation before & during trace ___

ID	Location of Dye Receptors	Background (Date 3-25)	3-30	4-15	4-22	5-11	5-20	Results
	Duration							
2	French Creek	–	–	–	–	–	–	
9	Head Wolf Creek	–	–	–	–	–	–	
10	Head Spring Creek	L	–	–	–	/	–	
11	Hamilton Hill Bluehole	/	/	L	– P	/	–	
12	Boiling Spring	–	–	+	–	–	–	
17	Sugar Tree Spring (Burton's Hole)	/	/	+++	+	?	–	
~~18~~	~~Sinking Cr. above Boiling~~							End Trace
19	Mystic Overflow	/	/	/	/	–	R	
20	Sugar Tree Run Overflow	/	/	/	/	/	/	
~~21~~	~~Yellow Bank Cr.~~					/		
22	CM Church, Left	N	–	–	/	/	/	
23	CM Church, Right	N	–	–	/	/	/	
24	Webster Overflow	N	– P	– P	/	/	/	
25	Parks Sp Run	N	+++	+++	+	/	–	
26	Sample Sp (3-19)	/	/	/	–	LN	/	

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- P Poor Circulation

Remarks ___

Interpretation ___

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Lawson Sinking Sp # 99-21-JAR (Year – Trace # – Initials)
2. Date of Injection: 3 (Month) / 25 (Day) / 99 (Year) Time: 19:15 ( ) a.m. (✓) p.m.
3. Owner of Injection Site: B. S. Lawson Phone: (502) 422-2738
4. Quadrangle/County: Irvington / Meade
5. Elevation: 645' (✓) map ( ) measured 6. Latitude: ______ Longitude: ______
7. Description of Injection Site:
   - ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other (✓) Sinking Sp.

   Remarks ______
8. Formation Receiving Tracer Injection: Ste. Genevieve
9. Flow Conditions: ( ) low (✓) moderate ( ) high
10. Induced Flow? ( ) no ( ) yes ______ (Pre-injection) / ______ (Post-injection) ______ (Elapsed Time) minutes
11. Tracing Agent: Amt 21 oz ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (✓) other SRB

RECORD OF DYE TRACE

Principal Investigator Joseph Ray Field Personnel ______

Precipitation before & during trace ______

	Date	3-25	3-30	4-15	4-22	5-11	5-20								
	Duration														
ID	Location of Dye Receptors	Background	Results												
2	French Creek	–	++	+	–	–	–								
9	Head Wolf Creek	–	–	–	–	–	–								
10	Head Spring Creek	L	–	–	–	/	–								
11	Hamilton Hill Bluehole	/	/	L	–P	/	–								
12	Boiling Spring	–	–	–	–	–	–								
17	Sugar Tree Spring Bottom Hole		/	–	–	–	–								
~~18~~	~~Sinking Cr. above Boiling~~								End Trace						
19	Mystic Overflow	/	/	/	/	–	R								
20	Sugar Tree Run Overflow	/	/	/	/	/	/								
~~21~~	~~Yellow Bank Cr.~~														
22	CM Church, Left	N	–	–	/	/	/								
23	CM Church, Right	N	–	–	/	/	/								
24	Webster Overflow	N	–P	–P	/	/	/								
25	Parks Sp. Run	N	–	–	–	/	–								
26	Sample Sp. (3-19)	/	/	/	–	LN	/								

Legend:
+ Positive
++ Very Positive
+++ Extremely Positive
– Negative Results
B Perceptible Background (slight)
B+ Significant Background (problematic)
NR Not Recovered (high water, stolen receptor, etc)
R Receptor removed
/ Receptor Not Changed
L Receptor lost
N New Receptor Installed
P Poor Circulation

Remarks Small sp near bridge was only one not positive.

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** 272 Swallet **#** 99-22-JAR (Year – Trace # – Initials)
2. **Date of Injection:** 4 / 14 / 99 (Month / Day / Year) **Time:** 9:30 (✓) a.m. ( ) p.m.
3. **Owner of Injection Site:** ______ **Phone:** ( ) ______
4. **Quadrangle/County:** Church Hill / Christian
5. **Elevation:** 482 (✓) map ( ) measured 6. **Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   - (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ______
8. **Formation Receiving Tracer Injection:** ______
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-Injection / Post-Injection) ______ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 2 oz ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (✓) other SRB

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** ______
Precipitation before & during trace ______

ID	Location of Dye Receptors	Back-ground	Results				
	Date	4-13	4-20	4-29	6-2		
	Duration						
1	River Bend Sp	/	/	—	/		
7	Caledonia BH	—	—	—	—	R	
9	Boyd Lake	/	/	L	—	R	
10	Mill Stream Sp	—	—	—	/		
17	Ezell Sp	N	—	—	—	R	
18	John Zook Window	N	++R	- Intermittent			
19	Ezell Overflow	N	—	—	—	R	
20	Riverside Cr.	N	—	/	—	R	
21	Price Sp	N	—R				
22	Gee Sp	N	—	—	L	R	
23	Sinking Fork above Sinks	N	—	/	—	R	
24	~~Post sp Tran~~ Roaring crack		N	/	L	R	
25	Little River @ Striped Br.		N	/	+*	R	

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- — Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks * Positive from 99-26-JAR

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Anderson B.H. Window # 99-23-JAR (Year – Trace # – Initials)

2. **Date of Injection:** 4 (Month) / 14 (Day) / 99 (Year) **Time:** 9:45 (✓) a.m. ( ) p.m.

3. **Owner of Injection Site:** Mrs Anderson **Phone:** ( ) ____

4. **Quadrangle/County:** Church Hill / Christian

5. **Elevation:** 520' (✓) map ( ) measured 6. **Latitude:** ____ **Longitude:** ____

7. **Description of Injection Site:**
   ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   ( ) losing stream (✓) karst window ( ) monitoring well ( ) septic system
   ( ) lagoon ( ) cave stream ( ) other

   Remarks ____

8. **Formation Receiving Tracer Injection:** ____

9. **Flow Conditions:** ( ) low (✓) moderate ( ) high

10. **Induced Flow?** (✓) no ( ) yes ____ Pre-Injection / ____ Post-Injection ____ Elapsed Time minutes

11. **Tracing Agent:** Amt 2 oz ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (✓) other Eosine

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel** ____

Precipitation before & during trace ____

ID	Date / Duration / Location of Dye Receptors	Background														
	Date	4-13	4-20	4-29	6-2											
	Duration															
ID	**Location of Dye Receptors**	**Back-ground**	**Results**													
1	River Bend Sp	/	/	–	/											
7	Caledonia BH	–	–	–	–	R										
9	Boyd Lake	/	/	L	–	R										
10	Mill Stream Sp	–	?	–	/											
17	Ezell Sp	N	+++	?	–	R										
18	John Zook Window	N	– R													
19	Ezell Overflow	N	?	–	–	R										
20	Riverside Cr.	N	–	/	–	R										
21	Price Sp	N	– R													
22	Gee Sp	N	–	–	L	R										
23	Sinking Fork above Sinks	N	?	/	–	R										
24	~~[illegible]~~ Roaring crack		N	/	L	R										
25	Little River @ Striped Br.		N	/	–	R										

Legend:
+ Positive
++ Very Positive
+++ Extremely Positive
– Negative Results
B Perceptible Background (slight)
B+ Significant Background (problematic)
NR Not Recovered (high water, stolen receptor, etc)
R Receptor removed
/ Receptor Not Changed
L Receptor lost
N New Receptor installed

Remarks ____

Interpretation ____

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Price Sp. Swallet # 99 - 24 - JAR
   (Year – Trace # – Initials)
2. Date of Injection: 4 / 20 / 99 (Month / Day / Year) Time: 5:10 ( ) a.m. (✓) p.m.
3. Owner of Injection Site: KY 272 Right-of-way Phone: ( ) ____
4. Quadrangle/County: Church Hill / Christian
5. Elevation: 480' (✓) map ( ) measured 6. Latitude: ____ Longitude: ____
7. Description of Injection Site:
   - ( ) sinking stream
   - ( ) losing stream
   - ( ) lagoon
   - ( ) sinkhole
   - (✓) karst window
   - ( ) cave stream
   - ( ) water well
   - ( ) monitoring well
   - ( ) other
   - ( ) injection well
   - ( ) septic system

   Remarks ____
8. Formation Receiving Tracer Injection: ____
9. Flow Conditions: ( ) low (✓) moderate ( ) high
10. Induced Flow? (✓) no ( ) yes ____ / ____ (Pre-Injection / Post-Injection) ____ minutes (Elapsed Time)
11. Tracing Agent: Amt 0.5 oz (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other ____

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray Field Personnel ____
Precipitation before & during trace ____

ID	Location of Dye Receptors	Date: 4-20 / Background	Date: 4-29	Date: 6-2	
	Duration				
1	River Bend Sp	/	–	/	
7	Caledonia BH	–	–	–	R
9	Boyd Lake	/	L	–	R
10	Mill Stream Sp	–	–	/	
17	Ezell Sp	–	–	–	R
18	John Zook Window	– R			
19	Ezell Overflow	–	–	–	R
20	Riverside Cr.	–	/	–	R
21	Price Sp	– R			
22	Gee Sp	–	++	L	R
23	Sinking Fork above Sinks	–	/	–	R
24	~~Post ... ~~ Roaring crack	N	/	L	R
25	Little River @ Striped Br.	N	/	–	R

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ____
Interpretation ____

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): 2nd Moore Swallet @ Disk # 99-25-JAR (Year – Trace # – Initials)
2. Date of Injection: 4 / 29 / 99 (Month / Day / Year) Time: 1:30 ( ) a.m. (✓) p.m.
3. Owner of Injection Site: Dewayne Moore Phone: ( )
4. Quadrangle/County: Church Hill / Christian
5. Elevation: 490 (✓) map ( ) measured 6. Latitude: Longitude:
7. Description of Injection Site:
   - (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks 0.2 cfs
8. Formation Receiving Tracer Injection:
9. Flow Conditions: ( ) low (✓) moderate ( ) high
10. Induced Flow? (✓) no ( ) yes ___ / ___ (Pre-injection / Post-injection) ___ minutes (Elapsed Time)
11. Tracing Agent: Amt 10 OZ (✓) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 ( ) other

RECORD OF DYE TRACE

Principal Investigator Joseph Ray Field Personnel

Precipitation before & during trace ~1.0 in prior

ID	Location of Dye Receptors	Back-ground	4-29	5-6	5-17	6-2										
	Duration															
			Results													
1	River Bend Sp	–	+	–	/											
7	Caledonia BH	–	+	/	–	R										
9	Boyd Lake	N	–	/	–	R										
10	Mill Stream Sp.	–	–	–	/											
26	Caledonia East BH	N	+	/	–	R										
27	Caledonia South BH	N	++	/	–	R										
28	USGS "Spring"	N	++	/	–	R										
25	Little River @ Striped Bridge	/	/	/	–	R										

Legend: + Positive; ++ Very Positive; +++ Extremely Positive; – Negative Results; B Perceptible Background (slight); B+ Significant Background (problematic); NR Not Recovered (high water, stolen receptor, etc); R Receptor removed; / Receptor Not Changed; L Receptor lost; N New Receptor Installed

Remarks

Interpretation

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Garnett Swallet # 99-26-JAR (Year -- Trace # -- Initials)
2. **Date of Injection:** 4 / 29 / 99 (Month / Day / Year) **Time:** 1600 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Tom + Bill Garnett **Phone:** ( )
4. **Quadrangle/County:** Hopkinsville / Christian
5. **Elevation:** 542 (✓) map ( ) measured 6. **Latitude:** **Longitude:**
7. **Description of Injection Site:**
   (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   ( ) lagoon ( ) cave stream ( ) other
   Remarks 0.5 cfs
8. **Formation Receiving Tracer Injection:**
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes --- / (Pre-injection / Post-injection) (Elapsed Time) minutes
11. **Tracing Agent:** Amt 202 ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (✓) other SRB

RECORD OF DYE TRACE

Principal Investigator Joseph A. Ray **Field Personnel**

Precipitation before & during trace

ID	Location of Dye Receptors	Background	Date 4-29	Date 5-5	Date 6-2	Results												
	Duration																	
1	Hayslip Sp*		N	+	−	R												
2	South Fork Little R		N	−R														
3	Round BH		4-21 N	+R														
4	Rock Bridge Br. up from Round BH		N	/	L													
5	Double BH. Win.		N	+R														
6	Ebb + Flow Win.		N	−R														
7	Sinuous Win.		N	+R														
8	Bath Tub Win.		N	+R – Intermittent														
25	Little River @ Striped Bridge		/	/	+	R												

Legend: + Positive; ++ Very Positive; +++ Extremely Positive; − Negative Results; B Perceptible Background (slight); B+ Significant Background (problematic); NR Not Recovered (high water, stolen receptor, etc); R Receptor removed; / Receptor Not Changed; L Receptor lost; N New Receptor Installed

Remarks * Changed name to Johnston Sp

Interpretation

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

Replicated

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Stull Sinkhole #99-27-JAR (Year – Trace # – Initials)
2. Date of Injection: April / 30 / 99 (Month / Day / Year) (Rep: May 20 99, 19:10) Time: 16:30 ( ) a.m. (X) p.m.
3. Owner of Injection Site: Howard Stull Phone: (270) 442-3826
4. Quadrangle/County: Irvington / Meade
5. Elevation: 645 (X) map ( ) measured 6. Latitude: ________ Longitude: ________
7. Description of Injection Site:
   - ( ) sinking stream (X) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ________
8. Formation Receiving Tracer Injection: STE. GENEVIEVE
9. Flow Conditions: (X) low ( ) moderate ( ) high
10. Induced Flow? ( ) no (X) yes 50 gal. (Pre-injection) / 150 gal. (Post-injection) 10 (Elapsed Time) minutes
11. Tracing Agent: Amt ~~4 oz.~~ 1 lb. ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (X) other Eosine

RECORD OF DYE TRACE

Principal Investigator Joe Ray Field Personnel JACK Moody, PAT KEEFE

Precipitation before & during trace None / 2" on 5-5

ID	Location of Dye Receptors	Background	5-6	5-11	5-20		5-26	6-3	6-15	6-24	6-30	7-7	7-15	?-22		
	Duration															
2	French Creek		–	–	–		–	–	–	–	–	–	–	–		
9	Head Wolf Creek		–	–	–		–	–	–	/	/	/	/	–	End Trace	
10	Head Spring Creek		–	/	–		–	/	–	/	/	LR				
11	Hamilton Hill Bluehole		–	/	–		– P	L	L	–	L	–	?	?		
12	Boiling Spring		/	–	–		–	–	–	/	–	/	–	/		
17	Sugar Tree Spring		/	–	+		+	+	++	/	+++	/	++	/		
25	Parks Sp. Run		–	/	+		–	–	–	/	–	/	–	/		
19	Mystic Overflow		/	+R												
26	Sample Sp			N	/		–	/	–	/	/	/	/	/		

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- P Poor Circulation

Remarks ________

Interpretation Low-flow velocity was > 80'/hr but < 150'/hr

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

Replicated

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Clark Sinkhole # 99-28-JAR (Year – Trace # – Initials)

   Rep: May 20 2010

2. **Date of Injection:** April / 30 / 99 (Month / Day / Year) **Time:** 18:00 ( ) a.m. (X) p.m.
3. **Owner of Injection Site:** Don Clark **Phone:** (270) 422-2448
4. **Quadrangle/County:** Guston / Meade
5. **Elevation:** 635 (X) map ( ) measured 6. **Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   - ( ) sinking stream (X) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ______

8. **Formation Receiving Tracer Injection:** ST. LOUIS
9. **Flow Conditions:** (X) low ( ) moderate ( ) high
10. **Induced Flow?** ( ) no (X) yes 50 gal / 150 gal (Pre-Injection / Post-Injection) 8 minutes (Elapsed Time)

    Rep. 1 lb Fluor.

11. **Tracing Agent:** Amt 5 oz ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (X) other SRB

RECORD OF DYE TRACE

Principal Investigator Joe Ray **Field Personnel** Jack Moody, Pat Keefe

Precipitation before & during trace 2" rain on 5-5

ID	Location of Dye Receptors	Background	5-6	5-11	5-20			5-26	6-3	6-15	6-24	6-30	7-7	7-15	7-22		
	Duration																
			Results														
2	French Creek		+?	–	–			–	–	++	+	+	?	–	–		
9	Head Wolf Creek		–	–	–			–	–	–	/	/	/	/	–	End Trace	
10	Head Spring Creek		–	/	–			–	/	–	/	/	L	R			
11	Hamilton Hill Bluehole		–	/	–			–P	L	L	++	L	+	?	–		
12	Boiling Spring		/	–	–			–	–	–	/	–	/	–	/		
17	Sugar Tree Spring		/	–	–			–	–	–	/	–	/	–	/		
25	Parks Sp. Run		–	/	–			–	–	–	/	–	/	–	/		
19	Mystic Overflow		/	–	R												
26	Sample Sp			N	/			–	/	–	/	/	/	/	/		

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- P Poor Circulation

Remarks ______

Interpretation Low flow velocity was > 57'/hr but < 107'/hr

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** West Big Spring Window # 00 - 4 - JAR (Year – Trace # – Initials)
2. **Date of Injection:** 3 (Month) / 23 (Day) / 00 (Year) **Time:** 18:15 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Kentucky Land, Inc. **Phone:** ( )
4. **Quadrangle/County:** Big Spring /
5. **Elevation:** 670' (✓) map ( ) measured **6. Latitude:** **Longitude:**
7. **Description of Injection Site:**
   - ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream (✓) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks
8. **Formation Receiving Tracer Injection:**
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ____ / ____ (Pre-injection / Post-injection) ____ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 14 oz ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (✓) other Eosine

RECORD OF DYE TRACE

Principal Investigator Joseph Ray **Field Personnel** Jack Moody, Pat Keeker, Rob Blair

Precipitation before & during trace

ID	Location of Dye Receptors	Background	Results				
	Date	3-23	3-29	4-7	4-13	5-2	
	Duration				&	5-4	
1	Fiddle Spring		–	–	/	–	
2	Connors Spring	–	++	/	–	/	
3	Flat Rock Sp.		++	/	?	–	
4	Shooting Star Sp		++	/	?	/	
5	Board Cave Sp		–	/	–	/	
6	Drake Sp		/	/	– R		
7	Blue Fork @ bridge	–	–	/	–	–	END
8	Stoney Fork Sp		–	/	–	–	Trace
9	Ross Cave Sp		++	/	?	D	
10	Gilpin		++	/	+	–	
11	Buffalo Cr. Sp.				/	–	
12	Dyer Cave				/	–	
13	Duncan Valley @ Bridge				N	/	
14	Muddy Prong Bluehole				–	/	
15	Spencer Cave		N	/	– R		
16	Fromme Cave		N	/	– R		

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks

Interpretation

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Dyer / Arch Swallet **#** 00 - 7 - JAR
   (Year -- Trace # -- Initials)
2. **Date of Injection:** 4 / 18 / 00 (Month / Day / Year) **Time:** 1:30 ( ) a.m. (✓) p.m.
3. **Owner of Injection Site:** Kentucky Land **Phone:** ( )
4. **Quadrangle/County:** Constantine / Hardin
5. **Elevation:** 690' (✓) map ( ) measured **6. Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   ( ) lagoon ( ) cave stream ( ) sinking spring ( ) other

   Remarks 0.05 cfs
8. **Formation Receiving Tracer Injection:** ______
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-Injection / Post-Injection) ______ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 4 oz (✓) Fluor. ( ) Rhod. WT ( ) SRB ( ) Eosine ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph Ray **Field Personnel** ______

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background	Results 4-18	Results 4-26	Results 5-4	Results 5-9
	Duration					
7	Blue Fork @ bridge		–	–	–	–
8	Stoney Fork Sp.		–	++	+	?
13	Duncan Valley @ bridge		–R			
14	Muddy Prong BH		/	/	/	–
17	McGuffin Br		/	–	/	–
18	Drakes Cr.		/	–D	–	see 00-13
19	Keesee Karst Window		N	/	/	/
20	Duncan Valley N. Sp		N	–	/	–
21	Duncan Valley E.		N	–	/	–

End Trace

Legend:
+ Positive
++ Very Positive
+++ Extremely Positive
– Negative Results
B Perceptible Background (slight)
B+ Significant Background (problematic)
NR Not Recovered (high water, stolen receptor, etc)
R Receptor removed
/ Receptor Not Changed
L Receptor lost
N New Receptor Installed
D Dry Receptor

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Alexander Swallet **#** 00 - 8 - JAR (Year – Trace # – Initials)

2. **Date of Injection:** 4 (Month) / 18 (Day) / 00 (Year) **Time:** 2:30 ( ) a.m. (✓) p.m.

3. **Owner of Injection Site:** Alexander (Mrs.) **Phone:** ( )

4. **Quadrangle/County:** Constantine / Breckinridge

5. **Elevation:** 720 (✓) map ( ) measured **6. Latitude:** ______ **Longitude:** ______

7. **Description of Injection Site:**
   - (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) sinking spring ( ) other

   Remarks: 0.1 cfs

8. **Formation Receiving Tracer Injection:** ______

9. **Flow Conditions:** ( ) low (✓) moderate ( ) high

10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)

11. **Tracing Agent:** Amt 4 oz ( ) Fluor. ( ) Rhod. WT (✓) SRB ( ) Eosine ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph Ray **Field Personnel** ______

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background	4-18	4-26	5-4	5-9
	Duration					
7	Blue Fork @ bridge		–	–	–	–
8	Stoney Fork Sp.		–	++	–	–
13	Duncan Valley @ bridge		R			
14	Muddy Prong BH		/	/	/	–
17	McGuffin Br		/	–	/	–
18	Drakes Cr		/	–D	–	–
19	Keesee Karst Window		N	/	/	/
20	Duncan Valley N. Sp.		N	–	/	–
21	Duncan Valley E.		N	–	/	–

End Trace

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- D Dry Receptor

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Polly Brown Springs **#** 00 - 9 - JAR (Year – Trace # – Initials)

2. **Date of Injection:** May / 2 / 2000 (Month / Day / Year) **Time:** 19:13 ( ) a.m. (X) p.m.

3. **Owner of Injection Site:** Wayne Roberts **Phone:** (270) 828 3351

4. **Quadrangle/County:** Guston / Meade

5. **Elevation:** 800 (X) map ( ) measured **6. Latitude:** ________ **Longitude:** ________

7. **Description of Injection Site:**
( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
( ) lagoon ( ) cave stream (X) sinking spring ( ) other

Remarks ________

8. **Formation Receiving Tracer Injection:** Ste Genevieve

9. **Flow Conditions:** ( ) low (X) moderate ( ) high

10. **Induced Flow?** (X) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)

11. **Tracing Agent:** Amt 8 oz (X) Fluor. ( ) Rhod. WT ( ) SRB ( ) Eosine ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Jack Moody **Field Personnel** Pat Keefe + Beverly Oliver

Precipitation before & during trace 0.6 inch night before, none on 5/2

ID	Location of Dye Receptors	Background	5-9	5-16	5-23	6-1
1	Fiddle Sp		–	–	–	–
2	Connors Sp		–	/	/	/
3	Flat Rock Sp		?	++	+	–
4	Shooting Star Sp		?	/	/	/
5	Board Cave Sp		–	/	/	–
7	Blue Fork @ Bridge		–	–	–	/
8	Stoney Fork Sp.		see 00-7	–	–	/
9	Ross Cave Win.		?	+	+	–
10	Gilpin Win.		–	–	–	–
24	Boiling Sp		–	+	–	–
25	Parks Sp. Run		–	/	/	–
26	French Cr.		–	/	–	/
27	Hamilton Hill BH		–	/	?	/
28	Head of Doe Run		+++	++	+	?

END TRACE

Legend: + Positive; ++ Very Positive; +++ Extremely Positive; – Negative Results; B Perceptible Background (slight); B+ Significant Background (problematic); NR Not Recovered (high water, stolen receptor, etc); R Receptor removed; / Receptor Not Changed; L Receptor lost; N New Receptor Installed; D Dry Receptor

Remarks ________

Interpretation ________

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Red Barn Sinking Sp # 00 - 10 - JAR (Year – Trace # – Initials)
2. Date of Injection: 5 / 3 / 00 (Month / Day / Year) Time: 14:00 ( ) a.m. ( ) p.m.
3. Owner of Injection Site: ______ Phone: ( ) ______
4. Quadrangle/County: Big Spring / Meade
5. Elevation: 730 (✓) map ( ) measured 6. Latitude: ______ Longitude: ______
7. Description of Injection Site:
   - ( ) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream (✓) sinking spring ( ) other

   Remarks 0.05 cfs
8. Formation Receiving Tracer Injection: ______
9. Flow Conditions: ( ) low (✓) moderate ( ) high
10. Induced Flow? (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)
11. Tracing Agent: Amt 8 oz ( ) Fluor. ( ) Rhod. WT (✓) SRB ( ) Eosine ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph Ray Field Personnel ______

Precipitation before & during trace 1-2 inches by evening

		Date	5-3	5-9	5-16	5-23	6-1
		Duration					
ID	Location of Dye Receptors		Background	Results			
1	Fiddle Spring		–	–	–	–	–
2	Connors Sp		/	–	/	/	/
3	FlatRock Sp		–	–	–	–	–
4	Shooting Star Sp		/	–	/	/	/
5	Board Cave Sp		/	–	/	/	–
7	Blue Fork @ Bridge		–	–	–	–	/
8	Stoney Fork Sp.		–	–	–	–	/
9	Ross Cave Win.		D	–	–	–	–
10	Gilpin Win.		–	–	–	–	–
24	Boiling Sp		N	–	–	–	–
25	Parks Sp Run		N	–	/	/	–
26	French Cr.		N	–	/	–	/
27	Hamilton Hill BH		N	–	/	–	/
28	Head of Doe Run		N	+	?	+	–

END Trace

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- D Dry Receptor

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): Lost Run Swallet # 00 - 11 - JAR (Year -- Trace # -- Initials)

2. Date of Injection: 5 / 4 / 00 (Month / Day / Year) Time: 10:00 (✓) a.m. ( ) p.m.

3. Owner of Injection Site: Eddy Dyer Phone: ( )

4. Quadrangle/County: Custer / Breckinridge Co

5. Elevation: 575 (✓) map ( ) measured 6. Latitude: ______ Longitude: ______

7. Description of Injection Site:
   - (✓) sinking stream
   - ( ) losing stream
   - ( ) lagoon
   - ( ) sinkhole
   - ( ) karst window
   - ( ) cave stream
   - ( ) water well
   - ( ) monitoring well
   - ( ) sinking spring
   - ( ) injection well
   - ( ) septic system
   - ( ) other

   Remarks 3 cfs

8. Formation Receiving Tracer Injection: ______

9. Flow Conditions: ( ) low (✓) moderate ( ) high

10. Induced Flow? (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)

11. Tracing Agent: Amt 0.5 oz (✓) Fluor. ( ) Rhod. WT ( ) SRB ( ) Eosine ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph Ray Field Personnel ______

Precipitation before & during trace ~1" day before

ID	Location of Dye Receptors	Background (Date: 5-4)	Results (Date: 5-9)	Results (Date: 5-16)
	Duration			
11	Buffalo Cr Sp	–	++	+
12	Dyer Cave	–	– D	/
30	Cr @ Richard Moore Rd	N	–	/
31	North Fork @ 1073	N	–	/

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- D Dry Receptor

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Lucas Swallet **#** 00-12-JAR (Year – Trace # – Initials)
2. **Date of Injection:** 5 / 4 / 00 (Month / Day / Year) **Time:** 11:00 ( ) a.m. ( ) p.m.
3. **Owner of Injection Site:** Brenda Lucas **Phone:** (270) 536-3705
4. **Quadrangle/County:** Garfield / Breckinridge
5. **Elevation:** 700' (✓) map ( ) measured **6. Latitude:** ______ **Longitude:** ______
7. **Description of Injection Site:**
   - (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) sinking spring ( ) other

   Remarks 0.2 cfs
8. **Formation Receiving Tracer Injection:** ______
9. **Flow Conditions:** ( ) low (✓) moderate ( ) high
10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)
11. **Tracing Agent:** Amt 6 oz ( ) Fluor. ( ) Rhod. WT ( ) SRB (✓) Eosine ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph Ray **Field Personnel** ______

Precipitation before & during trace 1" day before

ID	Location of Dye Receptors	Background (Date 5-4)	5-9	5-11	5-16	5-23	6-1	6-7
	Duration							
7	Blue Fork @ Bridge	–	–	/	–	–	/	/
8	Stoney Fork Sp	–	–	/	–	–	/	/
11	Buffalo Cr. Sp.	–	–	/	–	/	/	/
12	Dyer Cave	–	–	/	/	/	/	/
30	Cr. @ Richard Moore Rd	N	–	/	/	/	/	/
31	North Fork @ 1073	N	–	/	/	/	/	/
32	Turpin Sp			N*	–	/	/	/
33	Watt Hole			NW –	/	/	++	/
34	Hardin Springs			NW –	/	+	?	–

END Trace

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- D Dry Receptor
- W Water Sample

Remarks * No positive in 5.5 hr

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Keesee Br. Swallet **#** 06 - 13 - JAR
   Year – Trace # – Initials

2. **Date of Injection:** 5 / 4 / 00 (Month / Day / Year) **Time:** 15:15 ( ) a.m. ( ) p.m.

3. **Owner of Injection Site:** ______ **Phone:** ( ) ______

4. **Quadrangle/County:** Constantine / Hardin

5. **Elevation:** 590' (✓) map ( ) measured **6. Latitude:** ______ **Longitude:** ______

7. **Description of Injection Site:**
   (✓) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   ( ) lagoon ( ) cave stream ( ) sinking spring ( ) other

   Remarks ______

8. **Formation Receiving Tracer Injection:** ______

9. **Flow Conditions:** ( ) low (✓) moderate ( ) high

10. **Induced Flow?** (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)

11. **Tracing Agent:** Amt 1 oz (✓) Fluor. ( ) Rhod. WT ( ) SRB ( ) Eosine ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph Ray **Field Personnel** ______

Precipitation before & during trace 1" day before

		Date		5-9	5-16	5-23											
		Duration															
ID	**Location of Dye Receptors**		**Background**	**Results**													
7	Blue Fork @ Bridge		–	–	–	–											
8	Stoney Fork Sp		B	see 00-7	–	–											
14	Muddy Fork BH		–	–	/	/											
17	McGuffin Br		–	–	/	/											
18	Head Drakes Cr.		–	+++	+	/											
19	Keesee Karst Win.		–	/	/	/											
20	Duncan Valley N. Sp		–	–	/	/											
21	Duncan Valley E.		–	–	/	/											

Legend:
+ Positive; ++ Very Positive; +++ Extremely Positive; – Negative Results
B Perceptible Background (slight); B+ Significant Background (problematic); NR Not Recovered (high water, stolen receptor, etc); R Receptor removed
/ Receptor Not Changed; L Receptor lost; N New Receptor Installed; D Dry Receptor

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): 630' Swallet # 00-14-JAR (Year – Trace # – Initials)
2. Date of Injection: 5 / 10 / 00 (Month / Day / Year) Time: 0945 (✓) a.m. ( ) p.m.
3. Owner of Injection Site: ______ Phone: ( ) ______
4. Quadrangle/County: Constantine / Hardin
5. Elevation: 630' (✓) map ( ) measured 6. Latitude: ______ Longitude: ______
7. Description of Injection Site:
   - (✓) sinking stream
   - ( ) losing stream
   - ( ) lagoon
   - ( ) sinkhole
   - ( ) karst window
   - ( ) cave stream
   - ( ) water well
   - ( ) monitoring well
   - ( ) sinking spring
   - ( ) injection well
   - ( ) septic system
   - ( ) other

   Remarks ______
8. Formation Receiving Tracer Injection: ______
9. Flow Conditions: ( ) low (✓) moderate ( ) high
10. Induced Flow? (✓) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)
11. Tracing Agent: Amt 2 oz ( ) Fluor. ( ) Rhod. WT (✓) SRB ( ) Eosine ( ) other ______

RECORD OF DYE TRACE

Principal Investigator ______ Field Personnel ______

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background	Results													
	Date	5-9	5-16	5-23												
	Duration															
7	Blue Fork @ Bridge	–	–	–												
8	Stoney Fork Sp	–	–	–												
17	McGuffin Br	–	/	/												
18	Head of Snakes Cr.	–	++	/												
19	Kersee Karst Window	/	/	/												

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- D Dry Receptor

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. Name of Dye Trace (Site Location): HICKS SPRING # 00 - 15 - JAR (Year – Trace # – Initials)
2. Date of Injection: 5 (Month) / 16 (Day) / 2000 (Year) Time: 20:00 ( ) a.m. (x) p.m.
3. Owner of Injection Site: DAPHINE LAIRMORE Phone: (270) 828-2871
4. Quadrangle/County: BIG SPRING / MEADE
5. Elevation: 710 (X) map ( ) measured 6. Latitude: ______ Longitude: ______
7. Description of Injection Site:
   - (X) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) other

   Remarks ______
8. Formation Receiving Tracer Injection: STE GENEVIEVE
9. Flow Conditions: (X) low ( ) moderate ( ) high
10. Induced Flow? (X) no ( ) yes ______ (Pre-injection) / ______ (Post-injection) ______ (Elapsed Time) minutes
11. Tracing Agent: Amt 4 oz. ( ) Fluor. ( ) Rhod. WT ( ) OB ( ) DY96 (X) other EOSINE

RECORD OF DYE TRACE

Principal Investigator JOE RAY Field Personnel JACK MOODY / PAT KEEFE

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background (Date 5-16)	5-23	6-1	6-7	6-13	6-21									
	Duration															
1	Fiddle Sp	–	–	–	–	–	–									
2	Connors Sp	/	/	/	/	/	/									
3	Flat Rock Sp	–	–	+	?	+	–									
4	Shooting Star	/	/	/	/	/	/									
5	Board Cave Sp	/	/	?	–	/	–									
7	Blue Fork @ Bridge	–	–	/	/	/	/	End								
8	Stoney Fork Sp	–	–	/	/	/	/		Trace							
9	Ross Cave Win.	–	–	–	?	+	–									
10	Gilpin Win	–	–	–	–	/	/									
24	Boiling Sp	–	–	+	/	–	–									
25	Davis Sp Run	/	/	–	–	/	/									
26	French Cr.	/	–	/	–	–	–									
27	Hamilton Hill BH	/	–	/	–	–	–									
28	Head of Doe Run	–	–	–	–	/	–									

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Haysville Sinkhole # 00-16 -JAR (Year – Trace # – Initials)

2. **Date of Injection:** 6 / 1 / 00 (Month / Day / Year) **Time:** 4:00 ( ) a.m. (✓) p.m.

3. **Owner of Injection Site:** Butler **Phone:** ( )

4. **Quadrangle/County:** Guston / Meade

5. **Elevation:** 675' (✓) map ( ) measured 6. **Latitude:** ____ **Longitude:** ____

7. **Description of Injection Site:**
( ) sinking stream (✓) sinkhole ( ) water well ( ) injection well
( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
( ) lagoon ( ) cave stream ( ) sinking spring ( ) other

Remarks ____

8. **Formation Receiving Tracer Injection:** ____

9. **Flow Conditions:** ( ) low (✓) moderate ( ) high

10. **Induced Flow?** ( ) no (✓) yes 100 gal (Pre-injection) / 500 gal (Post-injection) 45 (Elapsed Time) minutes

11. **Tracing Agent:** Amt 15 oz ( ) Fluor. ( ) Rhod. WT (✓) SRB ( ) Eosine ( ) other ____

RECORD OF DYE TRACE

Principal Investigator Joseph Ray **Field Personnel** Jim Currens/Randy Paylor (KGS)

Precipitation before & during trace ____

	Date	6-1	6-7	6-13	6-21	7-6	7-10	7-21	9-29
	Duration								
ID	Location of Dye Receptors	Background	Results						
1	Fiddle Sp.	—	—	—	—	—	/	—	
3	Flat Rock Sp.	—	—	—	—	—	/	—D	
5	Board Cave Sp	—	—	/	—	—	/	—	
9	Ross Cave Win.	—	—	—	—	—	/	/	
10	Gilpin Win.	—	—	/	/	/	/	/	
24	Boiling Sp.	—	/	—	+	+	—	—D	END TRACE
25	Parks Run	—	—	/	/	—	/	/	
26	French Cr.	/	—	—	—	/	—	—	
27	Hamilton Hill BH	/	—	—	—	L	—	—	
28	Head Doe Run	—	—	/	—	/	/	—	
35	Burtons Hole	N	—	/	—	/	/	—	

Legend:
+ Positive
++ Very Positive
+++ Extremely Positive
— Negative Results
B Perceptible Background (slight)
B+ Significant Background (problematic)
NR Not Recovered (high water, stolen receptor, etc)
R Receptor removed
/ Receptor Not Changed
L Receptor lost
N New Receptor Installed
D Dry Receptor

Remarks ____

Interpretation Flow velocity >2112 ft/day <3520 ft/day (est. 2600 ft/day for 16 days)

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Dooley Sinkhole # 00 - 17 - JAR (Year – Trace # – Initials)

2. **Date of Injection:** 6 / 21 / 00 (Month / Day / Year) **Time:** 14:00 ( ) a.m. ( ) p.m.

3. **Owner of Injection Site:** ______ **Phone:** ( ) ______

4. **Quadrangle/County:** Guston / Meade

5. **Elevation:** 710' (✓) map ( ) measured 6. **Latitude:** ______ **Longitude:** ______

7. **Description of Injection Site:**
   - ( ) sinking stream (✓) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) sinking spring ( ) other

   Remarks ______

8. **Formation Receiving Tracer Injection:** ______

9. **Flow Conditions:** (✓) low ( ) moderate ( ) high

10. **Induced Flow?** ( ) no (✓) yes 50 (Pre-injection) / 350 (Post-injection) 60 (Elapsed Time) minutes

11. **Tracing Agent:** Amt 14 oz (✓) Fluor. ( ) Rhod. WT ( ) SRB ( ) Eosine ( ) other ______

RECORD OF DYE TRACE

Principal Investigator Joseph Ray **Field Personnel** Jack Moody

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background (Date 6-21)	7-6	7-10	7-20	7-27	8-1	8-8	8-16	8-23	8-30	9-29				
1	Fiddle Sp	–	–	/	–	/	/	/	/	/	/	–				
3	Flat Rock Sp	–	–	/	–D	/	/	/	/	/	/	L				
5	Board Cave Sp	–	–	/	–	/	/	/	/	/	/	–				
9	Ross Cave Win.	–	–	/	/	/	/	/	/	/	/	/				
24	Boiling Sp	–	–	–	–D	–	–	–	–	–	–	–				
26	French Cr.	–	/	–	–	–	–	–	/	B	+	+	END TRACE			
27	Hamilton Hill BH	–	L*	–D	?	–D	2xBg	++	/	/	++	+				
28	Head Doe Run	B	/	/	B	/	–	/	/	/	B	–				
35	Burtons Hole	–	/	/	–	/	–	/	–	/	/	/				

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- D Dry Receptor

Remarks Recovered 7-10; Negative.

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

TRACER INJECTION SITE

1. **Name of Dye Trace (Site Location):** Sugar Cane Sink **#** 00 - 19 - JAR (Year – Trace # – Initials)

2. **Date of Injection:** August / 08 / 2000 (Month, Day, Year) **Time:** 20:20 ( ) a.m. (X) p.m.

3. **Owner of Injection Site:** ______ **Phone:** ( ) ______

4. **Quadrangle/County:** GARFIELD / BRECKINRIDGE

5. **Elevation:** ______ ( ) map ( ) measured **6. Latitude:** ______ **Longitude:** ______

7. **Description of Injection Site:**
   - (X) sinking stream ( ) sinkhole ( ) water well ( ) injection well
   - ( ) losing stream ( ) karst window ( ) monitoring well ( ) septic system
   - ( ) lagoon ( ) cave stream ( ) sinking spring ( ) other

   Remarks ______

8. **Formation Receiving Tracer Injection:** ______

9. **Flow Conditions:** ( ) low (✓) moderate ( ) high

10. **Induced Flow?** ( ) no ( ) yes ______ / ______ (Pre-injection / Post-injection) ______ minutes (Elapsed Time)

11. **Tracing Agent:** Amt 8 oz ( ) Fluor. ( ) Rhod. WT (X) SRB ( ) Eosine ( ) other ______

RECORD OF DYE TRACE

Principal Investigator JOE RAY **Field Personnel** JC BLAIiSET, JACK MOODY

Precipitation before & during trace ______

ID	Location of Dye Receptors	Background	8-8	8-16	8-23	8-30	9-28									
		Duration														
24	Boiling Sp	–	–	–	–	–										
34	Hardin Sp	–	–	–	++	–										
36	Sinking Cr. @ Dent Br.	N	–	–	–	–	END TRACE									

Legend:
- \+ Positive
- ++ Very Positive
- +++ Extremely Positive
- – Negative Results
- B Perceptible Background (slight)
- B+ Significant Background (problematic)
- NR Not Recovered (high water, stolen receptor, etc)
- R Receptor removed
- / Receptor Not Changed
- L Receptor lost
- N New Receptor Installed
- D Dry Receptor

Remarks ______

Interpretation ______

Please identify injection and recovery sites on photocopy of topographic map. Kentucky Division of Water 10/1993

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