

**Project Title: Little River Karst Watershed Boundary Delineation:
Groundwater Tracer Testing and Unit Base Flow**

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Ralph Ewers and Peter Idstein of Ewers Water Consultants assisted with coordination of simultaneous field studies in the West Fork of Red River and Little River study areas. This coordination documented the highest four-day groundwater-flow velocity determined in this study. These data indicated that the leading edge of a dye trace to Spring Hill Spring exceeded 3.1 km (1.9 mi) per day over an interpreted flow route of 12.4 km (7.7 mi).

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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)	28.32	L/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	0.0353	ft ³ /s
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

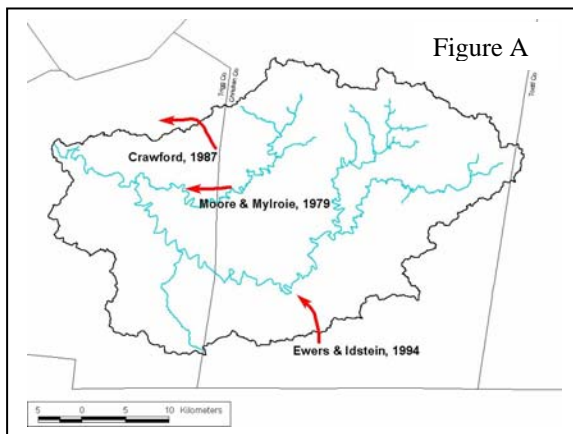
Miscellaneous abbreviations:

DOW - Division of Water
EPPC - Environmental and Public Protection Cabinet
EWC - Ewers Water Consultants
ft³/s - Cubic Feet per Second
GQ - Geological Quadrangle
GIS - Geographic Information System
HUC - Hydrologic Unit Code
KGS - Kentucky Geological Survey
L/s - Liters per Second
NPS - Nonpoint Source
SRB - Sulforhodamine B tracer dye
TMDL - Total Mean Daily Loading
UBF - Unit Base Flow (base flow per unit area)
USEPA - United States Environmental Protection Agency
USGS - United States Geological Survey

EXECUTIVE SUMMARY

Introduction. This project was designed to further delineate the karst watershed of the Little River in southwestern Kentucky. Originating with the North and South Forks of the Little River near Hopkinsville, the main stem of the Little River flows southwest and then northwest to its confluence with Muddy Fork and Lake Barkley backwaters. Two major tributaries of Little River are Sinking Fork to the northwest and Casey Creek to the southwest. The hydrology of the southwestern two thirds of the Little River basin is dominated by well-developed karst. Two previous groundwater-tracer investigations in

1987 and 1994 documented karst underflow of topographically identified watershed boundaries (Figure A).



Accurate karst watershed information is vital for effective emergency response to spills and reliable monitoring of waste and industrial sites. Likewise, groundwater data are important for assessment of nonpoint source (NPS) pollution from agricultural, transportation, and urban settings, and for evaluation of Total Maximum Daily Loadings (TMDL's) of

pollution for regional streams. Hydrologic Unit Code (HUC) watershed delineations mapped by the U.S. Geological Survey (USGS) comprise the existing watershed-boundary data-set to be tested by additional groundwater tracing. These digital HUC boundaries were mapped entirely from topographic divides, which often vary significantly from actual groundwater divides in karst regions.

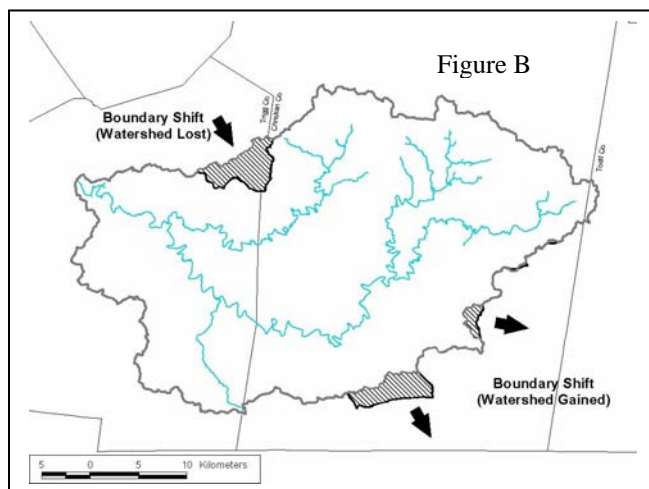
Methods. Groundwater-tracer testing was conducted to verify or modify the delineated HUC watersheds. Non-toxic fluorescent dyes were introduced into natural karst features such as sinkholes and sinking streams and recovered on dye receptors placed in streams and springs. Groundwater flow routes and basin boundaries are thus mapped and flow velocities are estimated. Unit Base Flow (UBF) assessment for karst springs is a secondary method used in this study. UBF analysis uses a base-flow spring discharge/basin-area ratio to estimate a groundwater-runoff quantity per unit area of watershed.

UBF complements groundwater tracing by providing an estimate of the groundwater basin area to be delineated by targeted tracer injections. Also, anomalous groundwater runoff values derived by this method can identify basins with UBF deficits that may be yielding unobserved discharges below stream level, or springs with UBF excesses that may be augmented by cutoff diversions from nearby streams. This combination of tracer testing and UBF assessment is a powerful methodology to help interpret and map complex karst drainage and basin boundaries.

Dye-Test Results. This project expanded on a previous NPS groundwater investigation by Ray and others (2005). Forty-nine tracer tests were conducted. Forty dye injections were successfully detected in 17 spring basins and two sub-basins, for an 82% test-recovery rate. Interpreted groundwater flow paths averaged 5.3 km (3.3 mi), but ranged up to a maximum of 15.0 km (9.3 mi). Demonstrated groundwater flow velocities averaged >0.7 km (0.4 mi) per day, whereas the highest documented velocity exceeded 3.1 km (1.9 mi) per day. These lengthy groundwater flow paths and rapid velocities demonstrate the sensitivity of karst terrane to spills and pollution and highlight the importance of their identification.

UBF Results. Field measurements indicate that minimum annual discharge of study-area springs ranges from 1.7-169.9 L/s (0.06-6.0 ft³/s). Groundwater basin and sub-basin areas, based on tracer tests and topographic divides, range from 2.0-186.6 km² (0.78-72.0 mi²). UBF, or the ratio of discharge to basin area, ranges from 0.44-14.54 L/s/km² (0.04-1.33 ft³/s/mi²). Mill Stream Spring, Cowherd, Torian, and Hunt spring basins yield relatively low UBF of <1.2 L/s/km² (<0.11 ft³/s/mi²). These basins drain low-storage sandstone or moderately-developed shallow karst within the northern portions of the Sinking Fork, Little River, and West Fork Red River basins. Most basins in the southern and western portions of these watersheds yield 2.0-2.75 L/s/km² (0.18-0.25 ft³/s/mi²) from well-developed karst. Within this latter hydrogeologic setting, Spring Hill/Herndon and Buchanan springs yield deficits possibly due to unobserved sub-fluvial springs. Murphy Spring yields the greatest UBF because of unaccounted cutoff sources from Montgomery Creek. Identified basins with spring discharges that are difficult to gage can be calculated using UBF reference yields.

Misbehaved Drainage. Karst groundwater drainage that is incongruous with topographic basins is termed "misbehaved". For the purposes of this study, misbehaved karst drainage is defined as *verified conduit flow passing beneath a delineated 14-digit or lower HUC boundary*. As shown by successful tracer tests, 39% of 17 karst basins contain misbehaved drainage, ranging from 10-99% of basin areas. Of the 638 km² (246 mi²) karst-basin area in which tracer tests were conducted, 48% exhibited misbehaved drainage. These data demonstrate that identified karst drainage basins, rather than HUC



delineations, comprise the most accurate and appropriate watershed research and management units in karst areas.

Southeastern Shift of the Little River Watershed. Based on HUC delineations, the Little River watershed above the confluence with Muddy Fork contains an area of 1122.8 km² (433.5 mi²). This study found a nearly identical total area of 1122.5 km² (433.4 mi²). However, the similarity is misleading because

these total areas are balanced by basin enlargement in the southeast, with watershed-area gains from West Fork Red River of about 23 km² (9 mi²), and compensating basin reduction in the northwest with watershed-area losses to Muddy Fork (Figure B). The eastern Little River watershed enlargement occurs where the Buchanan and Spring Hill/Herndon spring basin boundaries shift southeast toward West Fork, while the watershed reduction occurs in the Cook Spring basin, which shifts its basin boundary southeast toward Sinking Fork.

Hopkinsville Karst Atlas. Karst groundwater basins and internal flow routes mapped during this NPS study will contribute significantly to a new issue of the Kentucky Geological Survey's Map and Chart Series entitled *Mapped Karst Groundwater Basins in the Hopkinsville 30 x 60 Minute Quadrangle*. Acquisition of these important karst data is a very useful and efficient use of 319h Nonpoint Source funding.

Introduction and Methodology

This study was designed to map the ambiguous portions of the karst watershed of the Little River in southwestern Kentucky. Watershed verification is required where boundaries traverse sinkhole-plain terrane and the direction of groundwater flow is unknown and difficult to predict. This verification was accomplished by traditional qualitative groundwater tracing with fluorescent dyes. Groundwater tracer introduction was limited to natural features such as streams, stream swallets, karst windows, and sinkholes, and included one unused water well with visible cave flow. Soil borings were not used for dye introduction. Springs, karst windows, streams, and a cave stream were monitored with activated carbon dye receptors to detect and map the tracers.

Springs and streams in the study area were gaged during minimum annual discharge, usually in September and October. Discharge was measured by the velocity-area method using a Marsh-McBirney model 201D portable electromagnetic water-current meter. Spring-basin boundaries were digitized at a scale of 1:24,000, and basin areas were derived using ArcView 3.2© GIS Software from ESRI™. The ratio of base flow/basin area provides UBF, which is useful as a predictor of groundwater runoff in similar hydrogeologic settings. UBF anomalies can also suggest measurement problems and atypical springs.

The current base-map of Kentucky watersheds, or HUC's, has been developed by the USGS. Eighteen tracer-mapped karst basins and a sub-basin in the Little River area were compared with these HUC delineations. Verified conduit flow routes indicate that nearly half of the total karst watershed tested drains beneath HUC boundaries. This "misbehaved" groundwater drainage supports the concept that in karst terrane, hydrologic research and management units must account for karst-drainage mapping rather than be based solely on topographic delineation.

Location of Study Area

The Little River basin is in Trigg, Christian, and Todd counties in southwestern Kentucky. The study area includes all or part of the Cobb, Gracey, Caledonia, Church Hill, Herndon, Hopkinsville, Oak Grove, Pembroke, Pleasant Green Hill, and Trenton 7.5 minute topographic quadrangles. Most tracer tests were conducted in areas between the Little River and West Fork Red River in the eastern part of the study area, ranging westward to areas between Sinking Fork and Muddy Fork (West Fork Red River is hereafter called West Fork). [Plate I](#) outlines the Little River basin, including all mapped streams above the confluence with Muddy Fork. Twenty karst basins tested in this study, totaling about 647 km² (250 mi²), are identified by spring name, spring symbol, and a dashed basin boundary. Four contiguous basins included in the UBF assessment are indicated by spring symbols and names.

Previous Work

Local disparities between topographic divides and karst groundwater flow within the Little River watershed were originally identified by Crawford (1987), during a gasoline spill response, and Ewers and Idstein (1994), during groundwater basin mapping for the Fort Campbell Military Reservation. Other karst and caving work at West Fork and Sinking Fork were conducted by Moore and Mylroie (1979), McDowell (1983), and Mylroie and Mylroie (1991). Additional tracing work by DeFosset and others (Ewers Water Consultants, 2001), was conducted on Sinking Fork and springs draining to Muddy Fork. Ray and others (2005) completed hydrogeologic inventories and groundwater tracer testing that was a precursor to this Little River investigation. That study included 18 tracer tests in nine karst basins.

Regional Hydrogeology

The principal aquifer, including most large springs in the Little River region, is developed in Mississippian-aged limestones of the Pennyroyal or Mississippian Plateau, primarily within a 60 m (200 ft) thickness of the Ste. Genevieve Limestone. Some springs also occur in the upper part of the subjacent St. Louis Limestone and in the lower portion of the overlying Renault Limestone. The Ste. Genevieve and St. Louis limestones consist of the upper section of the Meramecian Series of the Mississippian System, whereas the Renault Limestone comprises the base of the Chester Series.

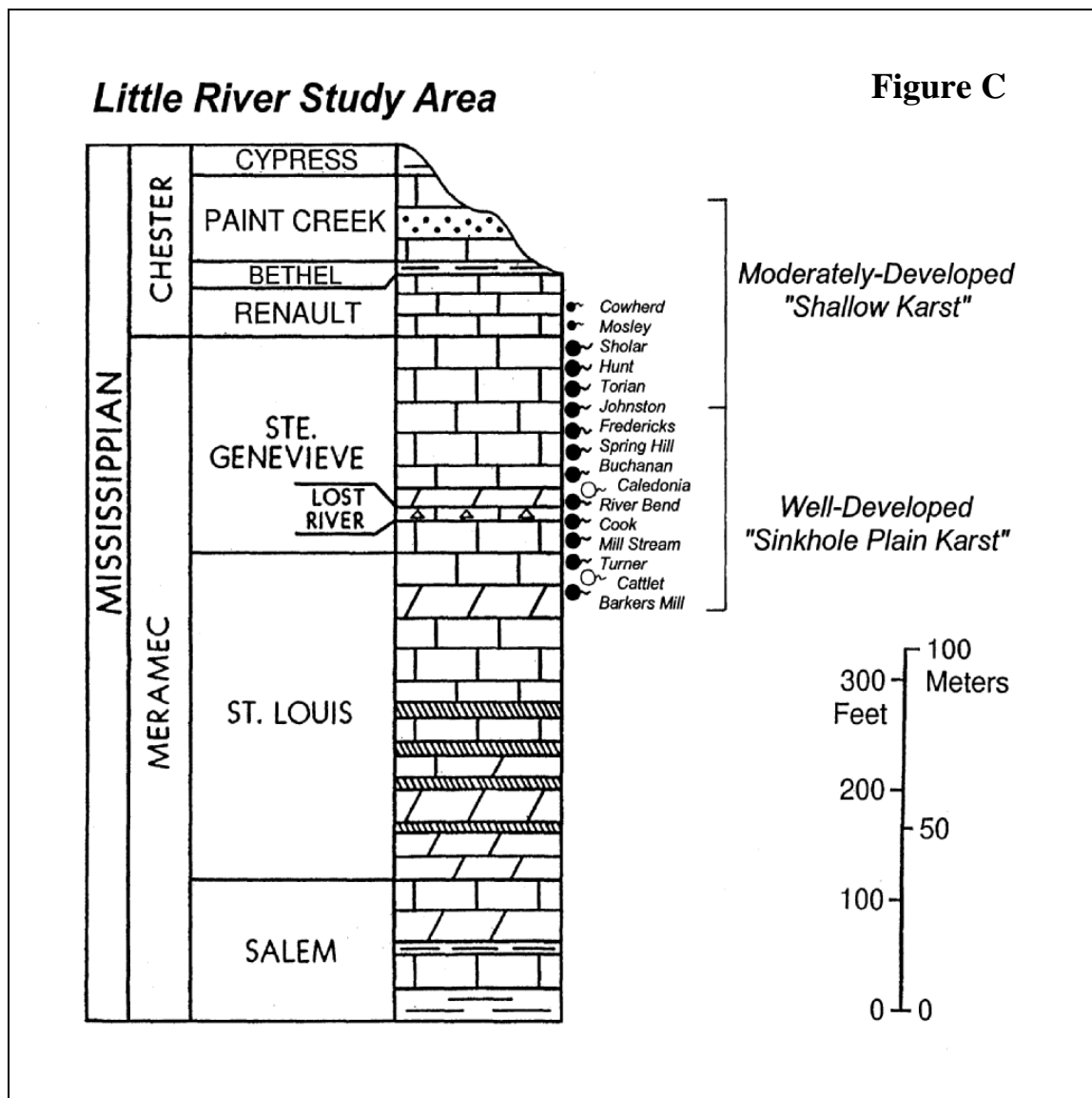
Perennial master streams are fairly common within this low-relief karst plain, although sinkholes, karst windows, and losing and sinking streams exist locally. The main streams of the area are Little River and West Fork, which are moderately incised to depths of about 40 m (130 ft). Major tributaries 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 and Montgomery Creek. Elevation of study area springs ranges from about 113-170 m (370-557 ft), while the highest elevation along the northeastern divide of the Little River watershed is 268 m (880 ft). Average rainfall is about 127 cm/yr (50 in/yr).

Hydrogeology of the Little River Study Area

The purity and high solubility of the Ste. Genevieve Limestone make the terrane of much of the Little River watershed 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 typically contains numerous shallow sinkholes and caves, losing and sinking streams, stream-less valley segments, intermittent lake basins, and large springs. However, unusual karst drainage documented in this study include intermittent karst windows/lakes, seasonal overflow distributary springs, perennial distributary springs, an audible underground waterfall, conduit flow beneath a perched aquifer, and conduit underflow of the bedrock channels of West Fork

and Montgomery Creek. Ray and others (2005) also documented conduit underflow of the Little River.

Figure C shows a generalized stratigraphic column of soluble rocks of the Little River study area (adapted from Ettensohn and Dever (1979)). The relative stratigraphic position of several springs discharging from the Ste. Genevieve Limestone and adjacent units are represented with perennial (black) and intermittent (open) spring symbols beside the geologic column. Limestone is represented by a rectangular-brick pattern, whereas dolostone or dolomitic limestone is shown by a slanted-brick pattern. The diagonally hachured zones in the lower section of the St. Louis Limestone identify gypsum and anhydrite beds. Less soluble rocks include shale, indicated by horizontal dashes, and sandstone represented by dots. The triangles 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 bulk of the springs drain terrane characterized as Well-Developed "Sinkhole Plain Karst", while the upper portion of the group is characterized as Moderately-Developed "Shallow Karst". The latter term was used by Ray and others (2005) to describe the landscape developed on the upper Ste. Genevieve and overlying Renault and Paint Creek limestones. Fluvially dissected terrane predominate in this upper portion of the watershed, with karst development being more subdued than in the lower, sinkhole-plain portion of the watershed. This shallower, moderately-developed karst also yields less UBF, apparently because of reduced depth of soils and weathering, and retarded evolution of the epikarst. Because most long-term karst groundwater storage occurs in the soil and epikarst (weathered bedrock zone), its retardation in the shallow karst areas results in UBF values of roughly 50% of spring-yield in the well-developed sinkhole plain. This study addresses several springs and streams draining the shallow karst to further define this moderately-developed karst setting. Additionally, the upland divide area of the Little River watershed to the northeast is described as "Sandstones and Minor Karst". These dissected terraces are assumed to yield little dry-season base flow, although data are lacking.

Groundwater Tracing

Qualitative groundwater tracer tests, as described by Quinlan (1986) and Aley (1999), were conducted using four non-toxic fluorescent dyes. The names of dyes used in this study are shown in bold:

Dyes Used	Trade Name	Color Index	Number of Injections
SRB (Sulforhodamine B)	Ricoamide Red XB	Acid Red 52	20
Eosine	15189 Eosine OJ	Acid Red 87	16
Uranine	Uranine Conc (Disodium Fluorescein)	Acid Yellow 73	10
Rhodamine WT	Keyacid Rhodamine WT Liquid	Acid Red 388	3

As indicated by Schindel and others (1994) and Field and others (1995), these fluorescent dyes are optimal for use in groundwater-basin delineation because of non-toxicity, availability, analytical detectability, moderate cost, and ease of use. The quantity of fluorescent dye used for these tests was determined empirically over several years of field experience. Prior to fieldwork, powdered dye was dissolved in water at a concentration of eight oz (226 g) per gallon (4 L). For uranine and eosine, this liquid-dye mixture was injected into active swallet sites at a rate of about one pint (0.5 L) per mile (1.6 km) of expected flow distance (equivalent to about one ounce (30 g) of powdered dye per mile). Twice as much SRB dye was used for equivalent flow distances. Rhodamine WT, marketed as a 20% liquid mixture, was used at a rate of about one quart (1.0 L) per mile (1.6 km). Greater quantities of dye were used at dry sinkhole sites flushed with hauled water or during high-flow conditions.

During movement of tracers through monitored sites, fluorescent dyes were adsorbed and accumulated onto activated carbon samplers. In some cases, when the dye receptor was missing, dye was sampled directly by water samples. The carbon dye receptors were deployed in flowing water of springs, streams, and caves by use of a modified "gumdrop" anchor (Quinlan, 1986), or brick fitted with a vinyl-clad copper wire and commercially available "trot line clip" for securing the receptors ([Figure 1](#)). (In electronic versions of this report, Figures 1-81 and Plates I-IV are accessible by clicking the blue reference "hyperlink". Figures 1-81 and Plates I-IV in paper reports are available in Appendix B)

Background dye receptors were usually deployed, exchanged, and analyzed prior to dye injection in the study area. These background dye receptors served as controls for comparison with subsequently recovered receptors. In some cases background assessment was not used in order to take advantage of unusual field opportunities to inject dye. Dye receptors were typically exchanged weekly.

For analytical processing, samples of the retrieved carbon dye receptors were rinsed with tap water and eluted at room temperature for at least 15 minutes in a solution of 50% 1-propanol, 30% de-ionized water, and 20% ammonium hydroxide (NH₄OH). The eluted samples from this study were processed at the DOW's Groundwater Laboratory and analyzed for absence or presence and relative intensity using a scanning spectrofluorophotometer. The DOW's Shimadzu RF-5301 PC instrument was purchased in 1998 and a computer sequence for analyzing dye samples was programmed by Peter Edstein, PhD candidate at Eastern Kentucky University. A macro to aid setup of the page printout, including site identification data, dye wavelength analyses, and scan specifications, was designed by Jack R. Moody. All printouts of dye analyses are archived in the Groundwater Branch Laboratory. [Figure 2](#) shows a typical dye curve analyzed on the spectrofluorophotometer. The horizontal position of a dye peak indicates the fluorescence wavelength, which identifies the type of dye. The vertical height of the curve indicates the relative fluorescence intensity of the recovered dye and thus the qualitative confidence level of the positive dye recovery.

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

Documentation of Tracer Tests

During this project, 49 reconnaissance groundwater tracer tests were conducted for the purpose of basin delineation and verification or modification of HUC boundaries. The results of these investigations are discussed individually for each basin, and are listed under abbreviated dye-trace ID numbers such as 99-20 (Year-sequence of dye injection; the senior author was the principal investigator for all 49 tests). Analyzed dye-intensity level from recovered dye receptors is indicated by the following symbols, which represent the qualitative confidence level of a dye recovery and hydrologic connection:

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

An inconclusive result indicates that dye was apparently recovered at less than the criterion of 4X the background level. In two cases, discussed below, dye recovery at less than four times background was considered positive because of supporting factors. These two traces are illustrated with a finer flow line to indicate that they were tentatively accepted below the 4X background criterion. In some cases water samples were assessed to compare with carbon samples or when a carbon sample was missing at the monitoring site.

New tracer data for seventeen mapped basins, plus two sub-basins, are described below. A map of each karst watershed shows the final results of flow-path interpretation and delineation of the approximate basin boundary. Diagrams are presented on US Geologic Survey 30 x 60 Minute Metric Topographic Quadrangle base-maps, or 7.5 Minute Series Topographic Quadrangle base-maps, depending on the land area represented by the image. Topographic contours and cultural features are presented in gray tone for improved discrimination of the color-coded tracer data. Inferred groundwater flow routes are illustrated as minimum straight-line to curvilinear distances, which are less than actual conduit pathways. Some basin-boundary segments are delineated based on topographic divides when tracer data are lacking. The dashed boundary line indicates the imprecise nature of karst groundwater divides. Groundwater recharge about 300 m (1000 ft) on either side of a mapped divide should be assumed to potentially drain to both neighboring basins.

RESULTS OF GROUNDWATER INVESTIGATIONS

Of the 49 groundwater tracer tests conducted, 40 were successfully recovered in one or more of 19 springs or basin distributaries, for an 82% success rate. The main reason for lost dyes was the use of marginal dye injection locations such as dry sinkholes, where the dye was flushed into the sinkhole with hauled water. These sinkhole dye injection locations were assumed to be more risky than stream-swallet injections but were tested because of the need for delineating upland groundwater divides. Four springs were previously studied by Ray and others (2005). Descriptions for Barkers Mill, Cook, Mill Stream, and River Bend springs are reproduced from that document. A unique four-digit identification number is provided for each spring referenced in this study. This number is derived from the Kentucky DOW's Consolidated Groundwater Database ID system. For example, Spring Hill Spring (ID # 9000-**1857**) is identified simply as Spring Hill (1857).

Brief descriptions of all 19 basin discharge springs and sub-basin springs (including some significant overflow springs) are given below with dye-trace data, basic measurements, and figures showing digital photographs and maps. [Figure 3](#) is a legend for the tracer data illustrated on these basin maps. Non-recovered dye injections are described under

the spring to which they are hypothesized to drain. In the descriptions below, reference to an *unmapped spring* means the spring does not appear on published topographic or geologic maps.

Description of Springs and Basins, with Summary of Tracer Tests

Spring Hill Spring and Herndon Spring Distributary

Spring Hill (1857)

Spring Hill Spring is in the south-central portion of the Church Hill Topographic Quadrangle, but is not mapped. It discharges at about 140 m (460 ft) elevation [N36° 45' 32"/W87° 33' 06"] from the south bank of the Little River about 150 m (500 ft) southwest of Striped Bridge. Discharging from the Ste. Genevieve Limestone (Ulrich, 1966), Spring Hill Spring is a free-draining gravity spring issuing from a large bank cavity. Most of the flow is jetting into the river from a low conduit beneath a large boulder at the downstream edge of the cavity ([Figure 4](#)). Smaller flows from talus occur both up and downstream of the main spring. A related intermittent overflow spring occurs about 50 m (160 ft) upstream of the spring ([Figure 5](#)). On 10/10/2001, Spring Hill Spring's discharge was measured at 44.5 L/s (1.57 ft³/s) by gaging the Little River above and below the spring and deriving the gain.

Herndon (1445)

Herndon Spring is in the north-central portion of the Herndon Topographic Quadrangle, but is not mapped. It discharges at about 137 m (455 ft) elevation [N36° 44' 51"/W87° 34' 25"] from the south bank of the Little River, about 0.65 km (0.4 mi) upstream of the KY 117 Little River bridge. Two related karst windows occur about 200 m (650 ft) southeast of the spring. An additional overflow karst window in a deep sink is 1.9 km (1.2 mi) east-southeast of the spring. Discharging from the Ste. Genevieve Limestone (Klemic, 1966), Herndon Spring rises at the base of a 6 m (20 ft) wide limestone ledge and runs through an alluvial channel about 15 m (50 ft) to the river ([Figure 6](#)). The spring was gaged at 48 L/s (1.7 cfs) on 9/17/97 and at only 5.9 L/s (0.21 ft³/s) on 10/10/2001. The latter flow was backponded by a beaver dam, which apparently diminished the discharge by raising the discharge elevation and diverting a greater portion of the distributary flow to Spring Hill Spring or potential sub-fluvial springs. The 2.2 km (1.3 mi)-wide perennial distributary discharged a combined 50.4 L/s (1.78 ft³/s) on 10/10/2001.

01-05 (Dye Non-recovery)

April 17, 2001: 340 g (12 oz) of uranine was injected into **Woodland Seepage**, 1.9 km (1.2 mi) west of Big Walnut Grove Church. Dye was injected into a small swallet accepting a trickle of about 0.3 L/s (0.01 ft³/s) over about one hour. Eight spring and stream sites along the West Fork and Little Rivers were monitored over eight weeks with negative dye recovery. The non-recovery was assumed to result from a poor dye

injection site where much of the water and dye may have been absorbed by soil and tree roots.

01-06

April 17, 2001: 460 g (16 oz) of SRB dye was injected into **Noland Sinking Spring** 2.4 km (1.5 mi) northeast of Fidelio, Kentucky. The dye was injected over 30 minutes into about 0.6 L/s (0.02 ft³/s) of runoff from a seasonal sinking spring draining into a well-defined sink about two meters deep ([Figure 7](#)). The same eight sites as above were monitored. Within eight days dye was recovered in two springs on the Little River. Both Spring Hill Spring (++) , 10.4 km (6.4 mi) to the west, and Herndon Spring (++) , 12.0 km (7.5 mi) to the west, were very positive for SRB. This indicated a groundwater flow rate of greater than 1.5 km (0.9 mi) per day during moderate flow conditions. These sites were positive for an additional three weeks. Also, a karst window 0.34 km (0.2 mi) southeast of Spring Hill Spring was positive.

01-07

April 17, 2001: 230 g (8 oz) of eosine dye was flushed with 760 L (200 gallons) of hauled water into **Folz Sinkhole**, 1.2 km (0.75 mi) north-northwest of Longview Church. This sinkhole was a recently formed circular cover-collapse pit about 2 m (7 ft)-wide and greater than 6 m (20 ft)-deep where limestone ledges could be observed beneath the soil ([Figure 8](#)). The collapse was located at the edge of broad, flat sink that contains an intermittent lake during floods. This sink apparently lies along the subsurface flow route followed by the above trace from Noland Sinking Spring. Within eight days both Spring Hill Spring and Herndon Spring to the west were very positive (++) for eosine. These sites were positive for an additional six weeks. Likewise, the karst window near Spring Hill Spring was positive.

The above two dye traces proved that the identified groundwater basin discharged from a 2.2 km (1.4 mi)-wide perennial distributary on the Little River. This is the widest confirmed perennial groundwater distributary in Kentucky.

01-26

December 12, 2001: To further define the Spring Hill Spring/Herndon Spring basin and to document the destination of spills or storm-water runoff from Interstate 24 into a sinking stream watershed, 230 g (8 oz) of SRB was injected into **Flooded Shaft Sink**. This feature, 1.6 km (1.0 mi) southeast of the KY 345 overpass at I-24, was a 10 x 12 m (30 x 40 ft)-wide sinkhole that was flooded by a heavy rain. The dye injection was initiated during a stop along Interstate 24 in the midst of the rainstorm. A shaft-like structure in the northern portion of the sinkhole was reconnoitered previously, and the dye was poured into pooled floodwater above the shaft.

Ten spring and stream sites were monitored during this test and seven days later on the first receptor exchange, Spring Hill Spring (+), 3.9 km (2.4 mi) to the west-northwest,

and Herndon Spring (+), 5.2 km (3.2 mi) to the west, were both positive for SRB. The dye drained through the system rapidly because of high-flow conditions and was not detected during later monitoring. This dye injection point lies in a sinkhole cluster near the terminal area of a minor stream sinking just south of Interstate-24. The trunk conduit draining to Spring Hill Spring/Herndon springs is interpreted to pass beneath this sinkhole cluster and sinking stream. Consequently, this flow route is highly vulnerable to spills where crossed by the interstate highway.

02-01

January 10, 2002: 115 g (4 oz) of SRB dye was injected at **Gilkey Swallet**, a vertically installed drainage culvert with welded rebar grate, located 2.4 km (1.5 mi) southeast of Flat Lick Church. This trace was injected during moderate flow conditions into gradual flow through a pooled area above the culvert opening ([Figure 9](#)). Nine sites on the Little River were monitored for dye. Seven days later, on the first receptor exchange, SRB dye was recovered at Spring Hill Spring (+) 3.9 km (2.4 mi) to the northwest and Herndon Spring (+) 4.7 km (2.9 mi) to the west-northwest, within the previously mentioned distributary. Additionally, Hillview Overflow Karst Window (+) ([Figure 10](#)), 1.95 km (1.2 mi) east-southeast of Herndon Spring, and an overflow spring (+) just northeast of Spring Hill Spring were positive. Because of the locations of Hillview Overflow Karst Window and aligned sinkholes, this dye trace suggests that the bifurcation within the distributary is probably located about 2 km (1.2 mi) southeast of the Little River.

02-12

June 18, 2002: 460 g (16 oz) of eosine dye was injected at **Pool Lake Swallet** ([Figure 11](#)), 1.35 km (0.85 mi) southwest of the intersection of KY 1027 and KY 109. This minor swallet accepted about 1.5 L/s (0.05 ft³/s) at the edge of a receding intermittent lake. The primary terminal sink point for this lake was inundated on this date. Seven sites on Little River and West Fork were monitored. Ten days later, on the first dye receptor exchange, Spring Hill Spring (++) was very positive for eosine. Spring Hill Spring was positive for an additional two dye-receptor exchanges over three weeks.

Peter Idstein of Ewers Water Consultants (EWC) exchanged an independent dye receptor at Spring Hill Spring on June 22, as part of tracer testing at Fort Campbell Military Reservation, which was coordinated with DOW. This receptor detected the leading edge of the dye slug from this test in only four days. Based on this recovery, the conduit-flow velocity over the interpreted flow route of 12.4 km (7.7 mi) exceeded 3.1 km (1.9 mi) per day. Since Herndon Spring was previously demonstrated as part of this distributary, it was not monitored during this test. However, the interpreted flow-route distance to Herndon Spring is 13.8 km (8.6 mi), which is one of the longest karst flow routes in southern Kentucky ([Figure 12](#)).

Turner (1910)

Turner Spring is a backponded spring at the inside of a narrow meander on the west bank of West Fork [N36° 40' 50.4"/W87° 20' 30.3"] ([Figure 13](#)). It is on the Trenton Topographic Quadrangle but is not mapped. Discharging from the top of the St. Louis Limestone (Klemic, 1966) at about 132 m (434 ft) elevation, the 15 m (50 ft)-long spring run is surrounded by a river cane thicket and is backponded by a beaver dam at the mouth. A bluehole karst window lies about 6 m (20 ft) above the springhead, including a dangerous narrow hole in the bridge between the two features. The spring was gaged at 53.8 L/s (1.9 ft³/s) on 10/9/01.

Turner Spring, on the west side of West Fork, lies about 1.5 km (0.9 mi) upstream of Barkers Mill Spring and 4 km (2.5 mi) downstream of Cattlet Overflow Spring. Although Turner Spring lies within the Barkers Mill distributary, previous studies have shown that it is not hydrologically connected to Barkers Mill Spring (Ewers, 2000; Turner Spring was named Wheat field Spring (#6) in EWC reports). Because of the lack of an identifiable drainage basin for Turner Spring on the west side of West Fork, its watershed was hypothesized to lie on the east side of West Fork, with the spring being fed by a conduit passing beneath the channel of West Fork. To test this hypothesis, a connection dye trace to Turner Spring was attempted from Watts Cave, 1.3 km (0.8 mi) east of the spring, by Pete Idstein and Joe Ray in 1999. The result was not conclusive but a connection was suggested. In 2001, Preston Forsythe and others were remapping Twin Level Cave and offered to inject dye into the stream flowing through the cave and to monitor several sites inside the cave and on West Fork.

01-22

November 1, 2001: 115 g (4 oz) of eosine was injected into the stream in **Watts Cave** Karst Window. Seven days later on the first exchange, Turner Spring (++++) and the Sump Pool (+++), 90 m (300 ft) inside of the Cliff Entrance to Twin Level Cave, were extremely positive for eosine. Another upstream cave site, Turner Window Stream (+++), was extremely positive for eosine. Also, Turner Karst Window (++), 6 m (20 ft) upstream of the spring, was very positive for eosine. Four additional sites in West Fork, upstream of Turner Spring, were negative for dye, indicating that the cave stream did not discharge to West Fork upstream of Turner Spring. This is a clear-cut case of conduit flow beneath a regional perennial stream ([Figure 14](#)). An unusual bedrock cavity containing water is located on the right bank of West Fork, approximately along the sub-fluvial flow line. This pool is separated from the low-flow edge of the stream. This feature did not appear to contain circulating groundwater and was not monitored during the dye test. However, it may be an overflow spring or estavelle related to the traced flow route and should be investigated in any future work.

Buchanan (0569)

Buchanan Spring is on the Herndon Topographic Quadrangle, but is not mapped. Discharging from the Ste. Genevieve Limestone (Klemic, 1966), the spring rises at the south bank of Little River 1.0 km (0.6 mi) northwest of Herndon [N36° 44' 11"/W87° 34' 33"], at about 138 m (452 ft) elevation. This spring exhibits little morphological evidence and was not observed during the first spring inventory conducted on Little River (Cary, 1991). It was originally inventoried by Peyton Adams (7/27/94) during a complaint investigation by the DOW's Madisonville Regional Office. However, its significance to regional hydrology was not recognized until the second Little River spring inventory conducted in November, 1997, by the DOW (Ray and others, 2005). The spring has been developed as a farm water supply with a steel casing installed into the small bluehole to exclude river water from the intake. Due to the slightly inundated rise pit, the flow is difficult to accurately gage ([Figure 15](#)). A discharge of 35 L/s (1.23 ft³/s), \pm 20% was measured during drought conditions on 12/9/99. 43 L/s (1.52 ft³/s) \pm 20% was obtained during more normal conditions on 10/10/01.

01-27

December 19, 2001: To further define the groundwater divide between Spring Hill Spring/Herndon and Buchanan spring basins, 460 g (16 oz) of uranine was injected into **Ballard Sinkhole**, 0.75 km (0.5 mi) northwest of the intersection of KY 117 and Newton Lane. The dye was poured into a trickle of drainage from an intermittent pond, which was flowing into the sinkhole. Twelve spring and stream sites were monitored and 15 days later, on the second receptor exchange, both Buchanan Spring (+), 8.7 km (5.4 mi) to the west-northwest and Herndon Overflow Spring (+) ([Figure 16](#)) draining to the Little River were positive for uranine. This was the first tracer test recovered at Buchanan Spring and it demonstrated that Herndon Overflow Spring is a seasonal discharge feature of the Buchanan Spring basin. Both springs were positive over the next two weeks, with the Herndon Overflow Spring (++) very positive on the third week. In retrospect, Barkers Mill Spring should have also been monitored during this test.

03-02

January 8, 2003: To further define the boundary between Little River and West Fork drainage 685 g (24 oz) of eosine was injected at **Roberts Sinkhole (F)**, about 1.0 km (0.6 mi) northeast of Gate #4 at the Campbell Army Airfield. (*This sinkhole was the site of two non-recovered dye injections, using Direct Yellow 96 dye, 15 years earlier during Fort Campbell groundwater investigations (Ewers, 1989). Buchanan Spring was not monitored, but Herndon Overflow Spring (EWC #61) was negative during these earlier tests. Three dye injections from different sites were later recovered at this overflow spring by EWC (1994).*) 1500 L (400 gal) of hauled water was used to flush the dye into the sinkhole drain. Eleven spring and stream sites were monitored. Seven and fourteen days later, Herndon Overflow Spring (+), 8.2 km (5.1 mi) to the northwest, was positive for eosine. It was negative on 1/31 and inconclusive (?) on 2/11, but positive (+) again

on 2/20, 2/28, and 3/26. By 4/17 the dye recovery at Herndon Overflow Spring (?) was inconclusive.

Buchanan Spring, 9.4 km (5.8 mi) to the northwest, had previously been determined to be the underflow spring for Herndon Overflow Spring (01-27). At the first exchange on 1/15, the Buchanan Spring dye receptor was missing. However, Buchanan Spring water samples indicated eosine was present at over five times background levels on that date, and four times background on 1/22. The bulk of dye from this test was apparently being discharged from the overflow spring before arriving at Buchanan Spring. Because of partial river inundation of the Buchanan Spring bluehole, this site was also a less efficient dye monitoring location than Herndon Overflow Spring. Dye was not recovered at Quarles Spring (draining to Little West Fork), which was nearer to the dye injection site than the Buchanan Spring distributary. This dye trace adjusted the groundwater divide 2.5 km (1.6 mi) to the southeast of the topographic HUC boundary between Little River and West Fork ([Figure 17](#)).

Frederick Spring Distributary and Spring Hill Spring/Herndon Spring Distributary

Fredericks (1867)

Fredericks Spring is on the Trenton Topographic Quadrangle, 400 m (1300 ft) west-southwest of the KY 1453 bridge over Montgomery Creek. This unmapped spring rises at about 152 m (500 ft) elevation, at the base of a minor bluff ([Figure 18](#)). Discharging from the Ste. Genevieve Limestone (Klemic, 1966), this spring occupies the head of a narrow 400 m (1300 ft)-long pocket valley west of Montgomery Creek [N36° 43' 49"/W87° 19' 52"].

When Fredericks Spring was originally inventoried in September 1997, only 4 L/s (0.15 ft³/s) of base flow was observed from the main spring, suggesting a minor basin. At that time, the lower two springs of the distributary were unknown. However, during later tracer tests in 2002-03, the main spring exceeded about 50 L/s (1.8 ft³/s) during base flow. A potential explanation for the observed flow variation is excessive agricultural irrigation within the basin in 1997, although this is unlikely as late as September. The more plausible explanation is that during 1997 most of the basin's discharge emerged unobserved from the underflow springs (a sub-fluvial rise within the lower end of the spring run, plus a small sand boil at the far side of Montgomery Creek). However, by 2002 these lower springs had become mostly clogged, causing an increased portion of flow from the main spring.

02-13

June 18, 2002: To test the groundwater divide between the Little River and West Fork, 230 g (8 oz) of uranine was injected at **Pruitt Lake Swallet**. A shallow channel was excavated by shovel to induce a minor flow from the edge of an intermittent lake into a small depression. This site is 0.45 km (0.3 mi) northwest of the intersection of KY 109

and Pruitt Lane. Eight spring and stream locations on both Little River and West Fork were monitored for this test. After ten days, on the first dye receptor exchange, Spring Hill Spring (+), 12.6 km (7.8 mi) to the west was positive for uranine. Also, West Fork above Murphy Spring (+) was positive. One week later, only West Fork exhibited a minor positive for dye.

Apparently, the majority of dye entered the West Fork above Murphy Spring. Consequently, in order to determine the actual discharge point of the dye, on July 10th, dye receptors were placed upstream at three sites, including Fredericks Spring and Hunts Spring. Twenty-four hours later the Fredericks Spring (+) receptor was positive for uranine. Therefore, twenty-three days after dye injection, uranine continued to emerge from Fredericks Spring, 7.4 km (4.6 mi) to the east-southeast of the Pruitt Lake injection point. On July 18, Hunts Spring was negative, but all three springs at Fredericks Spring were positive. This includes the main Fredericks Spring (+), a minor bluehole (+) in the spring run about 30 m (100 ft) from West Fork, and a "sand boil" (+) at the far bank of West Fork. *(An old dye receptor recovered from the sand boil was very positive (++) . This receptor had been set during the fall of 2001 during an attempt to replicate a failed dye test of Montgomery Creek's losing point (97-24). However, the replication was not initiated because the sink-point had been obscured by a beaver dam, and the old dye receptor had remained deployed in the sand boil for about nine months. See test 02-16, below.)*

These results established that the Fredericks system was a linear distributary about 400 m (1300 ft) in length, part of which contributed conduit flow beneath the West Fork to a sub-fluvial sand boil at the far bank ([Figure 19](#)). Between July 5th and 18th, the formerly positive receptor site in West Fork above Murphy Spring was negative. This indicates that the recession of dye discharging at the Fredericks Spring distributary during that period was not adequate to be detected in West Fork 6.3 km (3.9 mi) downstream. However, in this case the West Fork site was an important failsafe monitoring location that salvaged the dye trace.

03-14

March 19, 2003: To delineate the boundary between Fredericks Spring basin and Barkers Mill Spring basin, 450 g (16 oz) of eosine was poured into standing water at the edge of an intermittent lake overlying a 3 m (10 ft)-deep cover-collapse sinkhole (**B. Glass Lake**). Five sites were monitored. Seven days later Fredericks Spring (+++), 5.8 km (3.6 mi) to the east-southeast, was extremely positive for eosine. It was also positive on two additional exchanges.

03-36

August 20, 2003: In a low-flow replication of 02-13, to further refine the groundwater divide between Little River and Montgomery Creek (tributary of West Fork), 1360 g (48 oz) of uranine was injected into **Pruitt Lake Sinkhole**, 0.45 km northwest of the intersection of KY 109 and Pruitt Lane. This sinkhole is about 65 m (215 ft) south of the lake swallet used in 02-13. The dye was flushed with 1325 L (350 gal) of hauled water.

Unfortunately, on August 22, two days after injection, rainfall increased the discharge of Little River from 1,190 to 56,600 L/s (42 to 2,000 ft³/s) eliminating the low flow condition. Within seven days, on the first exchange, Fredericks Spring (+++), 7.4 km (4.6 mi) to the east-southeast, was extremely positive for uranine, and was very positive on four additional exchanges over two months. Six other sites were negative. 512 Bluehole, an intermittent bluehole at the bottom of a 60-ft deep sinkhole ([Figure 20](#)), located 2 km (1.2 mi) west of Fredericks Spring, was also positive for uranine based on a water sample collected on September 11. This rain-altered low-flow trace did not show the positive connection west to Spring Hill Spring, as was documented in the previous trace conducted from near this location (02-13) when the sink was flooded during moderate flow conditions.

03-37

August 20, 2003: Testing the hypothesis that drainage from the **B. Glass Sinkhole** might contribute to Barkers Mill Spring during low flow conditions (likewise altered by rainfall on August 22), the 3 m (10 ft)-deep cover-collapse sinkhole, originally tested by dye injection 03-14, was injected with 1135 g (40 oz) of eosine. The dye was flushed by 720 L (190 gal) of hauled water. Fifteen days later a water sample from Fredericks Spring (+) was positive for eosine (the dye receptor was lost on this date). Twenty-two days after injection, a water sample from 512 Bluehole (+) was positive for eosine, corroborating the results of 03-36. Seven additional sites, including Barkers Mill Spring, were negative. Fredericks Spring groundwater basin is shown in [Figure 21](#).

Hunt (1487)

Hunt Spring is a free-draining gravity spring issuing from a low cave opening at the base of a 4 m (12 ft)-high bluff ([Figure 22](#)). This unmapped spring is located on the northwestern portion of the Trenton Topographic Quadrangle, 2.6 km (1.6 mi) northwest of the KY 1453 Montgomery Creek bridge. It discharges from the Ste. Genevieve Limestone (Klemic, 1966), at about 156 m (512 ft) elevation [N36° 44' 53"/W87° 20' 54"]. Hunt Spring is primarily fed by Hargrove Spring near Pembroke, which sinks about 1.0 km (0.6 mi) to the northwest ([Figure 23](#)). Hunt Spring's discharge was measured at 62.3 L/s (2.2 ft³/s) on 9/10/97.

02-16

The replication of a dye trace first attempted in 1997 was conducted at a losing point of Montgomery Creek, 6.8 km (4.3 mi) east of the intersection of US 41 and KY 115 in Pembroke. The original test was designed to determine the source of Venable Spring but was lost due to inadequate spring monitoring locations. However, the dye was recovered downstream in West Fork by EWC (Peter Idstein, personal comm., 1997). The actual resurgence point into West Fork remained unknown.

This replicated dye injection was designed to test the hypothesis that Montgomery Creek contributes to Murphy Spring, 8 km (5 mi) to the south. Murphy Spring, the largest

resurgence upstream of Barkers Mill Spring, yields an excess UBF anomaly suggesting a losing-stream source.

July 11, 2002: 315 g (11 oz) of SRB dye was injected into a sinkhole (**Beaver-patch Swallet**) along the east bank of Montgomery Creek. A shallow excavated trench allowed about 3.0 L/s (0.1 cfs) of creek water to flush into the stick-clogged swallet ([Figure 24](#)). With the exception of this induced flow, no other sinking water was observed in the vicinity.

Nine spring and stream sites were initially monitored. Within seven days, Hunt Spring (++++) was extremely positive for SRB, which was also recovered downstream at two additional stream sites. Hargrove Spring, a sinking spring located 1.9 km (0.7 mi) upgradient of Hunt Spring, was belatedly monitored on 7/22/03, eleven days after dye injection. Two dye receptors were recovered from Hargrove Spring twenty-two days after dye injection that were positive (+) for SRB. This test demonstrates that losing flow from Montgomery Creek, at about 166 m (545 ft) elevation, follows a 2.5 km (1.6 mi)-long southwesterly cutoff route to Hargrove Spring, at about 160 m (525 ft) elevation. This Montgomery Creek diversion route passes beneath a more elevated perched flow route that trends southeasterly from Mitchell Sinkhole, at about 180 m (590 ft) elevation, to Venable Spring, at about 161-163 m (530-535 ft) elevation. These distinct groundwater flow routes may be separated by an approximate bedrock thickness of 9-12 m (30-40 ft), within Ste. Genevieve Limestone, where they appear to cross as an "X" on a plan map ([Figure 25](#)).

Barkers Mill Spring Distributary

Barkers Mill (0959)

Barkers Mill Spring 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 the west bank of West Fork ([Figure 26](#)). This large 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 (Ray and Blair, 2005), but it is not mapped on the Trenton 7.5 minute Topographic Quadrangle nor the corresponding Geologic Quadrangle (Hammacksville). This spring was first inventoried 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 ft³/s), but drought flow (12/9/99) was about 40% less at 102 L/s (3.6 ft³/s).

03-01 (Dye Non-recovery)

January 7, 2003: This tracer test was designed to establish the groundwater divide between Little River and West Fork in the vicinity of US 41-A. 685 g (24 oz) of uranine

was injected into **Cherry Sinkhole**, 300 m (1000 ft) south of the intersection of US 41-A and KY 756. Located in the vicinity of both the topographic and estimated groundwater divide, this 100 m (330 ft)-wide, shallow sinkhole contained a small collapse feature about 36 m (120 ft) west of US 41-A.

About 3800 L (1000 gal) of water from a fire hydrant near the highway was used to flush dye into the sinkhole. At an introduction rate of about 80 L/m (20 gpm), the sinkhole immediately pooled water. Apparently, the throat of the collapse was partially clogged, accepting water at about one half the rate that was flushed from the hydrant. Although the inflow rate was less than optimal and therefore risky, the additional water available from the hydrant made this sinkhole an acceptable dye-injection site.

Twelve spring and stream sites were monitored for a seven-week period with no positive results. Apparently, most of the tracer dye filtered through sediment where it adsorbed to organic material and soil particles.

03-03

January 8, 2003: In an additional test of the HUC boundary between Little River and West Fork, 685 g (24 oz) of SRB was injected at **I-24 Swallet**, 3.4 km (2.1 mi) northwest of the I-24 overpass of US 41A. About 3 L/s (0.1 ft³/s) of stream flow entering a sinkhole drain carried the dye underground. Eleven spring and stream sites were monitored. Seven days later on the first exchange, Barkers Mill Spring (++), 12.5 km (7.8 mi) to the southeast, and Cattlet Overflow Spring (++), 12.0 km (7.5 mi) to the east-southeast, were very positive, while nearby Upper Overflow (+) was positive. Two weeks later Barkers Mill Spring (?) and Cattlet Overflow Spring (?) were inconclusive. This brief dye recovery demonstrates that the conduit flow route was efficient enough to transmit most of the dye slug to the springs over 12 km away within a few days. Also, the recovery at the two overflow springs documents a 2.9 km (1.8 mi)-wide groundwater distributary, the second largest overflow distributary in western Kentucky.

03-06

February 11, 2003: Stoltzfus Swallet is the sinkpoint of a karst window about 1.0 km (0.6 mi) west of Cattlet Overflow Spring. Stoltzfus Swallet is the apparent entrance to Gates Cave (McDowell, 1983; Mylroie and Mylroie, 1991). During low-flow conditions, when the Cattlet Overflow Spring was dry, 1.0 L (1.0 qt) of Rhodamine WT was injected at **Stoltzfus Swallet** to test the hypothesis that the inflow of about 7 L/s (0.2 ft³/s) would drain south to Barkers Mill Spring. However, heavy rain occurred in the area within 24 hrs and the dye discharged from the activated Cattlet Overflow Spring (++), 0.9 km (0.5 mi) to the east.

03-10

February 19, 2003: To verify the configuration of the local flow system feeding Cattlet Overflow Spring, 170 g (6 oz) of eosine was injected during high flow conditions at

Stoltzfus Karst Window ([Figure 27](#)), 1.2 km (0.7 mi) west-northwest of Cattlet Overflow Spring. This dye primarily emerged about 100 m (330 ft) southwest at Stoltzfus Spring (++) ([Figure 28](#)), but also at a small spring (++), about 100 m (330 ft) to the southeast, feeding the Stoltzfus Spring run. This stream continues an additional 250 m (820 ft) to a major swallet below a bluff (Stoltzfus Swallet). Eosine was also recovered about 0.9 km (0.6 mi) to the west of the bluff swallet, at Cattlet Overflow Spring (++).

03-12

March 5, 2003: To determine a boundary between Barkers Mill Spring basin and Spring Hill/Herndon springs basin, a potential dye-injection point at **Cherry Bluehole**, an intermittent karst window, was located 1.95 km (1.2 mi) east-northeast of the intersection of US 41A and KY 1453. On this date, during moderate flow conditions, water ponded within the sinkhole was neither muddy with sediment nor stagnant and brown with tannin. Instead, it was deep blue in color, indicating significant groundwater circulation ([Figure 29](#)). The pool's edge was searched for sinking water and a significant swallet was discovered at an indentation along a southwest bank of the sink.

680 g (24 oz) of SRB was injected at this pool swallet and eight sites were monitored for the dye. Six days later Barkers Mill Spring (+), 9.4 km (5.8 mi) to the southeast, and Cattlet Overflow Spring (+), 8.2 km (5.1 mi) to the east-southeast were both positive for SRB. A week later, Stoltzfus Karst Window (++) and Stoltzfus Spring (++) were exchanged for the first time during this test and were very positive for SRB. Cattlet Overflow Spring (+) was positive for a second week. Stoltzfus Overflow Karst Window (+), a deep collapse feature ([Figure 30](#)) 0.4 km (0.25 mi) west-northwest of Stoltzfus Karst Window, was also positive. On this date (3/18/03) a dye receptor was placed in the newly discovered Cherry Karst Window, about 1.0 km (0.6 mi) south of the dye injection site. However, by this time most of the dye had drained out of the area to the Barkers Mill distributary. Consequently, Cherry Karst Window was inadequately monitored for this test. Later attempts to link the two intermittent karst windows failed because of a lack of flow for dye injection at the intermittent Cherry Bluehole. Because Spring Hill Spring was negative for this test, a basin boundary was delineated, primarily along a broad topographic divide between Cherry Bluehole and the apparent basin drained by Spring Hill/Herndon Springs.

03-34

July 23, 2003: In a replication of dye injection 03-06, 115 g (4 oz) of SRB was injected into 7 L/s (0.25 ft³/s) of inflow at **Stoltzfus Swallet** ([Figure 31](#)). Thirteen days later on August 5th, Cattlet Overflow Spring (+) was positive for SRB, but Barkers Mill Spring was negative. Twelve days elapsed between the dye injection and heavy rains on August 4th that may have reactivated Cattlet Overflow Spring. This was adequate time to test for flow to Barkers Mill Spring.

The northern branch of the overflow distributary is undoubtedly a feature developed by the Barkers Mill basin. However, this overflow route is occupied during base flow by

minor discharge generated by the local Stoltzfus basin. This minor basin, draining through Stoltzfus Swallet, apparently discharges to West Fork via unobserved underflow seepage from the vicinity of Cattlet Overflow Spring.

03-38

September 4, 2003: To determine if two recently mapped karst windows were located along the main flow route of the headwaters of Barkers Mill Spring basin, 115 g (4 oz) of SRB was injected at **Under I-24 Sinking Stream**. This is the same sinking stream used in trace 03-03, except that this second dye was released into the stream flowing beneath I-24. Seven days later, on the first exchange, KY 1453 Sinkhole/Lake (+), 2.0 km (1.2 mi) to the east, and Cherry Bluehole Karst Window (+), 3.8 km (2.4 mi) to the east, were both positive for SRB. Both of the recovery points are intermittent lakes contained in sinkholes located above or near a conduit flow route. The known destination of this karst flow route is Barkers Mill Spring, which was inconclusive (?) for this trace due to the limited amount of dye injected.

The positive dye recoveries in the intermittent karst window/lakes indicate that rising groundwater is temporarily stored in the *backponded* depressions rather than being detained from surface storm-water runoff *into* the depression. During recession, part of this conduit flow can be temporarily observed as a spring rising and sinking in the lowest point of the Cherry Bluehole Karst Window. The landowner had also previously observed floodwater rising from this depression and flowing over a low divide into a neighboring sinkhole. This observation of flood-related groundwater rising and being stored for lengthy periods in compound surface depressions and intermittent lakes is important karst data that is rarely reported (Crawford, 1984; Ray, 2001; Campbell, 2005).

The Barkers Mill Spring groundwater basin is shown in [Figure 32](#). Note that Interstate 24 traverses 9 km (5.6 mi) of the southwestern portion of this karst basin, increasing its vulnerability to NPS pollutants and accidental spills. An enlargement of the northeastern distributary overflow route is shown in [Figure 33](#).

Cattlet Overflow (3122)

Cattlet Overflow Spring is the main seasonal overflow spring in the Barkers Mill distributary, discharging at the west bank of West Fork at about 136 m (446 ft) elevation [N36° 42' 06.7"/W87° 21' 12.7"] ([Figure 34](#)). This free-draining gravity spring is on the outside of a prominent meander, 2.7 km (1.7 mi) north of Barkers Mill Spring, and is the discharge point for Gates Cave (McDowell, 1983; Mylroie and Mylroie, 1990). Upper Overflow, a small related estavelle is located about 100 m (330 ft) upstream. During high-flow conditions, Cattlet Overflow Spring may yield as much as 2 m³/s (70 ft³/s) ([Figure 35](#)).

Mill Stream (0203)

Mill Stream Spring ([Figure 36](#)), in east-central Trigg County, is a rising spring that flows from the base of an 8 m (25 ft)-high limestone bluff, through a 180 m (600 ft)-long pocket valley [N36° 50' 38"/W87° 42' 49"]. 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. This spring, 3.0 km (1.7 mi) northwest of Caledonia, is one of four named springs on the Caledonia 7.5 Minute Topographic Quadrangle.

Mill Stream 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. About 18 km (11 mi) of Sinking Fork, shown as a blue-line stream on the Caledonia Topographic Quadrangle, is predominantly dry throughout this interval. Two minor sinking streams and numerous sinkholes contribute additional local recharge to the subsurface diversion 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 91 L/s (3.2 ft³/s) and 71 L/s (2.5 ft³/s) on 9-11-93 and 8-24-99, respectively. Earlier USGS measurements range from 42-5041 L/s (1.5-178 ft³/s) (Van Couvering, 1962).

03-18

March 27, 2003: To delineate the boundary between the Mill Stream Spring basin and the River Bend Spring basin, 225 g (8 oz) of uranine was injected into **Barnett Bluehole**, an intermittent karst window located in an intermittent-lake basin 2.0 km (1.2 mi) southeast of Julien ([Figure 37](#)). Seven days later Mill Stream Spring (++) , 8.4 km (5.2 mi) to the west-northwest, was very positive for uranine while Caledonia Overflow Spring was negative. All of the tracer dye passed through Mill Stream Spring within the first week. This trace confirmed that the tested groundwater divide lay 1.0 km (0.6 mi) south of the HUC topographic divide between Sinking Fork and Boyd Lake Branch. Boyd Lake Branch is an intermittent to seasonal stream/lake complex that overflows on the surface to the dry reach of Sinking Fork, but primarily contributes groundwater west to River Bend Spring on the Little River and the Caledonia Overflow-Spring distributary draining to Sinking Fork. The Mill Stream Spring groundwater basin is shown in [Figure 38](#).

Lilly (1395; sub-basin of Mill Stream)

Lilly Spring is a minor sinking spring mapped with a spring symbol in the west-central section of the Church Hill Topographic Quadrangle [N36° 49' 34"/W87° 35' 53"]. Located about 2.75 km (1.7 mi) northeast of the KY 164 overpass of Interstate 24, this spring flows from a concrete-block spring house and sinks in at least two locations 300-1000 m (1000-3300 ft) downstream, depending on flow conditions. This free-draining gravity spring discharges from the Ste. Genevieve Limestone (Ulrich, 1966), at about 150 m (495 ft) elevation. Low-flow discharge was gaged at 4.2 L/s (0.15 ft³/s) on 11/30/98,

but moderate-flow discharge ranges from 25-50 L/s (1-2 ft³/s) during the winter and spring season.

03-21

April 3, 2003: To further delineate the boundary between the Mill Stream Spring basin and the River Bend Spring basin, 225 g (8 oz) of eosine was injected into the swallet of **Ashby Sinking Spring**, 1.6 km (1.0 mi) south-southwest of Merrittstown, and flushed with 600 L (150 gal) of hauled water. Seven sites were monitored. Fourteen days later, on the second exchange, Lilly Spring (?), 2.0 km (1.2 mi) to the west-southwest, was inconclusive with a minor peak for eosine at about 2.1X background. Lilly Spring (?) was inconclusive 21 days later on the third exchange with a minor peak for eosine at about 1.4X background. Eosine was not detected at any of the other monitoring sites, although Lilly Bluehole (?), a minor karst window 400 m (1,200 ft) to the east of Lilly Spring, yielded a minor bump at the fluorescence wavelength of eosine.

Even though eosine was recovered at less than the positive criterion of 4X background, the low recovery of eosine on two successive exchanges at Lilly Spring suggests that the hydrologic connection was indeed positive to the Lilly Spring within the Mill Stream Spring basin. This interpreted tracer result shifted the local groundwater divide about 0.5 km (0.3 mi) south of the topographic HUC divide. The low recovery of eosine was detected at the second and third exchanges, 14-21 days after dye injection. This suggests that the groundwater velocity within this 2 km (1.2 mi)-long headwater flow system is slower and less efficient than typical. Consequently, much of the tracer dye may have been lost by adsorption onto sediment within the conduit system. The minor amount of flush water used may have also compounded this dye loss. The basin estimated for Lilly Spring, shown in [Figure 39](#), is very tentative. Centered on a local upland, it contains at least four minor surface valleys that may cause some stormwater to overflow the groundwater system during runoff conditions.

River Bend Spring Distributary

River Bend (0860)

River Bend Spring ([Figure 40](#)) in east Trigg County, 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 [N36° 48' 35"/W87° 44' 53"]. 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 alluvium at the north bank of the Little River. River Bend Spring is not shown on the Caledonia Topographic Quadrangle, although a minor perched spring is mapped about 0.5 km (0.3 mi) to the south. River Bend Spring is the 19th largest in the state and was first inventoried by Ray and others (2005).

The presence of this major regional underflow spring was initially hypothesized in this area due to the occurrence of large seasonal overflow springs on Boyd Lake Branch 5.0

km (3.0 mi) to the east-northeast. River Bend Spring is 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 ft³/s), but drought flow (12/8/99) was about 48% less at 82 L/s (2.9 ft³/s).

Caledonia Bluehole (1397)

Caledonia Bluehole Spring is the main spring of a network of five seasonal overflow outlets, comprising the northern portion of the River Bend Spring Distributary. Located about 245 m (800 ft) east-southeast of the KY 272 bridge over Boyd Lake Branch, this rising spring forms a bluehole basin in the south bank of Boyd Lake Branch [N36° 49' 10"/W87° 41' 56"] ([Figure 41](#)). This unmapped spring discharges from the Ste. Genevieve Limestone at about 130 m (428 ft) elevation (Ulrich and Klemic, 1966).

Other related overflow springs include Cane Overflow, which discharges to Sinking Fork 365 m (1200 ft) to the northeast of Caledonia Bluehole. Caledonia South Overflow Spring rises 1.0 km (0.6 mi) to the southeast of Caledonia Bluehole. USGS "Spring" is mapped on the Caledonia Topographic Quadrangle, about 1.05 km (0.7 mi) east-southeast of Caledonia Bluehole. Caledonia East Bluehole refers to a cluster of at least 4 springs discharging on both sides of Boyd Lake Branch, just to the north of USGS "Spring". An unobserved spring (GQ?) is shown on the Caledonia Geologic Quadrangle, near the mapped symbol of vertical joint measurements, about 200 m (650 ft) to the east of Caledonia Bluehole. Stilling Bluehole (SBH) is a minor intermittent bluehole that was not monitored during the tracer tests. The entire overflow distributary is shown in [Figure 42](#).

03-15 (Dye Non-recovery)

March 19, 2003: To delineate the boundary between the Adams Spring basin to the east on Little River and the River Bend Spring distributary to the west on Sinking Fork and Little River, 225 g (8 oz) of SRB was injected at **Coyote Lake**, the site of an intermittent lake in a broad depression, 1.0 km (0.6 mi) west-southwest of Church Hill. During moderate flow conditions, a small amount of water from a swamp puddle was channeled into a small sinkhole. Apparently the temporary inflow was inadequate to inject the dye into the karst flow system, because the dye was not recovered in either Adams Spring or Caledonia Overflow (the main outlet of the distributary below Caledonia Bluehole, monitored at the KY 272 bridge across the overflow spring run).

03-28

May 6, 2003: In a further attempt to delineate the boundary between the Adams Spring basin and the River Bend Spring distributary, 680 g (24 oz) of uranine was injected at **Flynn Sink, North**, about 1.0 km (0.6 mi) west of Church Hill (this site is only 100 m (330 ft) west of the failed Coyote Lake dye-injection site (03-15)). The injection site was a small ephemeral pool of groundwater at the bottom of a minor crevice-like shaft in a sinkhole. The pool was accessed with 20 ft of PVC conduit. The lower end of the

conduit was inserted into the pool at about a 45° incline and liquid dye mixture was poured into the upper end. The pool of water showed signs of groundwater circulation that gradually dispersed dye into the subsurface.

In eight days, Caledonia Overflow (+), 10.5 km (6.5 mi) to the west-northwest, was positive for uranine, whereas the nearer Adams Spring, 2.5 km (1.6 mi) to the east-southeast was negative. Caledonia Overflow, which is the nearest monitoring point within the River Bend Spring distributary, was positive (+) on two additional exchanges and inconclusive (?) by 7/3/03. The more distant River Bend Spring, 14.7 km (9.1 mi) to the west, was negative on the first exchange on 5/14/03, and inconclusive (?) by the next exchange on 7/3/03. Since the hydrology of the distributary was previously mapped by test #99-25 (Ray and others, 2005), River Bend Spring is known to be a valid recovery point for this groundwater test. At an interpreted length of 15.0 km (9.3 mi), this is the lengthiest known karst flow path in southwestern Kentucky.

03-29

May 7, 2003: An additional test 1.8 km (1.1 mi) southwest of the previous location (03-28) was conducted to confirm the boundary between the River Bend Spring distributary and Adams Spring. During the recession of high-flow conditions, 680 g (24 oz) of eosine was poured into **Flynn Sink, South**, a small ponded sink in the vicinity of a minor collapse feature that had been previously located. Seven days later Caledonia Overflow Spring (?), 10.5 km (6.5 mi) to the west-northwest, was inconclusive for eosine, but negative on three additional exchanges. Although the dye wavelength curve from the sample analysis indicated eosine at only 1.6X background, the much nearer Adams Spring, 3.5 km (2.2 mi) to the east-northeast, was negative. Also, this weak positive correlated with the uranine positive obtained from a sinkhole located in the same compound depression, only 1.8 km (1.1 mi) to the northeast (03-28). Consequently, this trace into the River Bend Spring system is considered valid even though the dye injection into standing water of a flooded sink resulted in a significant loss of dye and a substandard dye recovery. To indicate this non-standard dye recovery, the flow path is illustrated with a flow line that is less bold than typical ([Figure 43](#)).

Adams (1905)

Adams Spring ([Figure 44](#)) is part of a small distributary located 1.9 km (1.2 mi) east-southeast of Church Hill in the central portion of the Church Hill Topographic Quadrangle [N36° 47' 38.5"/W87° 33' 13"]. This spring was monitored during tracer testing in the River Bend Spring basin to the west. The free-draining gravity spring is not mapped on the topographic quadrangle but is located near the mouth of a mapped intermittent stream, at the west bank of Little River. Two related overflow springs occur a short distance up the dry stream channel. A fourth related spring, that may be perennial, emerges beneath a low Little River bluff, just downstream of the main spring run. The distributary discharges from the Ste. Genevieve Limestone (Ulrich, 1966), at about 144 m (471 ft) elevation. Based on the basin size, the low-flow discharge is calculated at about 20 L/s (0.75 ft³/s).

Sholar (2679)

Sholar Spring ([Figure 45](#)) is in west Todd County, 4.6 km (2.8 mi) southeast of the junction of US 68 and KY 115 [N36° 48' 35.1"/W87° 16' 21.8"]. It is not mapped on the Pembroke Topographic Quadrangle, although a related karst window spring is mapped 1.1 km (0.7 mi) to the northwest. Rising at about 169 m (555 ft) elevation, Sholar Spring discharges from the Ste. Genevieve Limestone, rising as a bluehole through West Fork alluvium (Moore, 1967). The spring was gaged at 15.0 L/s (0.53 ft³/s) on 10/23/03.

03-04

January 30, 2003: In a test of the divide between Montgomery Creek and West Fork, 85 g (3 oz) of SRB was injected at **Cunningham Window**, 2 km (1.2 mi) southwest of Fairview in eastern Christian County. This karst window (and seven nearby windows) lies in the northern topographic headwaters of Montgomery Creek. However, the dye flowed east and southeast into West Fork via four karst windows and Sholar Spring (++), 4.2 km (2.6 mi) to the east-southeast. The first of three karst windows near Sholar Spring, illustrated with a spring symbol on the Pembroke Quadrangle, is shown in [Figure 46](#).

03-05

January 31, 2003: To further define the Sholar Spring basin, 60 g (2 oz) of eosine was injected at **Blue Hose Window**, 1.5 km (0.9 mi) south of Fairview. Similar to trace 03-04, this dye also flowed southeast 3.7 km (2.3 mi) to Sholar Spring (++), via three karst windows. The Sholar Spring karst groundwater basin is illustrated in [Figure 47](#).

Mosley (3126)

Mosley Spring ([Figure 48](#)) is 0.4 km (0.25 mi) southwest of the US 68 bridge over the South Fork Little River [N36° 50' 51.9"/W87° 21' 21.5"]. It is not mapped on the Pembroke Topographic Quadrangle. This minor free-draining gravity spring discharges from the Renault Limestone (Moore, 1967) at about 169 m (555 ft) elevation and includes an overflow spring and pools in an extension of the channel to the south. No discharge to the South Fork Little River is visible during low-flow conditions.

03-07

February 12, 2003: To identify groundwater basins tributary to the South Fork Little River, 0.5 L (0.5 qt) of Rhodamine WT was injected at **Walker Karst Window**, 4.3 km (2.7 mi) west-southwest of Fairview. Six sites along the South Fork Little River were monitored (to expedite traces 03-07, -08, and -09, background dye receptors were not obtained from these springs prior to dye injections on 2/12/03). Eight days later, Mosley Spring (+++), 1.1 km (0.7 mi) to the north-northwest, was extremely positive for Rhodamine WT. During an additional eight days of monitoring only a small amount of dye was recovered, indicating that in moderate flow conditions the dye passed rapidly

through the karst system. Walker Bluehole ([Figure 49](#)), about 0.5 km (0.3 mi) upgradient of Mosley Spring, was suspected of exposing part of this flow route. However, both dye receptors were lost. Because most of the dye passed rapidly through the basin, water samples from the bluehole were inconclusive (?) for dye.

03-08

February 12, 2003: 60 g (2 oz) of eosine was injected at **Headwater Swallet**, a small sinking stream about 2 km (1.2 mi) east-southeast of Mosley Spring. Eight days later, after monitoring six locations, Mosley Spring (++) was very positive for eosine. Similar to the previous trace (03-07), little dye was recovered on the second exchange. The Mosley Spring groundwater basin is illustrated in [Figure 50](#).

Cowherd (3124)

Cowherd Spring ([Figure 51](#)) is 0.45 km (0.3 mi) north-northeast of the US 68 bridge over the South Fork Little River [N36° 51' 13.2"/W87° 20' 56.6"]. It is not mapped on the Pembroke Topographic Quadrangle. This small gravity spring discharges from the Renault Limestone (Moore, 1967) at about 170 m (557 ft) elevation. No low-flow discharge to the South Fork Little River is visible due to pooling of the spring mouth. However, a karst window about 12 m (40 ft) southeast of the spring contains flowing water, providing an adequate gaging location. A minor discharge of 1.7 L/s (0.06 ft³/s) was averaged from two measurements in this karst window on 10/23/03. Red Barn Karst Window, 150 m (490 ft) to the east, yielded 1.4 L/s (0.05 ft³/s). Beaver occupied the conduit between these two karst windows, increasing turbidity in the lower spring.

03-09

February 12, 2003: 60 g (2 oz) of SRB was injected at **Combs Swallet** ([Figure 52](#)), a 0.6 km (0.4 mi)-long sinking spring fed by two minor karst windows. Eight days later, after monitoring six locations, Cowherd Spring, (++) 2.3 km (1.4 mi) to the northwest was very positive for SRB. Red Barn Karst Window (++) , 150 m (490 ft) upgradient of Cowherd Spring, was also very positive. The Cowherd Spring groundwater basin is illustrated in [Figure 53](#).

Murphy (2520)

Murphy Spring ([Figure 54](#)) is 1.6 km (1.0 mi) west-southwest of the confluence of West Fork and Montgomery Creek [N36° 42' 15.5"/W87° 20' 45.8"]. This free-draining gravity spring, which is not mapped on the Trenton Topographic Quadrangle, discharges from the Ste. Genevieve Limestone (Klemic, 1966). It emerges from the north bank of West Fork at about 137 m (448 ft) elevation. Murphy Spring was gaged at 68.0 L/s (2.4 ft³/s) on 10/9/01.

Due to the minor basin (4.4 km²; 1.7 mi²) attributed to Murphy Spring, it yields seven times the regional reference value for base-flow groundwater runoff (Ray and others,

2005). 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 (interconnected horizontal caves developed in a river bluff) (Mason, 1982, McDowell, 1983). Mylroie & Mylroie (1990) also illustrate the Buzzards Folly Cave 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 minor high-level overflow swallets that are activated only when West Fork rises above bank-full conditions. Therefore, at some zone beneath water level, West Fork could be losing a portion of base flow that is not obvious (Ray and others, 2005).

03-11

February 20, 2003: To identify additional watershed for Murphy Spring, 60 g (2 oz) of SRB was injected during high flow conditions at **S. King Plunging Swallet**, about 0.65 km (0.4 mi) north-northeast of Murphy Spring. This swallet is an unusual intermittent karst window located at the terminal end of a mapped intermittent sinking stream. A spring rises as a minor bluehole in the valley bottom, flows about 20 m (65 ft), and drops 3 m (10 ft) into a terra rosa (soil) pit ([Figure 55](#)). Additional intermittent karst-window flow was observed at the base of the pit. Within eight days, Murphy Spring (+) was positive for SRB, while four other sites were negative. This result verified a local karst basin draining to Murphy Spring, in addition to the assumed cutoff source.

03-16 (Dye Non-recovery)

March 26, 2003: To test the occurrence of unobserved underflow cutoff loss from West Fork to Murphy Spring, 225 g (8 oz) of uranine was poured into **West Fork** just below the confluence with Montgomery Creek ([Figure 56](#)). A West Fork overflow channel that terminates at a swallet into a low bluff, just downstream from Buzzards Folly Cave, was dry during this test. Seven days later Murphy Spring and two upgradient karst windows were negative or inconclusive (?) for uranine. This test indicates that during moderate flow conditions, when the surface overflow channels feeding into the limestone bluff are inoperative, this portion of West Fork does not contribute significant cutoff flow to Murphy Spring. This assumed cutoff route functions primarily during bank-full or higher flow conditions.

03-22

April 10, 2003: In a further effort to determine a stream cutoff source of Murphy Spring, 225 g (8 oz) of SRB was injected at **Montgomery Creek Swallet**, 1.8 km (1.1 mi) northeast of Murphy Spring. This dye injection was conducted during high-flow conditions where elevated Montgomery Creek was losing minor flow into a boulder-choked swallet at the right bank of the 90° elbow of the creek ([Figure 57](#)). No water loss is apparent at this location during low-flow conditions. This stream swallet, 0.7 km (0.4

mi) above Montgomery Creek's confluence with West Fork, is apparently located along a prominent bedrock lineament oriented southwest-northeast.

Within seven days Murphy Spring (++) was very positive for SRB. Likewise, Murphy Karst Window (++) ([Figure 58](#)) and Murphy True Window (slot) (++) ([Figure 59](#)), about 0.6 km (0.4 mi) upgradient of Murphy Spring were both very positive. Cattlet Overflow Spring, just downstream of Murphy Spring was negative for dye. This confirmed stream cutoff route demonstrates that the primary source of Murphy Spring is most likely piracy from Montgomery Creek rather than West Fork. Murphy Spring is normally gaining about 58 L/s (2.0 ft³/s) from Montgomery Creek, even though the losing point(s) is not observable above stream level (except during high flow). West Fork is an assumed contributor to this perennial flow route during overflow conditions. The Murphy Spring groundwater basin and cutoff routes are illustrated in [Figure 60](#).

Johnston (1460)

Johnston Spring is 2.4 km (1.5 mi) west-northwest of the US 41A bridge over Rock Bridge Branch [N36° 47' 54.7"/W87° 29' 58.4"]. Johnston Spring, which is not mapped on the Hopkinsville Topographic Quadrangle, discharges from the Ste. Genevieve Limestone (Klemic, 1967), to the south bank of the South Fork Little River. At about 147 m (482 ft) elevation, this free-draining gravity spring discharges primarily below a 4 m (12 ft)-high bluff, but also from at least four additional locations over 20 m (70 ft) ([Figure 61](#)). Because multiple outlets at streamside make the spring difficult to gage, its low-flow discharge is calculated at about 50 L/s (1.8 ft³/s), based on the basin area. Further downstream along the low bluff, a large overflow spring has been observed to discharge more than 2 m³/s (70 ft³/s) of muddy water in high-flow conditions.

03-13

March 6, 2003: To document the southern headwaters of Johnston Spring basin, 85 g (3 oz) of eosine was injected at **Garnett Swallet**, 2.7 km (1.7 mi) northeast of Masonville. This minor sinking stream flows 0.7 km (0.3 mi) to the northwest from Elam Stoltzfus Spring. Four sites to the north and northwest were monitored. Thirteen days later Garnett Karst Window (+++), 200 m (660 ft) north-northeast of the swallet, was extremely positive for eosine and Philip Garnett Spring (++), 1.2 km (0.7 mi) northwest of the swallet, was very positive for eosine. The tributary headed by Philip Garnett Spring ([Figure 62](#)) joins Rock Bridge Branch, a losing stream that resurges at Johnston Spring.

03-31

June 17, 2003: To document the boundary between Johnson Spring basin (South Fork Little River) and Hargrove Spring (West Fork), 85 g (3 oz) of SRB was injected into **Dulin Karst Window**, 3.1 km (1.9 mi) north-northwest of Long Pond. Seven springs and stream sites were monitored during moderate flow conditions. Eight days later Dulin Bluehole (+++) ([Figure 63](#)), a karst window 0.4 km (0.25 mi) to the west-southwest, was

extremely positive for SRB. Likewise, Northern Tributary (+), an unmapped spring-fed tributary to Rock Bridge Branch, 6.3 km (3.9 mi) to the west, was positive. All of the dye passed through Dulin Karst Window within the first eight days, which was negative on the second exchange. Little residual dye remained in the Northern Tributary, which was inconclusive (?) on the second exchange. These results confirmed that a discrete karst flow route follows an arcing path in the northern portion of the Johnston Spring basin, north of the mapped headwaters of Rock Bridge Branch. This "*Northern Karst Tributary*", containing at least seven perennial and intermittent karst windows, joins Rock Bridge Branch, 300 m (980 ft) east of US 41A.

Bull Grove Branch, a local name for the northern-most sinking stream feeding the *Northern Karst Tributary*, apparently causes a roaring subterranean waterfall that is audible near a high-flow terminal sinkpoint of the branch. This hidden chamber is located about 1.7 km (1.0 mi) southwest of Casky, near the inferred subsurface tributary junction of the sinking stream and the *Northern Karst Tributary* ([Figure 64](#)). A similar audible waterfall was documented by Ray and others (2005) beneath the dry channel of Sinking Fork, 19 km (12 mi) to the west-northwest.

03-35

July 23, 2003: To further delineate the eastern extent of Johnson Spring basin, 85 g (3 oz) of SRB was injected into **Fleming Sinkhole**, 2.0 km (1.2 mi) north of Long Pond, and flushed with 1325 L (350 gal) of hauled water. Six days later on the first exchange, Dulin Bluehole (+), 1.65 km (1.0 mi) to the west-northwest, was positive for SRB. The nearby Dulin Karst Window, which is a small sinking spring, was negative in two exchanges and therefore is a local tributary to this identified flow route. Cornfield Karst Window (+), 6.0 km (3.7 mi) to the west-northwest, was also positive for SRB. This recently discovered spring is one of five perennial karst windows along the *Northern Karst Tributary* within the Johnston Spring basin. Hargrove Spring, to the east, was negative during this test. These data support the local HUC boundary between South Fork of Little River and Montgomery Creek (West Fork basin). [Figure 64](#) illustrates the Johnston Spring groundwater basin.

Interstate 24 (1858)

Interstate 24 Spring discharges to the south bank of the Little River beneath the westbound bridge of Interstate 24 [N36° 45' 49"/W87° 32' 37"]. This spring, which is not mapped on the Church Hill Topographic Quadrangle, discharges from the Ste. Genevieve Limestone (Ulrich, 1966), at about 140 m (461 ft) elevation. This spring consists of both a free-draining gravity spring flowing through crushed limestone boulder fill, as well as a sub-fluvial spring rising in the Little River about 2-3 m (7-10 ft) from the gravity spring ([Figure 65](#)). Because it is difficult to gage, the spring's low-flow discharge has been calculated at 65 L/s (2.3 ft³/s), based on the basin area. A seasonal stream joins the Little River just upstream of the spring ([Figure 66](#)). The watershed of this unnamed stream comprises the apparent recharge area for this spring.

01-25 (Dye Non-recovery)

December 12, 2001: 230 g (8 oz) of eosine was injected at **Driveway Sinkhole** into about 0.1 L/s (2 gpm) of storm-water runoff sinking into a small hole beside a driveway culvert. A larger discrete sinkhole was located a few meters away. This site is about 1.1 km (0.7 mi) northwest of Masonville, Kentucky. Eleven springs and stream sites along the Little River were monitored for four weeks with negative dye recovery. The lack of dye recovery was assumed to result from a poor dye injection feature where most of the dye was adsorbed by the soil.

03-17

March 27, 2003: To document groundwater flow to Interstate 24 Spring, 85 g (3 oz) of eosine was injected into **Woods Hole**, a minor karst window 4.0 km (2.5 mi) east-southeast of Interstate 24 Spring, within its apparent basin ([Figure 67](#)). Seven days later Interstate 24 Spring (+) was positive for eosine. Cherry Estavelle (?), about 1.55 km (1.0 mi) west and down gradient of Woods Hole, was inconclusive because of poor circulation of water through the dye receptor. Spring Hill Spring, just downstream of Interstate 24 Spring, was negative for this test. [Figure 68](#) illustrates the Interstate 24 Spring groundwater basin.

White (1396)

White Spring discharges to the west bank of North Fork Little River 2.2 km (1.35 mi) south-southwest of the KY 695 bridge over that stream [N36° 49' 23"/W87° 31' 20"]. This spring, which is not mapped on the Church Hill Topographic Quadrangle, discharges from a small cave in a low bluff formed in the Ste. Genevieve Limestone (Ulrich, 1966), at about 147 m (483 ft) elevation. This spring exhibits both a free-draining gravity spring flowing from a crevice cave (overflow spring?), as well as a minor boil rising a few meters upstream in the North Fork Little River ([Figure 69](#)). White Spring's base-flow discharge during April, 2003, was roughly estimated at about 28 L/s (1.0 ft³/s), however, low flow was calculated at 10.8 L/s (0.38 ft³/s), based on the basin area.

03-20

April 3, 2003: To compare the groundwater divide with the HUC topographic divide in the area southwest of Hopkinsville (2.1 km [1.3 mi] southeast of Merrittstown), 1.0 L (1 qt) of Rhodamine WT was poured into **Ashby Well**, a 20 m (65 ft)-deep well that intercepted a 2.4 m (8 ft)-high cave containing running water. By using a mirror to reflect sunlight down the well, the running water of a cave stream could be clearly observed flowing east. Residual dye was rinsed from the well casing by flushing about 100 L (25 gal) of water down the casing with a garden hose. Because this well was located near a triple-juncture topographic HUC divide, seven sites to the east, south, and west were monitored. Six days later White Spring (+++), 3.4 km (2.1 mi) to the east-southeast, was extremely positive for Rhodamine WT. White Spring (+) was also

positive on the next exchange two weeks later and inconclusive (?) on the last exchange a month later. No dye was recovered at any of the other six monitoring sites. This result shifted the apparent local groundwater divide up to 0.4 km (0.2 mi) to the west to accommodate a minor basin for the cave stream. [Figure 70](#) illustrates the White Spring groundwater basin.

Cook (1141)

Cook Spring ([Figure 71](#)), 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 Little River. The steep alluvial banks of the spring run 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 Gracey, Kentucky, in 1986 (Crawford, 1987). As suggested by Nicholas Crawford and John Mylroie (unpublished manuscript, circa 1987), 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 ft³/s).

03-19 (Dye Non-recovery)

April 2, 2003: In a test of the groundwater divide between Cook Spring basin and Cool Spring basin, 225 g (8 oz) of eosine was poured into a standing pool at **Hite "Spring" Bluehole**. This feature is labeled "Spring" on the Gracey 7.5 minute Topographic Quadrangle at the northern headwaters of Stillhouse Branch, 5.2 km (3.2 mi) north-northeast of Cool Spring. Placing dye into a standing pool is risky but it was hoped that some unobserved groundwater circulation was occurring or that the dye would be injected into the flow system as water level dropped in the bluehole. However, due to poor circulation or lack of connection with the groundwater system, this dye was not detected within four weeks in karst windows draining west to Cook Spring, nor within six weeks at Cool Spring to the south.

03-23

April 10, 2003: To delineate the boundary between Cook Spring basin and Cool Spring basin, 225 g (8 oz) of uranine was injected during high-flow conditions into **Hite Swallet**, an intermittent sinking stream 2.6 km (1.6 mi) northeast of Montgomery ([Figure 72](#)). Cool Spring and three karst windows in the Cook Spring system were monitored. Eight days later on the first exchange, Broadbent Karst Window (+++) ([Figure 73](#)), 2.5 km (1.5 mi) to the northwest was extremely positive for uranine, as was downgradient Luttrell Karst Window (+++). Most of the dye passed through the Cook Spring system in the first few days since Broadbent Karst Window was inconclusive (?) on the next exchange. This result expanded the Cook Spring groundwater divide to the south of the mapped HUC boundary by about 2.5 km (1.5 mi). In this area the HUC boundary is delineated

between the Muddy Fork Little River to the north (the Cook Spring basin is not recognized) and Stillhouse Branch to the south (part of the Sinking Fork watershed). Tracer testing has shown that the northern two-thirds of the Stillhouse Branch HUC basin drains northwest to Cook Spring, a karst tributary of the Muddy Fork Little River. Most of the remaining Stillhouse Branch groundwater drainage is to Cool Spring on Sinking Fork. [Figure 74](#) illustrates the Cook Spring groundwater basin.

Torian (3117; sub-basin of Mill Stream)

Torian Springs is named in the northeast corner of the Caledonia Topographic Quadrangle, and is shown as two springs 100 m (330 ft) apart, which form the headwaters of a 1.5 km (0.9 mi)-long spring run to Sinking Fork. The eastern spring is comprised of two free-draining gravity springs about 10 m (30 ft) apart, described as *East* and *Central*. The combined base flow was measured at 9.9 L/s (0.35 ft³/s) on 9/24/02. High flow was estimated 100 times greater at about 1.0 m³/s (35 ft³/s) ([Figure 75](#)). These springs discharge from the Ste. Genevieve Limestone (Ulrich and Klemic, 1966) at about 143 m (468 ft) elevation [N36° 52' 11"/W87° 37' 58.7"]. The base flow of the smaller gravity spring to the west was estimated at 1.4 L/s (0.05 ft³/s) and is mapped at 144 m (471 ft) elevation.

02-14

June 19, 2002: To test the groundwater divide between the Muddy Fork Little River and Sinking Fork, 85 g (3 oz) of SRB was injected at **Davis Swallet**, 120 m (400 ft) southwest of the intersection of KY 1026 and KY 1663 ([Figure 76](#)). The dye was injected into about 7 L/s (0.25 ft³/s) of flow sinking near the terminal point of minor blind valley. Fourshee Karst Window, in the Cook Spring basin to the west, and seven sites within the apparent basin of Torian Springs to the south were monitored for four weeks.

Porter Karst Window (++), 1.0 km (0.6 mi) to the southeast, was very positive within nine days on the first receptor exchange. Sixteen days later, the East (+) and Center (+) springs at Torian Springs were both positive and Porter Karst Window (+++) was extremely positive. Thirty-three days after injection, the east and center springs at Torian Springs (++) were both very positive and Porter Karst Window (+++) remained extremely positive. Porter Blueholes #1 (+) and #2 (++) upgradient of Porter Karst Window, were recovered only after 33 days. Porter Bluehole #3 was apparently a stagnant pool in a small sinkhole and was negative. Two additional negative sites were Fourshee Karst Window and the Western Torian Spring. This trace significantly reduced the size of the previously estimated basin of Cook Spring.

Steele Branch is neighboring basin east of Stillhouse Branch. The northern tip of the Steele Branch HUC basin has been shown to drain northwest to Cook Spring (Crawford, 1987). Test 03-24 was designed to determine if the northeastern portion of the Steele Branch HUC basin (1.6 km [1.0 mi] east-southeast of the Crawford dye injection point) also drains northwest to Cook Spring or east to Torian Springs. (*The losing portion of lower Steele Branch has been traced 1.5 km (0.9 mi) west-southwest to Decibel Cave*

(Mylroie and Mylroie, 1991). However, the surface discharge point of this cave into Sinking Fork has not been inventoried and was not monitored for this trace.)

03-24

April 10, 2003: 225 g (8 oz) of SRB was injected into **Baptist Church Karst Window**, 2.4 km (1.5 mi) west-northwest of Torian Springs. During moderate flow conditions, 5 L/s (0.2 ft³) of flow originated from a PVC field tile just south of Old US 68 and flows beneath the highway before entering the swallet. Consequently, this groundwater-recharging flow is vulnerable to highway spills in the immediate vicinity. Eight days after the dye injection on the first exchange, Torian Spring right (+) (combined *East* and *Center*) and left (+) (*Western*) were both positive for SRB. All of the dye had passed through Torian Springs by the first exchange. Three karst windows in the Cook Spring basin were negative during this test.

03-25 (Dye Non-recovery and Replication Non-recovery)

April 10, 2003: 85 g (3 oz) of eosine was injected into **West Union Church Swallet**, a small sinking stream 1.75 km (1.1 mi) north-northeast of Torian Springs. Located only 1.0 km (0.6 mi) west of a verified flow route to Torian Springs, this dye was expected to also drain to Torian Springs. However, three exchanges during April were negative at Torian Springs as well as at Rock Spring, a small intermittent spring flowing beneath US 68, 1.1 km (0.7 mi) southwest of the swallet. After inventorying and monitoring Triple Spring, 1.9 km (1.2 mi) east-southeast of the swallet, the dye injection at **West Union Church Swallet (Rep)** was replicated on April 30 with 110 g (4 oz) of eosine. The first exchange on May 7 was prevented at Triple Spring because of bottomland flooding by Sinking Fork. On the next exchange Triple Spring as well as Torian Springs were negative for eosine. The Triple Spring dye receptor was dry on this exchange but it should have been exposed to spring flow if the dye had emerged during high water conditions. The most likely destination for this lost dye is southeast to an unknown cutoff spring on Sinking Fork or possibly the lower spring run of Torian Springs.

03-26

April 24, 2003: An additional dye injection near Gracey was necessary to determine the destination of a second sinking spring, which could potentially flow northwest to the Cook Spring basin. 85 g (3 oz) of uranine was injected into **Gracey Swallet**, 150 m (500 ft) west of Baptist Church Karst Window (03-24). After five days both Torian Spring right (++) (combined *East* and *Center*) and left (++) (*Western*) were very positive for uranine while Fourshee Karst Window, in the Cook Spring basin was negative. This dye followed the same flow route as the previous Baptist Church Karst Window trace and suggests that the entire community of Gracy also drains to Torian Springs. This trace adjusts the groundwater divide 0.9 km (0.6 mi) to the west of the northeastern portion of the Steel Branch 14-digit HUC boundary (whereas, the 12-digit HUC boundary matches the adjusted groundwater divide in this area). [Figure 77](#) illustrates the Torian Springs groundwater basin, which is a sub-basin of Mill Stream Spring.

03-27 (Dye Non-recovery)

During the investigation of the lost dye injections at West Union Church Swallet (03-25) a high-flow losing point was discovered on a meander of Sinking Fork, 0.4 km (0.2 mi) south-southeast of Shiloh Church. This dye injection tested the possibility that part of Sinking Fork follows a southwesterly cutoff route 2.5 km (1.6 mi) to Torian Springs during high flow conditions. However, this possibility was not very likely because a relatively flat gradient exists between the two points, based on the topographic map elevation contours.

April 30, 2003: 225 g (8 oz) of SRB was injected into an overflow karst window, 60 m (200 ft) south of the **Sinking Fork Losing Point**. The overflow karst window, obviously fed by the losing point, was the only access to this flow route because the losing point was completely inundated by high flow on Sinking Fork. Eight days later both Torian Springs were negative for SRB. The result indicates that the cutoff route discharges at an undiscovered location lower on Sinking Fork or possibly the lower spring run of Torian Springs. This cutoff flow route is also the most likely destination of the lost traces from West Union Church Swallet (03-25).

Cool (2671)

Cool Spring discharges from a cave located in a small pocket valley on the north bank of Sinking Fork ([Figure 78](#)). This spring is incorrectly named "Coon" Cave Spring in the northwestern corner of the Caledonia Topographic Quadrangle. The cave, which is named after the spring, is called Cool Spring Cave (Moore and Mylroie, 1979). This free-draining cave spring discharges from the Ste. Genevieve Limestone (Ulrich and Klemic, 1966) at about 119 m (390 ft) elevation [N36° 50' 49.2"/W87° 43' 50.7"]. The discharge was estimated at 21 L/s (0.75 ft³/s) on 5/15/01. This biologically significant location has been posted by the US Fish and Wildlife Service as a bat hibernacula and brood cave.

03-32

July 5, 2003: In a cooperative effort to document a hydrologic connection between Ladd Cave and Cool Spring, 55 g (2 oz) of SRB was provided to cavers Preston L. Forsythe and Gerald W. Nix, for injection into a stream within **Ladd Cave**, 2.5 km (1.6 mi) south-southeast of the I-24/KY 80 interchange. In three days Cool Spring (+++), 1.6 km (1.0 mi) to the south-southwest of Ladd Cave was extremely positive for SRB. Sinking Fork above Cool Spring was negative. [Figure 79](#) illustrates the Cool Spring groundwater basin.

Table 1 shows a summary of dye-tracing results for this study. The most distant dye recovery site for each successful test is indicated in bold. Groundwater velocities shown with a greater-than (>) symbol indicates dye recovered on the first dye-receptor exchanged, therefore actual groundwater velocity is greater than shown. Of the 40 successful tracer tests, the longest interpreted groundwater flow path is 15.0 km (9.3 mi)

in length, from Flynn Sink North to River Bend Spring (03-28). The average flow length is 5.3 km (3.3 mi). The average groundwater velocity was 0.7 km (0.4 mi) per day.

Typically, groundwater velocity is based on dye recovery in the first exchange of carbon receptors, about one week after dye injection (85%). However, in test 02-12 the documentation of early arrival of dye over a 12.4 km (7.7 mi) distance in four days, established an upper groundwater velocity of >3.1 km (1.9 mi) per day. Assuming this rapid conduit flow is commonplace during moderate-flow conditions, some reported flow-velocities are underestimated by about 75%.

Table 1: Summary of groundwater tracer tests (4/17/01-9/4/03)

Dye Injection Number	Dye Injection Site	Dye Recovery Site(s)	Interpreted Flow Path (km)	GW-Flow Velocity (km/day)
01-05	Woodland Seepage	Non-Recovery (Spring Hill Spring/Herndon Spring?)		
01-06	Noland Sinking Spring	Spring Hill/Herndon springs, Herndon Window*, Spring Hill Window	12.0	>1.5
01-07	Folz Sinkhole	Spring Hill/Herndon springs, Herndon Window, Spring Hill Window	9.5	>1.2
01-22	Watts Cave	Turner Spring, Sump Pool Cave Stream, Turner Window Cave Stream	1.3	>0.1
01-25	Driveway Sinkhole	Non-Recovery (I-24 Spring?)		
01-26	Flooded Shaft Sink	Spring Hill/Herndon springs	5.2	>0.7
01-27	Ballard Sinkhole	Buchanan Spring, Herndon Overflow	8.7	0.6
02-01	Gilkey Swallet	Spring Hill/Herndon springs, Spring Hill Overflow Spring, Hillview Overflow Window	4.7	>0.7
02-12	Pool Lake Swallet	Spring Hill Spring	12.4	>3.1**
02-13	Pruitt Lake Swallet	Spring Hill Spring, West Fork above Murphy Spring	12.6	>1.3
02-14	Davis Swallet	Porter KW*, Porter BH #1 & #2, Torian Spring East and Center	4.0	>0.3
02-16	Beaver-patch Swallet	Hunt Spring, Montgomery Creek @ KY1453, West Fork above Murphy Spring, Hargrove Spring	4.0	>0.6
03-01	Cherry Sinkhole	Non-Recovery (Barkers Mill Spring?)		
03-02	Roberts "F" Sinkhole	Buchanan Spring, Herndon Overflow	9.4	>1.3
03-03	I-24 Swallet	Barkers Mill Spring, Cattlet Overflow, Upper Overflow	12.5	>1.8
03-04	Cunningham Window	Sholar Spring, Sholar Window #1, #2 Window Sink	4.2	>0.3
03-05	Blue Hose Window	Sholar Spring, Sholar Window #1	3.7	>0.3
03-06	Stoltzfus Swallet	Cattlet Overflow Spring, West Fork above Barkers Mill Spring	0.9	>0.07
03-07	Walker KW	Mosley Spring	1.1	>0.1
03-08	Headwater Swallet	Mosley Spring	2.0	>0.3
03-09	Combs Swallet	Cowherd Spring, Red Barn KW	2.3	>0.3
03-10	Stoltzfus KW	Cattlet Overflow Spring, Stoltzfus Spring, Stoltzfus Small Spring	1.2	>0.1
03-11	S. King Plunging Swallet	Murphy Spring	0.6	>0.07
03-12	Cherry Bluehole	Barkers Mill Spring, Cattlet Overflow, Stoltzfus Spring, Stoltzfus KW, Stoltzfus Overflow KW	9.4	>1.6
03-13	Garnett Swallet	Philip Garnett Spring, Garnett KW	1.2	>0.09
03-14	B. Glass Lake	Fredericks Spring	5.8	>0.8
03-15	Coyote Lake	Non-Recovery (River Bend Spring?)		
03-16	West Fork	Not Recovered in Murphy Spring		
03-17	Woods Hole	I-24 Spring	4.0	>0.6
03-18	Barnett Bluehole	Mill Stream Spring, downstream	8.4	>1.2
03-19	Hite "Spring" Bluehole	Non-Recovery (Cook Spring?)		
03-20	Ashby Well	White Spring	3.4	>0.6
03-21	Ashby Sinking Spring	Lilly Spring (?)	2.0	0.14
03-22	Montgomery Creek Swallet	Murphy Spring, Murphy KW, Murphy True Window	1.8	>0.3
03-23	Hite Swallet	Luttrell KW, Broadbent KW	6.3	>0.8

03-24	Baptist Church KW	Torian Spring Right (East & Central), Left (West)	2.4	>0.3
03-25	West Union Ch. Swallet	Non-Recovery (undiscovered cutoff spring)		
03-25 Rep	West Union Ch. Swallet	Non-Recovery (undiscovered cutoff spring)		
03-26	Gracey Swallet	Torian Spring Right (East & Central), Left (West)	2.5	>0.5
03-27	Sinking Fork Losing Point	Non-Recovery (undiscovered cutoff spring)		
03-28	Flynn Sink, North	Caledonia Overflow (composite of 4 overflow springs)	10.5***	1.3
03-29	Flynn Sink, South	Caledonia Overflow (?)	10.5	1.5
03-31	Dulin KW	Northern Tributary, Dulin Bluehole	6.3	>0.8
03-32	Ladd Cave	Cool Spring	1.6	>0.5
03-34	Stoltzfus Swallet	Cattlet Overflow Spring	0.9	>0.07
03-35	Fleming Sinkhole	Cornfield KW, Dulin Bluehole	6.0	0.5
03-36	Pruitt Lake Sinkhole	Fredericks Spring, 512 Elevation Bluehole, West Fork above Barkers Mill Spring	7.4	>1.1
03-37	B. Glass Sinkhole	(Water Samples) Fredericks Spring, 512 Elevation Bluehole	5.8	0.4
03-38	Under I-24 Sinking Stream	Cherry Bluehole KW, 1453 Sinkhole/Lake	3.8	>0.5

*Dye non-recovery emphasized in yellow, including most likely destination of drainage (?). *Karst Window
Early arrival of dye detected in four days by Pete Idstein, of EWC. *The entire interpreted flow route to River Bend Spring is 15 km (9.3 mi) in length. Trace 03-21 to Lilly Spring (?) and 03-29 to Caledonia Overflow (?) are interpreted to be positive at less than the standard criterion of 4X background.*

Unit Base Flow Assessment

In addition to tracer testing, Unit Base Flow (UBF) assessment was applied to most of the karst basins studied in the Little River area. In karst terranes, UBF (base-flow discharge per unit area) can be used to estimate the recharge area of springs, characterize their basins, and assess hydrogeologic relationships (Carey and others, 1994, Quinlan and Ray, 1995, Brahana, 1997, and Paylor and Currens, 2001).

UBF analysis is based on the assumption that equivalent units of watershed within similar hydrogeologic settings and climate will produce about the same amount of base-flow groundwater runoff. When applied to a regional population of springs the method can be useful to predict the size of spring basins from discharge measurements and infer source areas of spring pollution. Likewise, the occurrence of springs and extent of watersheds can be inferred to assist hydrogeologic and dye-trace investigations (Ray and Meiman, 1998). One of the more useful applications of this technique is the identification of basin UBF deficits and excesses compared to established reference values.

UBF is a ratio calculated by dividing the 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 km² equals a unit base flow of 2 L/s/km². 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 base-flow discharge of the spring draining an unknown basin is divided by the UBF of reference basins 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/km² equals a drainage area of 5 km². Considering the generalization and error inherent to discharge and basin-area measurements, UBF calculations should be rounded off to the nearest hundredth.

In the assessment of a regional group of springs, UBF anomalies, above or below the typical reference value, may suggest measurement errors or differing hydrogeologic conditions. UBF deficits may result from inadequate discharge measurements possibly due to unobserved sub-fluvial springs, less productive hydrogeologic settings, or excessive groundwater withdrawal in industrialized or agricultural basins. UBF excesses suggest undersized basin estimates, spring augmentation by unaccounted cutoff diversions from nearby streams, more productive hydrogeologic settings, or excessive groundwater recharge in urban sites (Paylor and Currens, 2001). 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. UBF analysis should be based on minimum annual discharge rather than mean flows, as described by Ray and Blair (2005). For those springs that are difficult to gage or not observed during low flow, the discharge may be calculated (Cal) from the estimated basin area using a UBF reference value (Ref) established from several sites within the same hydrogeologic setting.

Within the Mississippian Plateau study area, hydrogeologic settings composed of well-developed karst in Ste. Genevieve or St. Louis Limestones (Meramec Series) generally yield a reference UBF of about 2.2 L/s/km^2 ($0.2 \text{ ft}^3/\text{s/mi}^2$). The base-flow groundwater runoff tends to be similar, whether it is sinkhole-plain type or flat-lying, fluvial-network type topography. Conversely, units such as the Paint Creek and Renault limestones (Chester Series) include alternating limestone, shale, and sandstone sequences that tend to perch water and limit the depth of weathering. Consequently, these units retard karst development and limit groundwater storage. The resulting moderately-developed "shallow karst" terrane, typically producing fluvial-network type topography, yields about half the UBF of well-developed sinkhole-plain karst of Meramec Series units (Ray and others, 2005).

Only a few UBF measurements are completed within the Chester Series Limestones. However, about 1.1 L/s/km^2 ($0.10 \text{ ft}^3/\text{s/mi}^2$) appears to be a reasonable reference value. The headwaters of Little River and Sinking Fork (Mill Stream Spring basin) extend north beyond the soluble rocks, into non-karst shale and sandstone terrane of Big Clifty and Cypress units. These rocks may yield even less base-flow runoff than shallow karst.

The estimated distribution of hydrogeologic settings within the Little River Basin is provided in [Plate II](#) (Karst Development). *Shallow karst* and *sinkhole-plain karst* comprise the majority of the basin. A coverage of Karst Sinkholes in Kentucky (Paylor and others, 2004), shown in red, adds interesting texture to the image. Although sinkhole density varies across the basin, a greater concentration of sinkholes, including depressions up to 3 km (1.9 mi) long, tends to coincide with the orange, *sinkhole-plain karst*. With the exception of a few sinkhole clusters, the *shallow karst* tends to exhibit fewer and smaller sinkholes, up to 0.5 km (0.3 mi) long. *Thick cover karst*, to the southwest, and less soluble *sandstone and minor karst*, to the northeast, complete the basin's hydrogeologic settings.

Current UBF data for the Little River study area are in Table 2a/2b. Discharge and basin-area data are shown for seventeen traced basins and two sub-basins, including six contiguous basins not traced during this study. Minimum annual discharge ranges from 1.7-169.9 L/s (0.06-6.0 ft³/s), and basin areas range from 3.1-186.6 km² (1.2-72.0 mi²). The UBF values, ranging from a low of 0.44 to a high of 14.54 L/s/km² (0.04-1.33 ft³/s/mi²), are shown in bold. Because limited tracer data are available for estimating the drainage basin of Turner Spring Spring, its basin area was calculated using the higher UBF reference value applied to well-developed sinkhole-plain karst.

Table 2a: Metric Version: UBF data for Little River study area

Spring	ID #	Minimum Annual Discharge (L/s)	Basin Area (km ²)	UBF (L/s/km ²)
Murphy	2520	68.0	4.7	14.54
Venable	1488	13.3	3.1	4.26
Fredericks	1867	62.3	19.2	3.28
Barkers Mill	0859	169.9	61.9	2.73
Cadiz	0854	59.5	24.1	2.47
Quarles	2542	45.3*	19.2	2.40
River Bend	0860	158.6	71.2	2.23
Hunter	1140	31.1	14.0	2.23
Cook	1141	93.4	43.8	2.19
Turner Spring	1910	53.8	<i>24.9 Cal</i>	<i>2.19 Ref</i>
King	1489	59.5	28.2	2.11
Lilly (<i>sub-basin of Mill St</i>)	1395	4.25	2.0	2.08
Sholar	2679	15.0	8.8	1.75
Spring Hill/Herndon	1857/1445	53.8	36.3	1.53
Hunt	1487	62.3	53.9	1.20
Buchanan	0569	42.5 ± 20%	39.4	1.09
Torian (<i>sub-basin of Mill St</i>)	3117	9.91	14.0	0.66
Mill Stream	0203	82.1	186.6	0.44
Cowherd	3124	1.70	3.9	0.44
Interstate 24	1858	<i>65.1 Cal</i>	29.5	<i>2.19 Ref</i>
Adams	1905	<i>19.3 Cal</i>	8.8	<i>2.19 Ref</i>
Cool	2671	<i>27.2 Cal</i>	12.4	<i>2.19 Ref</i>
White	1396	<i>10.8 Cal</i>	4.9	<i>2.19 Ref</i>
Johnston	1460	<i>51.0 Cal</i>	30.3	<i>1.64 Ref</i>
Mosley	3126	<i>5.95 Cal</i>	3.6	<i>1.64 Ref</i>
Stream Site		Discharge (L/s) <i>October 23/24, 2003</i>	Basin Area (km ²) <i>(% Sandstone)</i>	UBF (L/s/km ²)
Montgomery Creek above Fredericks Sp.		130.3	67.1 (0)	1.94
South Fork Little River above Mosley Sp.		53.8	48.4 (33)	1.11
West Fork at US 68		11.3	17.4 (54)	0.65
Muddy Fork of Sinking Fork at US 68		6.80	21.5 (34)	0.32
Sinking Fork at US 68		5.66	77.3 (54)	0.07

* Discharge from AD Little, Inc. The metric conversion factor is: **10.931** x ____ ft³/s/mi² = ____ L/s/km². The English conversion factor is: **0.0915** x ____ L/s/km² = ____ ft³/s/mi².

Table 2b: English Version: UBF data for Little River study area

Spring	ID #	Minimum Annual Discharge (ft ³ /s)	Basin Area (mi ²)	UBF (ft ³ /s/mi ²)
Murphy	2520	2.4	1.8	1.33
Venable	1488	0.47	1.2	0.39
Fredericks	1867	2.2	7.4	0.30
Barkers Mill	0859	6.0	23.9	0.25
Cadiz	0854	2.1	9.3	0.23
Quarles	2542	1.6*	7.4	0.22
River Bend	0860	5.6	27.5	0.20
Cook	1141	3.3	16.9	0.20
Turner BH	1910	1.9	9.6 <i>Cal</i>	0.20 <i>Ref</i>
Hunter	1140	1.1	5.4	0.20
Lilly (<i>sub-basin of Mill St</i>)	1395	0.15	0.78	0.19
King	1489	2.1	10.9	0.19
Sholar	2679	0.53	3.4	0.16
Spring Hill/Herndon	1857/1445	1.9	14.0	0.14
Hunt	1487	2.2	20.8	0.11
Buchanan	0569	1.5 ± 20%	15.2	0.10
Torian (<i>sub-basin of Mill St</i>)	3117	0.35	5.4	0.06
Mill Stream	0203	2.9	72.0	0.04
Cowherd	3124	0.06	1.5	0.04
Interstate 24	1858	2.3 <i>Cal</i>	11.4	0.20 <i>Ref</i>
Adams	1905	0.68 <i>Cal</i>	3.4	0.20 <i>Ref</i>
Cool	2671	0.96 <i>Cal</i>	4.8	0.20 <i>Ref</i>
White	1396	0.38 <i>Cal</i>	1.9	0.20 <i>Ref</i>
Johnston	1460	1.8 <i>Cal</i>	11.7	0.15 <i>Ref</i>
Mosley	3126	0.21 <i>Cal</i>	1.4	0.15 <i>Ref</i>
Stream Site		Discharge (ft ³ /s) <i>October 23/24, 2003</i>	Basin Area (mi ²) <i>(% Sandstone)</i>	UBF (ft ³ /s/mi ²)
Montgomery Creek above Fredericks Sp.		4.6	25.9 (0)	0.18
South Fork Little River above Mosley Sp.		1.9	18.7 (33)	0.10
West Fork at US 68		0.40	6.7 (54)	0.06
Muddy Fork of Sinking Fork at US 68		0.24	8.3 (34)	0.03
Sinking Fork at US 68		0.20	29.8 (54)	0.007

*Discharge from AD Little, Inc. The metric conversion factor is: **10.931** x ____ ft³/s/mi² = ____ L/s/km². The English conversion factor is: **0.0915** x ____ L/s/km² = ____ ft³/s/mi².

With a low UBF of 0.44 L/s/km² (0.04 ft³/s/mi²), the yield of Mill Stream Spring is a major deficit anomaly, which defies easy explanation. With a basin of 186.6 km² (72.0 mi²) and a discharge of 82.1 L/s (2.9 ft³/s), it yields only 36% of expected base flow. Its basin yield is calculated below using two reference values and an assumed zero yield for sandstone and minor karst:

$$\begin{aligned}
 \text{Sinkhole-plain karst } 40\% &= 75.0 \text{ km}^2 \times 2.2 \text{ L/s/km}^2 = 165.0 \text{ L/s,} \\
 \text{Shallow karst } 31\% &= 58.2 \text{ km}^2 \times 1.1 \text{ L/s/km}^2 = 64.0 \text{ L/s,} \\
 \text{Sandstone and minor karst } 29\% &= 53.3 \text{ km}^2 \times \text{zero base flow} = 0.0 \text{ L/s,} \\
 \textbf{Total} &\textbf{ 229.0 L/s}
 \end{aligned}$$

In a similar calculation, Torian Spring, a sub-basin of the Mill Stream Spring basin, yields only 39% of its expected base flow. The reason for Mill Stream Spring's low yield

is unknown, but a portion of the deficit appears to result from low-yielding headwaters such as the Torian Spring sub-basin. Also, the Muddy Fork of Sinking Fork, with a UBF of 0.32 L/s/km² (0.03 ft³/s/mi²), is a relatively low yielding sub-basin of Mill Stream Spring. Nevertheless, the sinkhole-plain portion of the Mill Stream Spring basin alone should yield twice the observed discharge. An additional drainage anomaly must be present. The most likely cause is unobserved underflow to Sinking Fork downstream of the Mill Stream Spring gaging point. The former mill dam located just below the spring may maintain an artificially high spillover point for the spring, causing a portion of base flow to divert unobserved to a downstream underflow route. Future investigations should focus on underflow spring surveys downstream of Mill Stream Spring. Likewise, an additional survey is needed for a cutoff spring below the losing point of Sinking Fork described in the non-recovered dye injection 03-27.

To better understand the yield of *shallow karst* and *sandstone and minor karst* portions of the upper Little River basin, five gaged stream sites are included at the bottom of the table. At 0.07 L/s/km² (0.007 ft³/s/mi²), the Sinking Fork site yielded a deficit anomaly about an order of magnitude lower than the others. The discovery of a losing point of Sinking Fork, described in dye injection 03-27, about 0.5 km (0.3 mi) to the south of the gaging site, suggests that additional undiscovered stream losses may occur upstream of the gaging site. Consequently, this UBF value is suspect because of a probable incomplete discharge measurement of Sinking Fork at that location.

The Montgomery Creek site is located further to the south than the other four and contains no sandstone. Its higher yield is due to about 57% of its basin containing well-developed karst. Calculation of its basin yield using two reference values amounts to 90% of the observed discharge of 130.3 L/s:

$$\begin{aligned}\text{Sinkhole-plain karst } 57\% &= 38.6 \text{ km}^2 \times 2.2 \text{ L/s/km}^2 = 84.9 \text{ L/s}, \\ \text{Shallow karst } 43\% &= 29.0 \text{ km}^2 \times 1.1 \text{ L/s/km}^2 = 31.9 \text{ L/s}, \\ &\quad \textbf{Total 116.8 L/s}\end{aligned}$$

Of the remaining three stream sites, the basin component draining *sandstone and minor karst* ranges from 33-54%, with the remainder draining *shallow karst*. The UBF of these three sub-basins ranges from 0.32-1.11 L/s/km² (0.03-0.10 ft³/s/mi²), which is in general agreement with Cowherd, Torian, and Hunt springs, ranging from 0.44-1.20 L/s/km² (0.04-0.11 ft³/s/mi²). The UBF of Sholar Spring, entirely within the *shallow karst*, is only slightly higher than the nearby South Fork Little River above Mosley Spring, which drains 67% *shallow karst*. These initial measurements provide additional evidence of the reduced groundwater yield of basins heading in *shallow karst* and *sandstone and minor karst*. [Plate III](#) (Comparison of Springs and Streams in Shallow Karst) shows the location of these basins and the UBF reference values for the three hydrogeologic settings.

A regression analysis was performed on the spring Discharge and Basin Area data. Since the basin area of Turner Spring is poorly delineated, it is excluded from the regression analysis. Six additional springs, with discharges calculated from tracer-delineated basin areas, are also excluded. The remaining eighteen basins are assessed in a scatter plot in

[Figure 80](#). The R^2 value, "goodness of fit", represents the percentage of variation in base-flow discharge that can be explained by the basin area. Because Mill Stream Spring and Murphy Cutoff Spring deviate greatly from the main population (identified by the oval), the R^2 value is poor at 0.27. When those two springs are excluded from the group, the R^2 improves to 0.80 ([Figure 81](#)). This regression supports the concept of a direct relationship between base-flow discharge and basin area, a consistent correlation that inevitably draws attention to springs with excess or deficit anomalies and their implications.

Configuration of the Little River Karst Watershed as Verified by Groundwater Tracer Testing

The primary purpose of this study is to map the karst groundwater basins that contribute to the Little River basin. This delineation is important because significant portions of the basin boundary cross sinkhole-plain type karst terrane lacking contiguous surface drainage patterns. In these areas the delineation of a valid drainage divide and the destination of karst groundwater drainage are questionable. Indeed, the manually delineated 14-digit HUC and automated 12-digit HUC delineations often fail to match in the vicinity of some depressions along this boundary. [Plate I](#) shows the entire study area including the Little River stream network and karst drainage basins delineated by tracer testing. The primary data layers tested in these studies are the 12- and 14-digit hydrologic unit code (HUC) boundaries delineated by the US Geological Survey. These 12- and 14-digit HUC boundaries are identified as bold and fine orange lines, respectively, in each spring-basin illustration.

Assessment of the Little River HUC Delineations

The State of Kentucky, Hydrologic Unit Map-1974, was published in 1976 (US Geological Survey). This map includes a generalized 8-digit Subregional watershed boundary between the Little River/Sinking Fork system to the south and Pond and Tradewater rivers to the north. This boundary along non-karst terrane was not evaluated in this study. The map also includes a generalized 8-digit Catalogue Unit boundary between the Little River to the northwest and the Red River to the southeast. Part of this latter boundary was tested in this study. More detailed delineation, including the 11- and 14-digit HUC boundary layers, was completed for the Little River basin by the US Geological Survey (Nelson and others, 1997). The provisional 12-digit HUC boundaries are currently in review but will be finalized by USGS and NRCS as a seamless national data set. These watershed data are indispensable for investigating and managing natural resources and land-use activities within the US. However, the hydrologic units were delineated based on surface drainage-divide criteria without consideration of subsurface conduit hydrology.

Topographic divides are commonly employed as karst groundwater basin divides. However, depending on the local hydrogeology, this method is hypothetical without tracer verification. A comparison was made between tracer-delineated boundaries and topographic divides within 650 km² (250 mi²) of karst terrane, in three portions of

Kentucky's Mississippian Plateau. This comparison indicated that at least 15-20% of karst-aquifer drainage did not coincide with topographic watersheds (Ray and others, 2000).

However, the majority of an individual karst basin's drainage may deviate from its topographic watershed. For example, about 75% of the Green River's 233 km² (90 mi²) Turnhole Spring watershed, including the Park City area of south-central Kentucky, is incorrectly attributed to the Barren River basin where hydrologic units are based solely on topographic divides (Ray, 2001). This hydrologic-basin error, which incorrectly enlarges the Barren River basin by nearly 4%, was present on the 1976 state hydrologic unit map and was slightly expanded during delineation of the 11- and 14-digit HUC boundaries (Nelson and others, 1997). This watershed error continues to be utilized, for example, in a Kentucky State Nature Preserves Commission map of "hot spot" and priority watersheds for conservation of imperiled freshwater mussels and fishes in Kentucky (Cicerello and Abernathy, 2004).

Karst groundwater drainage that is incongruous with topographic basins has been termed *misbehaved* by White and Schmidt (1966). Although this term should not construe anthropogenic behavior by groundwater, it is useful to describe the divergence from a commonly assumed accordance of groundwater and surface topography. For the purposes of this study, misbehaved karst drainage is defined as *verified conduit flow passing beneath a delineated 14-digit or lower HUC boundary*. Table 3 summarizes the degree of misbehaved drainage in 18 karst basins and a sub-basin, as demonstrated by 40 successful tracer tests. Torian Spring is a sub-basin of Mill Stream and is therefore excluded from the totals. For seven basins, or 39% of the population, the ratio of misbehaved basin areas to total basin areas ranges from 0.10-0.99, or 10-99%. Eleven basins, or 61%, contain no identified misbehaved drainage. Considering the total watershed area of 638 km² (246 mi²) for the 18 karst drainage basins, 308 km² (119 mi²), or 48% of the total area consists of misbehaved drainage.

In the Buchanan and Spring Hill/Herndon spring basins to the southeast, misbehaved karst groundwater primarily drains beneath an 8-digit HUC boundary between Little River and Red River, both tributaries of the lower Cumberland River system. In the Cook Spring basin to the northwest, misbehaved karst groundwater drains beneath 12- and 14-digit HUC boundaries between Sinking Fork and Muddy Fork. The large misbehaved tract in the Mill Stream Spring basin drains beneath the dual 12- and 14-digit HUC boundary between the middle and lower reaches of Sinking Fork. The large misbehaved tract in the River Bend basin drains beneath the 12- and 14-digit HUC boundary between the middle reach of Sinking Fork and a lower main-stem reach of the Little River.

Although no tracer testing was conducted in the Venable Spring basin during this study, it is included in this spring population because it is relevant to trace #02-16, in the Hunt Spring basin. This dye trace, injected into a Montgomery Creek swallet, passes beneath the Venable Spring basin, and returns to the surface at Hargrove Spring, en route to Hunt Spring. The trace passes beneath an interfluvium separating Montgomery Creek and the unnamed stream to the west (occupied by Hargrove Spring run). The interfluvium is not

Table 3: Ratio of misbehaved karst basin area to total basin area

Spring Basin	Spring ID	Misbehaved Basin Area (km ²)	Total Basin Area (km ²)	Misbehaved Basin Ratio
Mill Stream	0203	184.6	186.6	0.99
River Bend	0860	68.7	71.2	0.96
Buchanan	0569	23.5	39.4	0.60
Cook	1141	24.2	43.8	0.55
Sholar	2679	1.9	8.8	0.22
Murphy	2520	1.0	4.8	0.21
Spring Hill/Herndon	1857/1445	3.8	36.3	0.10
<i>Torian*</i>	<i>3117</i>	<i>1.0</i>	<i>14.0</i>	<i>0.07</i>
Venable**	1488	0	3.1	0
Barkers Mill	0859	0	61.9	0
Hunt	1487	0	53.9	0
Fredericks	1867	0	19.2	0
Cowherd	3124	0	3.9	0
Turner BH	1910	0	24.9	0
Interstate 24	1858	0	29.5	0
Cool	2671	0	12.4	0
White	1396	0	4.9	0
Johnston	1460	0	30.3	0
Mosley	3126	0	3.6	0
Totals	-	307.7	638.5	0.48

**Torian Spring is a sub-basin of Mill Stream and is excluded from the totals. **Venable Spring is included because a dye trace in the Hunt Spring basin passes beneath the perched Venable Spring basin.*

delineated with a HUC boundary and therefore the trace is not misbehaved based on the HUC-criterion defined above. Nevertheless, in the strictest sense this unusual flow route could be considered doubly misbehaved by passing southwest beneath a local topographic divide that contains a perched karst flow route draining in a different direction (south-southeast from Mitchell Sinkhole to Venable Spring). Also, because the Mitchell Sinkhole trace bifurcated to a spring on Montgomery Creek above the 02-16 swallet, as well as Venable Spring, dye from this test exhibits the bizarre behavior of the eastern bifurcation route curving back to the west and draining independently beneath the southern bifurcation route.

[Plate IV](#) (Behaved & Misbehaved Karst Drainage) shows the investigated karst watersheds in the Little River basin that are behaved (green) and misbehaved (orange), relative to HUC boundaries. Verified conduit flow that passes beneath HUC boundaries renders the HUC delineation hydrologically invalid. As stated by Ray and others (2000), *"At a minimum, topographic divides in karst terrane should be depicted on HUC maps with dashed or dotted lines where the true nature of perennial stream flow and groundwater drainage is unknown. Traced groundwater-basin delineations should be utilized where available"*.

CONCLUSIONS

This study, largely funded by 319h EPA Nonpoint Source monies, has significantly advanced the knowledge of karst hydrology and watersheds in the Little River basin of

southwestern Kentucky. A southeastern shift of the Little River watershed was initially identified by previous work and verified and expanded by this investigation. Clearly, watershed research and management units in karst terrane must account for mapped karst drainage basins rather than being solely based on HUC topographic units.

Several conclusions about regional hydrology, drawn from tracer testing and base-flow gaging, are outlined below:

Results of Groundwater Tracer Testing:

(a) A dye trace from Roberts Sinkhole was recovered 9.4 km (5.8 mi) to the west-northwest at ***Buchanan Spring***, discharging at the south bank of the Little River. Dye from this test was also recovered in Herndon Overflow Spring located about 1.0 km (0.6 mi) southeast of Buchanan Spring. Roberts Sinkhole (F) was the location of two failed dye injections during previous regional investigations. About 40% of this karst basin drains beneath an 8-digit HUC boundary, slightly shifting the eastern portion of the Little River basin to the southeast.

(b) The ***Springhill Spring/Herndon Spring*** basin draining to the Little River transmits groundwater west as much as 14.5 km (9.0 mi) from a divide area that retains seasonal lakes. The documented conduit-flow velocity exceeded 3.4 km/day (2.1 miles/day). Groundwater from about 10% of this karst basin drains beneath an 8-digit HUC boundary, further shifting the Little River drainage basin to the southeast. At 2.3 km (1.4 mi) wide, this spring network is the widest confirmed ***perennial*** groundwater distributary in Kentucky.

(c) Over 50% of the ***Cook Spring*** basin consists of terrane where groundwater is pirated to Muddy Fork from the headwaters of Stillhouse Branch and Steele Branch, tributaries of Sinking Fork. These diversions decrease the northwestern portion of the Little River basin, which balances the southeastern watershed gains in Spring Hill/Herndon and Buchanan spring basins. Although the total area of the Little River basin above the confluence with Muddy Fork remains unchanged at 1122.5 km² (433.4 mi²), relative to the topographic divide, the effective karst watershed is shifted to the southeast by about 23 km² (9 mi²).

(d) An 8.0 km (5.0 mi)-long dye trace from a seasonal lake was recovered primarily to the east in ***Fredericks Spring***, a three-spring perennial distributary system discharging to West Fork (a western overflow connection to the Springhill Spring/Herndon Spring basin was also indicated by this trace). The conduit supplying the easternmost of the three springs passes beneath the bedrock channel of Montgomery Creek along an apparent lineament. Flow observations over six-years suggest a natural shifting of discharge within the distributary, possibly by clogging of the underflow element.

(e) A losing reach of Montgomery Creek was traced beneath a perched karst groundwater basin, just southeast of Pembroke, Kentucky. The perched flow route trends southeast to Venable Spring whereas the subjacent flow route drains southwest from Montgomery

Creek to Hargrove Spring, ultimately resurging at **Hunt Spring**. These separate groundwater flow routes appear to cross as an "X" on a plan map.

(f) **Turner Spring**, discharging to the west bank of West Fork, was traced from Twin Level Cave, lying on the east side of West Fork. This is an example of conduit underflow of a perennial base-level stream. The rising spring may have been completely overridden by a laterally migrating meander of West Fork.

(g) A karst distributary was identified within the **Barkers Mill Spring** basin, discharging from Cattlet Overflow Springs, 2.9 km (1.8 mi) to the north of Barkers Mill Spring. The northern fork of this distributary contains a large overflow karst window plus two seasonal-flow karst windows draining a local basin.

(h) A 7.5 km (4.7 mi)-long curvilinear karst flow route containing at least seven perennial and intermittent karst windows and an audible subterranean waterfall was identified in the northern portion of the **Johnston Spring** basin. None of these springs, including Johnston Spring, are mapped on the Hopkinsville 7.5 minute Topographic Quadrangle.

(i) Three failed tracer tests suggest that an undiscovered Sinking Fork cutoff spring is located on Sinking Fork upstream of **Torian Spring** or possibly on Torian Spring run.

Results of Unit Base Flow Assessment:

(j) At 68 L/s (2.4 ft³/s), the discharge of **Murphy Spring** appears to be seven times larger than its minor basin should yield. Both physical location and previous investigations infer that Murphy is a spring supplied primarily by a cutoff from West Fork. However, two different tracer dyes detected in the flow of West Fork were not conclusively detected in Murphy Spring. A newly discovered Montgomery Creek high-flow losing point, 0.7 km (0.4 mi) above Montgomery Creek's confluence with West Fork, did trace through a series of karst windows to Murphy Spring, confirming its cutoff source.

(k) The UBF of the **Buchanan Spring** basin is anomalously low, yielding only 50% of the discharge suggested by the identified basin size (reference value of 2.2 L/s/km² [0.20 ft³/s/mi²]). Unobserved underflow to the Little River along a possible lineament may account for the low measured spring flow.

(l) UBF of the adjacent **Springhill/Herndon** distributary is also relatively low, yielding 70% of the expected spring flow predicted from basin size, suggesting unobserved sub-fluvial springs. Declining discharge at Herndon Spring suggests that some portion of distributary flow may have been diverted to Springhill Spring (or undiscovered springs), possibly through slight increase of the elevation of Herndon Spring by recent beaver-damming. This 36 km² (14 mi²) basin includes about 5 km (3 mi) of Interstate 24 and the site of a proposed interchange with Pennyryle Parkway. This transportation corridor and the completion of a large Wal-Mart distribution center increase the basin's vulnerability to nonpoint source (NPS) pollutants and accidental spills.

(m) Hydrogeologic settings formed in upper Ste. Genevieve, Renault, and Paint Creek limestones are characterized as *shallow karst*. Possibly due to shallower soils and weathering and reduced epikarst storage, base-flow groundwater runoff appears to be about 50% of that from well-developed *sinkhole plain karst*.

(n) The UBF of *Mill Stream Spring* is anomalously low, yielding only 36% of calculated base flow. Part of this anomaly is due to low yielding sub-basins but an additional loss of flow to the spring is hypothesized as unobserved underflow to downstream Sinking Fork.

Assessment of HUC watershed delineations:

(o) Misbehaved karst drainage is defined as *verified conduit flow passing beneath a delineated 14-digit or lower HUC boundary*. Seven spring basins, or 39% of the population, contained misbehaved drainage ranging from 10-99%. Eleven basins, or 61%, contain no identified misbehaved drainage. However, 48% of the total spring-basin area consisted of misbehaved drainage. This degree of deviation of karst groundwater base flow from attributed watersheds can invalidate watershed calculations based on HUC units.

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APPENDIX A: Financial and Administrative Closeout

1. Work Plan Outputs

Period Start Date: 02/01

End Date: 01/06

Project Milestones

Milestone	Expected Begin Date	Expected End Date	Actual Begin Date	Actual End Date
1. Submit all draft materials to the Cabinet for review and approval.	Duration	"	"	"
2. Submit advanced written notice on all workshops, demonstrations, and/or field days to the Cabinet.	Duration	"	"	"
3. Submit Annual Reports and/or participate in the Cabinets sponsored biennial NPS Conference.	Duration	"	"	"
4. Conduct spring and swallet (sinkpoint) surveys.	07/99	12/00	02/01	08/03
5. Investigate potential dye injection points.	09/99	12/01	02/01	08/03
6. Conduct low-flow spring gauging of springs to estimate basin size.	09/99	12/99	10/01	10/03
7. Conduct background dye analyses at selected springs.	09/99	06/02	04/01	08/03
8. Design iterative dye-trace plans for the Little River and Sinking Fork watersheds and update as needed.	09/99	06/02	02/01	08/03
9. Conduct dye-trace studies.	09/99	06/02	04/01	09/03
10. Process and analyze dye receptors.	09/99	06/02	04/01	09/03
11. Provide preliminary results to TMDL developers.	11/00	06/01	09/02	11/05
12. Prepare and present annual report.	07/00	09/00	07/02	09/02
13. Summarize results of the dye-trace study.	01/02	05/02	07/02	09/02
14. Prepare and present annual report.	07/01	09/01	07/02	09/02
15. Prepare and distribute final study report.	06/02	12/02	06/05	01/06
16. Prepare close-out report.	09/02	12/02	11/05	12/05

2. Budget

Budget Summary:

Budget Categories (See explanations below)	Project Activity Categories						
	BMP Implementation	Project Management	Public Education	Monitoring	Technical Assistance	Other	Total
Personnel		\$3,637				\$32,737	\$36,374
Supplies							
Equipment							
Travel							
Contractual							
Operating Costs		\$1,497				\$13,474	\$14,971
Other							
TOTAL		\$5,134				\$46,211	\$51,345

Detailed Budget:

Budget Categories	Section 319(h)	Non-Federal Match	Total
Personnel	\$21,824	\$14,549	\$36,374
Supplies			
Equipment			
Travel			
Contractual			
Operating Costs	\$8,983	\$5,989	\$14,971
Other			
TOTAL	\$30,807	\$20,538	\$51,345
	60%	40%	100%

Budget Narrative

The Division of Water was responsible for managing, staffing, and providing or obtaining the equipment and necessary resources to complete the project, and provided all reports and materials produced under this project. The Division of Water, Groundwater Branch Manager provided review of all products for this grant and all such products are subject to the approval of the Division of Water. \$51,345 to conduct the dye-trace studies of the area to determine hydrologic basin boundaries represents approximately 0.75 FTE. The Division of Water provided all non-federal match with personnel and indirect costs. All equipment and laboratory costs are reflected in the indirect costs of a FTE.

APPENDIX B: Figures 1-81 and Plates I-IV (Paper Copy)

APPENDIX C: Individual Dye-Trace Records