RECHARGE AREA DELINEATION OF THE PAUTLER CAVE SYSTEM AND ANNBRIAR SPRING IN MONROE COUNTY, ILLINOIS

FINAL REPORT

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A contract study for the Illinois Nature Preserve Commission
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1.0 EXECUTIVE SUMMARY

This study was designed to delineate the recharge area of the Pautler Cave system in Monroe County, Illinois. The recharge area for a cave is the land area that contributes water to that cave and the streams that flow through the cave. A portion of the Pautler Cave system is within a proposed Illinois Nature Preserve. The cave fauna in the cave system includes the Federally listed endangered *Gammarus acherondytes*, commonly known as the Illinois Cave Amphipod.

In order to manage and protect the caves and cave fauna it is necessary to understand which lands provide recharge to the cave systems. The Ozark Underground Laboratory conducted this work with funding from the US Fish and Wildlife Service through the Illinois Nature Preserves Commission.

The recharge area delineation is primarily based upon groundwater tracing studies. These results were augmented with information and maps of the caves, flow rate measurements of springs, and hydrogeological considerations. The study was conducted during a twelve-month period and involved 19 new dye introductions that were detected at 25 sampling stations. Thirty-five sampling stations were established. Arc Info compatible Geographic Information System (GIS) themes as well as hard-copy figures show the traces and the recharge area delineation.

The following information summarizes the Pautler Cave system recharge area, delineated during this study, and identifies the associated springs.

Pautler Cave Recharge Area

The total size of the recharge area is approximately 6.3 square miles. Under normal flow conditions, groundwater in this system flows through Vandeventer Karst Window and is primarily discharged at Vandeventer Spring along with minor discharge from Ice Box Spring. Under very high flow conditions, most of the recharge area can overflow to Annbriar Spring. Figure 5 shows this hydrologic interaction.

Annbriar Spring Recharge Area

The size of this recharge area at normal flow is approximately 6.0 square miles. However, under high flow conditions approximately 12.1 square miles contribute water to Annbriar Spring. Most of the normal level recharge from the south side of Fountain Creek flows through Reverse Stream karst window, which is on the south side of Fountain Creek. However, there is also appreciable recharge of Annbriar Spring from the north side of Fountain Creek. Further, groundwater overflowing from the Pautler Cave groundwater system does not flow through Reverse Stream karst window.

Conducting the groundwater tracing studies led to several important discoveries; these include:

1) There is intermittent hydrologic interaction between the Pautler Cave and Annbriar Spring groundwater systems. This interaction is in the form of the Pautler Cave groundwater system overflowing to Annbriar Spring under high flow conditions.

2) An upstream portion of Fountain Creek is losing water into the groundwater system. In the Salem Plateau Karst, surface streams shown on the USGS topographic maps may lose some or all of their flow into the karst groundwater system.

3) There is either flow passing under Fountain Creek between Reverse Stream and Antler Spring. Or there is another losing section of Fountain Creek downstream of Annbriar Spring recharging Antler Spring.

4) Cedar Ridge Cave, an Illinois Cave Amphipod site, has been determined to be part of the Annbriar Spring groundwater system. Previous to this investigation, it was unclear whether it was part of the Pautler Cave system or part of the Annbriar system.

5) Groundwater in the Salem Plateau Karst can travel great distances. Two traces were detected over four miles from the dye introduction points (Table 5).

6) Mean groundwater gradients in this study range from 26 to 286 feet per mile, with 45 to 75 feet per mile being typical.

7) The persistence of dye pulses ranges from a few days to several months. Even in high flow systems, contaminants may not flush out quickly. Conversely, sampling for a contaminant pulse from some source areas may need to be conducted daily.

8) Runoff and spills from Route 156 and Maeystown Road have the potential to impact at least two populations of the Illinois Cave Amphipod.

This report makes the following recommendations:

1. A great deal of effort has gone into the groundwater tracing work to delineate the recharge area for the Pautler Cave system. These data need to be made available to public health, land use planning, agricultural services, and other relevant entities. Furthermore, these entities should be encouraged to incorporate the recharge area delineation results in their work in the region. Data left on the shelf do not help to enhance or protect public health and natural resources.

2. Site-specific groundwater tracing will be needed to assess particular issues, especially in areas near recharge area boundaries or in areas outside of the areas included in this study.

3. More detailed groundwater tracing should be conducted in areas that are receiving suburban land development pressures. More detailed groundwater tracing is also appropriate where other land uses which could significantly impact water resources are proposed or planned.

4. Vulnerability mapping should be conducted for the delineated recharge areas. As briefly mentioned in this report, the vulnerability of a cave groundwater system to contamination is not equal for all parcels of land within the recharge area. Tailoring of land uses to site suitability is a prudent and effective strategy for minimizing adverse impacts on groundwater and cave resources. Vulnerability mapping, which assesses the relative risks of groundwater contamination from land uses, is a valuable land management and land use planning tool. Vulnerability mapping typically identifies areas where the groundwater contamination risks to the associated groundwater system are high, where they are moderate, and where they are low.

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2.0 INTRODUCTION

The Illinois Nature Preserves Commission (INPC) published a Request for Proposal for the delineation of the groundwater recharge area for the Pautler Cave system in Monroe County, Illinois. Pautler Cave and Camp Vandeventer are Illinois Natural Area Inventory (INAI) sites. The State of Illinois seeks to protect the INAI sites and their karst ecosystems. The Pautler Cave system provides habitat for *Gammarus acherondytes*, commonly known as the Illinois Cave Amphipod. The amphipod is listed as Federally Endangered. Management is best served by a thorough knowledge of the cave biota, water quality, and land uses that might potentially degrade the resources. The land uses that most affect the cave systems are those taking place in the respective recharge areas.

Recharge areas often have little correlation with topographic basins. Groundwater tracing using fluorescent dyes is the most appropriate method for delineating cave and spring recharge areas (Aley and Aley, 1991).

This report covers all work performed by the Ozark Underground Laboratory (OUL) under contract to the INPC. Within this report is the delineation of the Pautler Cave system recharge area. In addition to the delineation, the dye traces and other supporting data are presented along with interpretations.

Some explanation of the terms used in this report is warranted. A <u>cave</u> is defined as a naturally occurring void in earth materials, which is humanly enterable for at least twenty feet (Illinois Speleological Survey definition). A <u>cave system</u> may contain multiple caves, water inlets, and springs that are all related speleogenetically. For management purposes, the cave system is generally the category of interest. The fauna and the water in the system are rarely restricted by the condition that it is impassable to people.

A <u>cave recharge area</u> is that surface land area that contributes water to a particular cave. A <u>recharge area for a spring</u> is similar in that it is the surface area which contributes water to that spring. We may speak of a cave's <u>groundwater system</u>; this term is generally analogous to the term recharge area except that it refers to the subsurface rather than the surface.

<u>Karst</u> is a three-dimensional landscape underlain by soluble rocks and having appreciable groundwater flow through dissolved out openings (internal drainage) in the rock. Water movement through the karst of the study area is characterized by rapid subsurface flow through conduits within the bedrock; some of the conduits are caves that people can enter. It is this fast flow nature of water movement and its localization in preferential flow routes that makes karst ecosystems especially vulnerable to degradation. There is little opportunity for adsorption, degradation, or other natural processes to cleanse the passing water of contaminants as the water rapidly flows through the preferential flow conduits.

Some springs discharge water only during higher flow conditions. This flow pattern is typically attributed to the presence of other spring discharge points that are typically located at lower elevations. The intermittent-flow springs are often called overflow springs. The perennial flow springs in such a system are often called underflow springs. A full-flow spring is a spring that is the sole discharge point for a groundwater system. We have used these terms at several points within this report when the dye tracing data support their use.

An estavelle is a karst feature that functions as a recharge point or sinkhole at low flow conditions and functions as a discharge point or spring under high flow conditions.

Shared recharge areas provide water to two or more groundwater systems. Such areas are typically located near recharge area boundaries. Shared recharge areas and their associated shared groundwater systems are undoubtedly important in explaining the subsurface distribution of aquatic cave fauna. Shared recharge areas are also discussed in the tracing results and delineated in this report.

A karst window is a roof collapse over a cave stream and provides a "window" into that stream.

2.1 Purpose of the Study

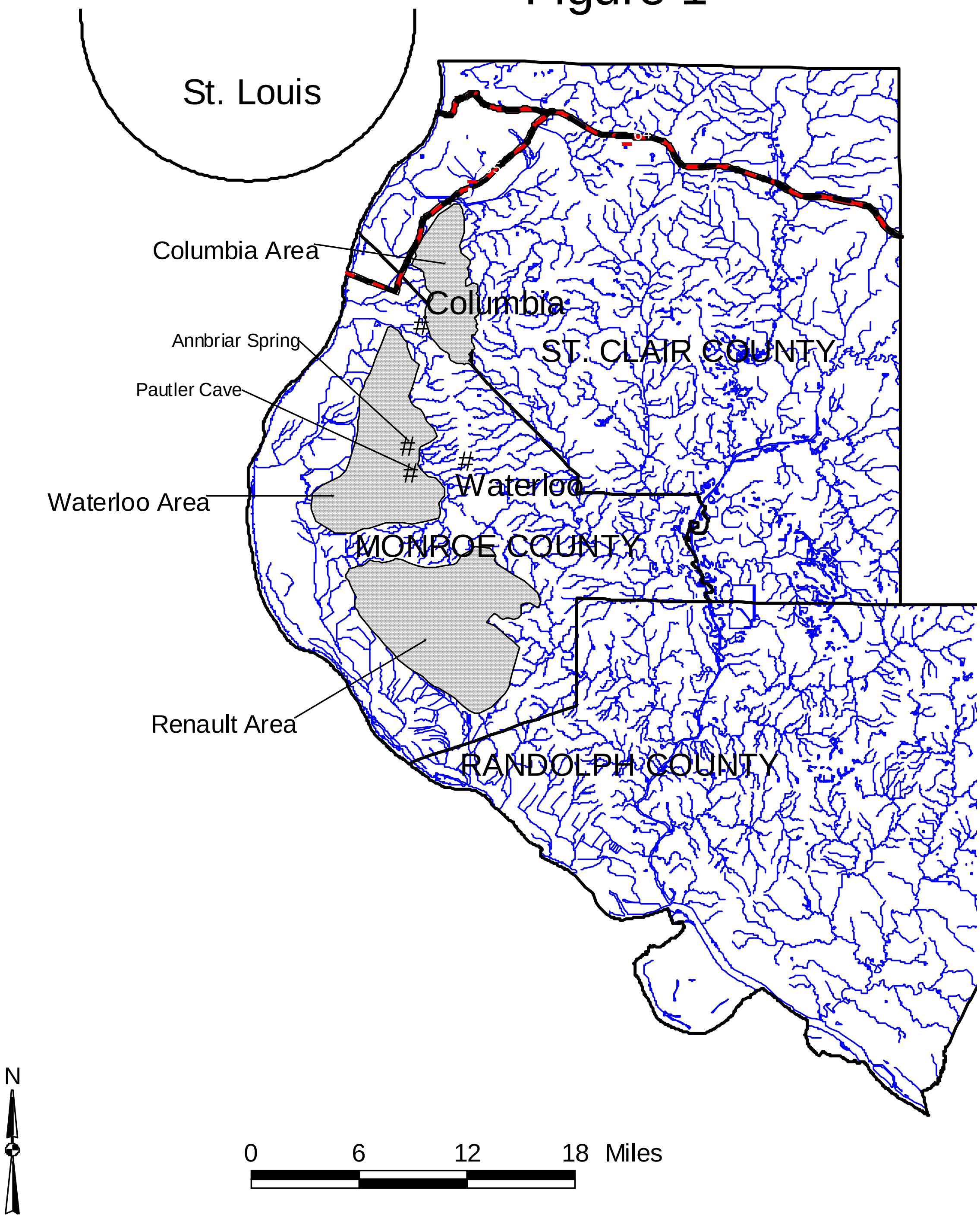
Delineation of the Pautler Cave system and Annbriar Spring Recharge Areas was conducted to enhance the protection that could be afforded the groundwater systems and the aquatic ecosystems they support. The Pautler Cave system and the Annbriar Spring groundwater system provide habitat for the Federally endangered Illinois Cave Amphipod (Lewis et al., 1999).

2.2 The Study Area

The study initially focused only on the Pautler Cave system within the Salem Plateau Karst region. This area is also known as the Southwest Illinois Karst and as the sinkhole plain. The study was later expanded to include the Annbriar Spring groundwater system that lies immediately west of the Pautler Cave system. The increase in scope of the project was with consent of INPC because the Annbriar Spring groundwater system is adjacent to the Pautler Cave system, provides habitat the Illinois Cave Amphipod, and could be done without increasing the budget. The Salem Plateau Karst includes three major areas that are intensely karstified. Near Columbia is the Columbia karst area, west of Waterloo is another intensely karstified area (where Pautler Cave and Annbriar Spring are located), and in the south near Renault is the Renault karst area. Figure 1 shows the relationship between the Salem Plateau Karst region and the three major, intensely karstified areas within it. This study area can be found on the Waterloo and Valmeyer 7.5-minute quadrangle maps.

Areas of Intense Karst Development

Figure 1



2.3 Geologic Setting

The Southwest Illinois Karst is part of the Salem Plateau physiographic province (Willman et al., 1975). Much of the karst area is a sinkhole plain which is bounded on the west and north by the Mississippi River floodplain alluvium. Pennsylvanian Period insoluble, granular sedimentary rocks bound the karst area on the east and south. The dominant rocks in the karst areas are Mississippian Period limestones of the Valmeyeran Series. These geologic units are covered by Pleistocene loess that is commonly 40 feet thick between sinkholes.

The Southwest Illinois Karst lies between the Ozark Dome and the Illinois Basin. This results in a regional dip to the northeast. Locally, the Columbia Syncline appears to have considerable influence on the flow of groundwater. Several major springs are located near the apex of the syncline.

The rocks affecting the karst development (from oldest to youngest) are the Salem Limestone, the St. Louis Limestone, the Ste. Genevieve Limestone, and the Aux Vases Sandstone. Both the Ste. Genevieve Limestone and the Aux Vases Sandstone are often absent. Pautler Cave appears to be limited to the St. Louis Limestone. Very little of the cave system carrying water to Annbriar Spring has been observed, but it is probably developed within the St. Louis Limestone also.

Panno et al. (1997a) report that about 9% of the State of Illinois is included within the state's five karst regions. The five karst regions are:

1) The Driftless Area,
2) North-central Illinois,
3) The Shawnee Hills,
4) The Lincoln Hills,
5) The Salem Plateau Karst Region (where this study took place).

The Waterloo Area, in which Pautler Cave and Annbriar Spring are located, is underlain primarily by St. Louis Limestone (Weller and Weller, 1939). Titus (1976) investigated factors controlling the karst processes in Monroe County, Illinois. He made inferences about the pattern of limestone underlying the loess (subcropping) in the karst area based on sinkhole distribution. Titus (1976) infers that sinkholes in Monroe County are restricted to areas where there is St. Louis or Ste. Genevieve Limestone subcropping. He states that the Salem Limestone does not readily form surficial karst features. The majority of the karst groundwater flow in the study area is within the St. Louis Limestone.

2.4 Hydrogeologic Setting

The Salem Plateau Karst is an outstanding example of surficial karst topography and has an unusually high density of sinkholes. Additionally, it has relatively large areas where virtually all the drainage is through the subsurface. Surface streams are generally a few hundred to a few thousand feet long and typically lose all of their flow into dissolved out openings in the limestone. There are a few "base level" streams that have perennial flow at the surface. If Fountain Creek is typical, they have both losing and gaining reaches and are not truly base level streams.

A flow boundary is a drainage divide on the surface or subsurface. There can also be a "no flow" boundary where the water in the subsurface is not moving. Flow boundaries are equivalent to watersheds (Schindel et al., 1996). In karst, the recharge areas for groundwater systems are defined by flow boundaries. Dye tracing is the best available tool for defining such flow boundaries (Aley and Aley, 1991).

Surface watersheds can be divided by finite lines that separate waters that flow into one basin from waters that flow into an adjacent basin. In contrast, in many karst settings such finite flow division lines do not exist. Zones that contribute some water to adjacent groundwater basins (called shared recharge areas) are common features in the regions between karst groundwater basins. Shared recharge areas may vary in size under different flow conditions.

Another feature of karst groundwater basins is that water from one basin may discharge from multiple springs (Lowe, 2000). The springs may be substantial distances from one another. As a result, it is important in karst areas to recognize that a particular spring does not necessarily represent a groundwater system separate from other groundwater systems. It is fairly common for there to be overflow routes that link otherwise separate groundwater systems at high flows.

The following dye tracing studies have been or are being conducted in the Salem Plateau Karst:

1) OUL is currently delineating the recharge area of Falling Springs in the Columbia Area and has done six traces that have not yet been reported in the literature.

2) Aley et al. (2000) reported 55 dye traces in the Columbia and Renault Areas.

3) Moss (1998) reported three dye traces in the Waterloo Area. One of these traces is relevant to the Annbriar Spring Recharge Area delineation and is shown on Figure 2.

4) Fifteen dye traces were conducted by OUL (Aley and Aley, 1998) under contract to the Mississippi Karst Resources Planning Committee and funded by a USEPA Section 319 Grant. In several cases, dye from a single introduction was detected at multiple springs. Three of the traces conducted for the Karst Committee were in the Renault Area, twelve other traces were conducted in the Waterloo Area. Eight of the Waterloo Area traces are relevant to this investigation and are shown on Figure 2.

5) Wightman (1969) reported four dye traces conducted in the Renault Area.

6) Sherrell (1998, personal communication) reported one dye trace in the Columbia Area.

7) Hruska (1998, personal communication) reported an unsuccessful 1982 attempt to replicate Father Wightman's Illinois Caverns trace. Hruska did not successfully recover any dye from his introduction.

The first four studies listed above involved quantitative tracing and spectrofluorophotometer analysis of samples. The last three studies listed above used qualitative and non-instrumental methods. The intent of the last three studies was to determine the discharge points for streams from particular caves.

Water quality has been a subject of concern in the Salem Plateau Karst, especially since the mid-1980s. Decreased water quality threatens both human health and the fauna inhabiting the karst. Bade and Moss (1998) note that Monroe County had the highest growth rate in the St. Louis Metro-East area for the period 1990 to 1995. They recite the changes in regulation in the sinkhole plain as part of a general groundwater protection strategy.

Panno et al. (1996) provide a comprehensive report on groundwater contamination problems in the Salem Plateau Karst; substantial data were included in this publication on bacteria, nitrates, and pesticides. Panno et al. (1997b) discuss bacterial contamination of groundwater resulting from private septic systems in the sinkhole plain.

There has been considerable discovery and mapping of caves in the Salem Plateau Karst. Oliver and Graham (1988) report on the natural resources of caves throughout Illinois, including the Salem Plateau Karst. The Illinois Speleological Survey, Inc.'s database contains many cave maps, overlays, and cave entrance locations that add to the understanding of the karst in Illinois.

2.5 Cave Biology

Peck and Lewis (1978) report on the biology of caves including Pautler Cave. The bioinventory indicates that Pautler has a diverse fauna that includes the Illinois Cave Amphipod.

Webb et al. (1993) report on the biology of the caves and other subterranean environments of Illinois. Webb (1993, 1995) reports on the status of the Illinois Cave Amphipod. The Illinois Cave Amphipod is historically only known from six cave systems, all in the Salem Plateau Karst. Webb (1995) reports that this amphipod was demonstrably present in three of these systems; the Krueger System, Illinois Caverns, and Fogelpole Cave. Webb et al. were unable to gain access to Pautler Cave.

Lewis et al. (1999) conducted a more comprehensive biological examination of the caves in the sinkhole plain. The number of globally rare karst-related species known to exist in the region was almost doubled as a result of Lewis' study. The Lewis et al. (1999) study also generated a better understanding of the status of the Illinois Cave Amphipod, discovered two new populations, and concluded that this amphipod is extant in six groundwater systems, three of which are in the Waterloo Area. One of these populations is in the Pautler Cave system. Lewis et al. were able to get access to Pautler Cave and two other caves in the Pautler Cave system that provide habitat for the Illinois Cave Amphipod. A population was found in two caves in the Annbriar Spring groundwater system. Another population was found in Frog Spring groundwater system. These Waterloo Area populations are additions to the extant populations that Webb et al. (1998) reported in the Renault karst area.

2.6 Acknowledgements

We greatly appreciate the landowners in the area who have been particularly helpful and trusting in allowing us to introduce dye and to sample for dye recovery on their property. We also wish to acknowledge the Illinois Speleological Survey, Inc. and its cooperators who helped discover and map caves in the Pautler Cave and Annbriar Spring systems. These maps increased the efficiency of the study.

A number of other people also assisted in the study through mapping caves, searching for good dye introduction points, and accompanying OUL personnel sampling for tracer dyes. We thank them all; they were (in alphabetical order):
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Bill Ebeler
Rick Haley
Myron Mugele
Terry Riebling
Valerie Schmidt
Tony Schmitt
Joe Sikorski

3.0 METHODS

3.1 Groundwater Tracing Methods

Groundwater tracing using fluorescent dyes is the most appropriate method for delineating cave and spring recharge areas (Aley and Aley, 1991). Fieldwork is conducted to identify locations where waters sink from the surface into the groundwater system and where cave streams are accessible for sampling and potential dye introductions. Next, a selected tracer dye can be introduced into the sinking water. Springs, surface streams, and any other potentially relevant locations are continuously sampled for the subsequent presence of the dye. By careful selection of dye introduction points, and by conducting multiple traces, one can delineate the area that contributes waters to a particular feature such as a cave or spring.

Five different dyes were used for the groundwater tracing investigations. These were fluorescein, eosine, rhodamine WT, pyranine and sulforhodamine B. All five of these dyes are environmentally safe (Smart, 1984; Field et al., 1995) and pose no risk to humans or to aquatic life in the concentrations used in professionally directed groundwater tracing work. Aley (1999) provides a detailed discussion of the performance characteristics of the five dyes used in this study and demonstrates that they are appropriate to the work that was conducted.

Appendix C provides details on the procedures and criteria used in dye tracing studies conducted by OUL. These approaches were used throughout this study. Background sampling from springs and surface streams was conducted prior to any dye introductions.

3.2 Dye Introductions

The results of 28 dye introductions are included in this report and used for the recharge area delineations. The current traces are numbered sequentially with the first two digits indicating the year, the third digit represents the study area, and the last pair of digits indicates the serial number of the trace. For example, Trace 00-305 was initiated in 2000, it is located in the Waterloo Area, and is the fifth trace initiated in that study area. Both sampling station numbers and trace numbers use the same scheme.

The "Results" section of this report contains the details of the individual dye introductions, including the locations and elevations of the dye introduction points. Table 4 (page 104) summarizes data on each of the dye introductions.

3.3 Access to Land

The delineation project depended on OUL's ability to get onto land in order to introduce dye and to get access for routine sampling. OUL secured permission to sample at a total of 36 different stations, most of them on private property. OUL initiated 19 new dye traces, most of which are on private property. Landowners have been extremely cooperative and helpful, and many have expressed great interest in the results of traces initiated or recovered on their property. We greatly appreciate the kindness, help, and trust we have received from landowners and residents in the study area.

3.4 Sampling Stations Used

The sampling stations are located on the Waterloo or Valmeyer 7.5-minute quadrangle maps. The locations of the sampling stations are shown on Figure 22 (page 115) and an index to dye sampling locations in presented in Table 1.

Table 1. Index to dye sampling stations.

Sta.	Station Name	Map	Location	El. (ft)
301	Vandeventer Spring	Waterloo	SE¼ SE¼ Sec 21 T2S R10W	450
302	Fountain Cr U/S Camp	Waterloo	SE¼ SE¼ Sec 21 T2S R10W	455
303	Ice Box Spr.	Waterloo	SE¼ SE¼ Sec 21 T2S R10W	452
304	Fountain Cr. @ Rt. 156	Waterloo	SE¼ SW¼ Sec 27 T2S R10W	505
305	Vandeventer Karst Window	Waterloo	NE¼ NE¼ Sec 28 T2S R10W	465
306	U/S Karst Window	Waterloo	NE¼ NE¼ Sec 28 T2S R10W	470
307	Dual Spring E	Waterloo	NW¼ SE¼ Sec 21 T2S R10W	435
308	Dual Spring W	Waterloo	NW¼ SE¼ Sec 21 T2S R10W	435
309	Annbriar Spring	Waterloo	NE ¼ NW ¼ Sec 21 T2S R10W	435
310	Fountain Cr. U/S Annbriar	Waterloo	NE¼ W¼ SE¼ Sec 21 T2S R10W	437
311	Fountain Cr @ HH Rd.	Waterloo	SE¼ NW¼ Sec 17 T2S R10W	420
312	Fountain Cr. nr. water plant	Waterloo	NW ¼ SE ¼ Sec 35 T2S R10W	540
313	Fountain Cr. @ JJ Rd.	Waterloo	SE¼ SW¼ Sec 2 T3S R10W	570
314	Fountain Cr. @ Maeystown Rd. Sec. 15	Waterloo	SW¼ NW¼ NW¼ Sec 15 T3S R10W	630
315	Dane's Parallel Str.	Waterloo	SE ¼ NE ¼ Sec 28 T2S R10W	485
316	Dane's D/S Overflow	Waterloo	SW ¼ NE ¼ Sec 28 T2S R10W	480
317	Tree Spring	Waterloo	NE¼ NW¼ SE¼ Sec 21 T2S R10W	437
318	Fountain Cr. U/S sink point	Waterloo	SW ¼ SE ¼ Sec 21 T2S R10W	438
319	Fountain Cr. D/S Annbriar	Waterloo	SW ¼ NE ¼ Sec 21 T2S R10W	435
320	Pautler Cave	Waterloo	NE ¼ NE ¼ Sec 33 T2S R10W	530
321	Floodplain Estavelle	Waterloo	NW¼ SE¼ Sec 21 T2S R10W	435
322	Acorns Pond #6	Waterloo	NE ¼ SW ¼ Sec 3 T3S R10W	529
323	Ebeler Cave	Waterloo	NW ¼ NW ¼ Sec 10 T3S R10W	583
324	Chantilly Spring	Waterloo	SW ¼ NE ¼ Sec 4 T3S R10W	610
325	Orange Spring	Waterloo	SW ¼ SW ¼ Sec 22 T2S R10W	450
326	Spring D/S Dual Spring	Waterloo	NE ¼ SW ¼ Sec 21 T2S R10W	435
327	Reverse Stream	Waterloo	NE ¼ SE ¼ Sec 29 T2S R10W	530
328	Culvert Spring	Waterloo	NW ¼ SW ¼ Sec 27 T2S R10W	510
329	Frog Spring	Waterloo	SW ¼ NE ¼ Sec 31 T2S R10W	500

(Continued)

Table 1 (Continued). Index to dye sampling stations.

Sta.	Station Name	Map	Location	El. (ft)
330	Schnellbecher Spring	Valmeyer	NW ¼ SW ¼ Sec 19 T2S R10W	500
331	Bond Creek @ HH Rd.	Waterloo	NE ¼ NE ¼ Sec 18 T2S R10W	425
332	Antler Spring	Waterloo	NE ¼ NW ¼ Sec 21 T2S R10W	440
333	Luhr Spring	Waterloo	NW ¼ NW ¼ Sec 21 T2S R10W	445
334	Barker Spring	Waterloo	NE ¼ NE ¼ Sec 20 T2S R10W	440
335	Bond Cr. U/S Schnellbecher	Valmeyer	NW ¼ SW ¼ Sec 19 T2S R10W	485
336	Hidden Spring	Waterloo	SE ¼ NW ¼ Sec 21 T2S R10W	435

Some sampling stations are control stations that can identify the input of fluorescent compounds into the study area that are not derived from dye introductions made by OUL. Surface sampling stations are established to identify potential groundwater discharges from unsampled springs. The remaining sampling stations sample groundwater directly and provide detail on the groundwater flow paths. A brief rationale for the establishment of each dye sampling station is presented in Table 2. Base flow discharge measurements from Aley and Aley (1998) are provided for relevant springs in parentheses. Estimated flows from this study are indicated by an asterisk.

Table 2. Sampling Station Rationale.

Sta.	Station Name	Rationale
301	Vandeventer Spring	A major spring in the study area demonstrated to be the main discharge point for the Pautler Cave system (552 gpm).
302	Fountain Cr U/S Camp	Surface sampling station to locate potential unknown springs
303	Ice Box Spr.	A minor spring in the study area demonstrated to be the main discharge point for the Pautler Cave system (5 gpm*)
304	Fountain Cr. @ Rt. 156	Surface sampling station to locate potential unknown springs
305	Vandeventer Karst Window	Major karst window associated with Pautler system
306	U/S Karst Window	Karst window with intermittent flow
307	Dual Spring E	One rise pool in two outlet major spring, intermittent flow
308	Dual Spring W	One rise pool in two outlet major spring, perennial flow (700 gpm*)
309	Annbriar Spring	Major spring in Fountain Creek; this spring has been alluviated and has numerous and rapidly changing discharge points including Tree Spring and Hidden Spring. This station was replaced by Station 319, which sampled the entire spring complex (455 gpm).
310	Fountain Cr. U/S Annbriar	Surface sampling station to locate potential unknown springs
311	Fountain Cr @ HH Rd.	Surface sampling station to locate potential unknown springs
312	Fountain Cr. nr. water plant	Surface sampling station to locate potential unknown springs
313	Fountain Cr. @ JJ Rd.	Surface sampling station to locate potential unknown springs
314	Fountain Cr. @ Maeystown Rd. Sec. 15	Surface sampling station to locate potential unknown springs
315	Dane's Parallel Str.	Control station, sampled once before dye was introduced downstream
316	Dane's D/S Overflow	Control station, sampled once before dye was introduced downstream
317	Tree Spring	Overflow spring for Annbriar Spring Complex
318	Fountain Cr. U/S sink point	Surface sampling station to locate potential unknown springs
319	Fountain Cr. D/S Annbriar	Surface sampling station to locate potential unknown springs
320	Pautler Cave	Major cave stream and focus of the study (10 gpm*)
321	Floodplain Estavelle	Estavelle between Vandeventer and Dual Spring
322	Acorns Pond #6	This station sampled water pumped from a karst window (30 gpm*) about 1,000 feet to the northeast. The location of the karst window is shown on the figures.
323	Ebeler Cave	Cave associated with Pautler system (20 gpm*)
324	Chantilly Spring	Minor spring lying within the Pautler system recharge area (15 gpm*).

(Continued)

Table 2 (Continued). Sampling Station Rationale.

Sta.	Station Name	Rationale
325	Orange Spring	Minor spring on the south side of Fountain Creek and sampled for the Benitone Trace (3 gpm*).
326	Spring D/S Dual Spring	Minor spring on the south side of Fountain Creek (6 gpm*)
327	Reverse Stream	Major karst window associated with the Annbriar Spring groundwater system (400 gpm*).
328	Culvert Spring	Minor spring on the west side of Fountain Creek and sampled for the Benitone Trace (5 gpm*).
329	Frog Spring	Major spring on the east side of Bond Creek (316 gpm).
330	Schnellbecher Spring	Moderate spring on the east side of Bond Creek (85 gpm)
331	Bond Creek @ HH Rd.	Surface sampling station
332	Antler Spring	Major spring on the north side of Fountain Creek (250 gpm*)
333	Luhr Spring	Moderate spring on the south side of Fountain Creek (112 gpm).
334	Barker Spring	Moderate spring on the south side of Fountain Creek (85 gpm).
335	Bond Cr. U/S Schnellbecher	Surface sampling station
336	Hidden Spring	One of multiple outlets in the Annbriar Spring Complex, sampled once because discolored water was observed.

* estimated discharge

3.5 Sampling and Analysis for Tracer Dyes

Sampling for tracer dyes placed primary reliance upon activated carbon samplers, and secondary reliance upon grab samples of water. All analysis was conducted using a Shimadzu RF5000U spectrofluorophotometer operated under a synchronous scan protocol. Details of the analytical approach are presented in OUL's procedures and criteria document that is included as Appendix C.

3.5.1 Activated Carbon Samplers

All five of the dyes used (fluorescein, eosine, rhodamine WT, pyranine, and sulforhodamine B) can be adsorbed onto laboratory grade coconut shell charcoal samplers. The samplers are placed in the water to be sampled and are left for periods which may range from a few hours to a couple of weeks or sometimes more.

The activated carbon samplers (simply called "samplers" or "packets" in the following discussions) are used as the primary sampling approach because they sample continuously and accumulate dyes. These samplers are ideal for determining whether a tracer dye has reached a sampling station. Two samplers were placed at each sampling station. This allows for the analysis of duplicate samples and provides a spare in case a sampler is lost or damaged.

Samplers placed at springs and surface streams were placed in flowing water, firmly anchored with wire, and weighted in place. Cords were sometimes run from the packets to trees along the banks so that samplers could be recovered even during relatively high flow events. Samplers were concealed to minimize disturbance or loss by people who might otherwise see them.

Samples collected in the field were immediately refrigerated and maintained under refrigeration until delivery to the laboratory. Upon arrival at OUL, samplers were immediately refrigerated at 4 degrees C. until analysis. All sampler placement, collection, and analysis work was conducted by OUL personnel.

3.5.2 Water Samples

Water samples were analyzed during the study for background fluorescence, if dye were detected in the associated carbon sample, or if activated carbon samplers had been lost to flood flows. Water collections were made in disposable 50 ml capped vials and kept refrigerated until analysis. Approximately 2.5 ml of the water sample was withdrawn with a disposable pipette and placed in a disposable cuvette. This sample was then subjected to analysis in OUL’s spectrofluorophotometer. All water samples were collected and analyzed by OUL personnel. These samples provide data on the quantities of dyes present at the time of collection.

4.0 RESULTS

4.1 Introduction

The contract required 12 dye traces using an estimated 15 sampling stations. OUL made 19 dye introductions specifically for this study and is including the results of 28 dye introductions in this report. Dye was detected for all dye introductions. Thirty-six sampling stations were established in the course of the study. Figure 22 (page115) shows the introduction points and the sampling stations used. This map also shows the diagrammatic path from the introduction point to the recovery point for each trace.

Eight relevant dye traces were conducted by OUL prior to this study. These were conducted under contract to the Mississippi Karst Resources Planning Committee and funded by a USEPA Section 319 Grant (Aley and Aley, 1998). One relevant dye trace was conducted by Philip Moss, now with OUL, under contract to the Illinois Environmental Protection Agency. These previous traces are discussed in Section 4.2.

For each dye introduction the following information is included:

1) the amount and type of dye used,
2) the elevation and location of the dye introduction point,
3) the date and time of dye introduction,
4) flow conditions at the dye introduction point at the time of dye introduction,
5) the stations sampled relating to the trace,
6) locations where dye was detected,
7) elevation difference between introduction and recovery points,
8) groundwater flow path gradient,
9) time of travel,
10) relevance to the project,
11) a figure showing the trace and relevant portions of the recharge areas,
12) and any other information that appears relevant.

A figure is included in each discussion for the convenience of the reader. They are routinely placed at the end of the narratives and tables for each of the described traces. The reader does not have to refer to the recharge area delineation map (Figure 22) to understand the geography of each trace. These figures include all the sampling stations that were used in this study. The lines representing the dye traces are generally shown as straight lines between the introduction point and each dye detection point. In some cases, the lines pass through or near sampling stations where dye was not detected. These instances are addressed in the discussion of the individual results. For some traces, the actual flow paths may be quite different from the generally straight lines presented in this report. In some instances, the lines shown on the figures have been curved to approximate the likely flow path.

Table 4 presents a summary of dye introduction data for both the previous traces and those that were conducted for this investigation. The table can be found at the end of Section 4.3 (page 104).

4.2 Previous Dye Tracing Results by Individual Traces

OUL was contracted to perform groundwater tracing in the Salem Plateau Karst by the Monroe-Randolph Bi-County Health Department funded from a USEPA Section 319 grant (Aley and Aley, 1998). The grant proposal was written by the Mississippi Karst Resources Planning Committee. Eight of the fifteen traces conducted in the 319 study are relevant to the Pautler Cave system investigation. The results of those eight traces are provided in the following sections. The trace segment lengths, elevation change, and gradients are summarized in Tables 4 (page 104) and 5**,** along with similar data from the current investigation. Figure 2 (page 32) shows these previous traces and relevant springs.

Philip Moss, now with OUL but working then as an independent consultant, made three dye introductions in the Waterloo Area under contract to the Illinois Environmental Protection Agency's Southern Regional Groundwater Protection Planning Committee (Moss, 1998). One of those traces (98-03) is relevant to the Annbriar Spring groundwater system and is included here for completeness.

4.2.1 Trace 96-01. Shivery Slither Trace.

Three pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced in the SE ¼ NE ¼ Section 32, T2S, R10W. The elevation of the dye introduction point is approximately 580 feet. The dye introduction point is located at the bottom of a sinkhole. The dye was introduced on July 29, 1996 at 1430 hours. At the time of dye introduction the flow rate entering the groundwater system at this location was estimated to be 20 gallons per minute. The dye introduction site can be found on the Waterloo 7.5-minute quadrangle map.

Dye from the Shivery Slither Trace was detected at Reverse Stream Karst Window, Fountain Creek downstream of Dual Spring, and Fountain Creek near Deer Hill Road. Annbriar Spring, was not sampled during Trace 96-01. However, Trace 00-316 indicates that Annbriar Spring is the primary groundwater discharge point for water passing through Reverse Stream Karst Window and that Shivery Slither lies within the Annbriar Spring recharge area. The straight-line distance to Annbriar Spring from the dye introduction point is approximately 10,800 feet.

The straight-line distance from the dye introduction point to Reverse Stream Karst Window is approximately 3,660 feet and the elevation loss is approximately 55 feet. The mean gradient along this flow path is approximately 79 feet per mile. Dye first arrived at Reverse Stream Karst Window within 15 days following dye introduction and was discharged from the Annbriar Spring Complex.

The straight-line distance from Reverse Stream Karst Window to Annbriar Spring is approximately 7,140 feet and the elevation loss is approximately 90 feet. The mean gradient along this flow path is approximately 67 feet per mile.

4.2.2 Trace 96-03. Schneider Sinkhole Trace.

Three pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced in the NE ¼ SE ¼ Section 33, T2S, R10W. The elevation of the dye introduction point is approximately 580 feet. The dye introduction point is located at the bottom of a sinkhole. The water used for dye introduction on July 30, 1996 was hauled to the site in two loads of 1,600 gallons each. The first load of water was discharged between 1315 hours and 1324 hours; the three pounds of dye was introduced at 1315 hours. The second load of water was introduced between 1404 and 1416 hours. There was no ponding of water in the sinkhole. The dye introduction site can be found on the Waterloo 7.5-minute quadrangle map.

Dye was detected in groundwater at Vandeventer Karst Window, Vandeventer Spring, and Ice Box Spring. Based upon the results from Trace 96-03 and Trace 97-10, Vandeventer Karst Window is located in the natural conduit system that carries water to Vandeventer Spring. This trace, along with the later Trace 00-312, demonstrates that the Schneider sink is within the Pautler Cave system recharge area.

Ice Box Spring is a small spring that discharges to Fountain Creek at a point about 200 feet downstream of Vandeventer Spring. Dye from Trace 96-03 was also detected at this small spring, but dye concentrations were much smaller than at Vandeventer Spring and the time of first dye arrival at this spring was later than at Vandeventer Spring. These results suggest that there are appreciable differences between the flow path to Ice Box Spring and the flow path to Vandeventer Spring.

Dye from Trace 96-03 was detected at Dual Spring West. Dual Spring is a large, two-outlet spring on the south side of the Fountain Creek Valley. The dye concentrations at this spring from Trace 96-03 were on the order of 4 to 8% of those at Vandeventer Spring. Trace 97-11 demonstrated that some water sinks in the channel of Fountain Creek downstream of Vandeventer; the volume of water sinking in the Fountain Creek stream segment between a point about 1,000 feet downstream of Vandeventer Spring and a point about 1,500 feet farther downstream was measured by Philip Moss at approximately 220 gallons per minute on August 14, 1997. Station 51 (Stream downstream Scout Camp) monitored dye concentrations in Fountain Creek in area where water sinks from the creek into the groundwater system. During Trace 96-03, dye concentrations at Station 51 were similar to those at Dual Spring West. Based upon the above data, it is our conclusion that all of the dye detected at Dual Spring West from Trace 96-03 reached that spring via Fountain Creek. The dye in Fountain Creek was in turn derived from dye discharged from Vandeventer Spring and, to a much lesser degree, from dye discharged from Ice Box Spring.

Dye was also detected at three sampling stations on Fountain Creek. Data from these stations do not indicate the presence of any other springs which may have discharged eosine dye from this trace since the eosine dye concentrations decreased from upstream to downstream stations.

The straight-line distance from the dye introduction point to Vandeventer Spring is approximately 9,685 feet. The straight-line distance from the dye introduction point to Vandeventer Karst Window is approximately 8,600 feet and the elevation loss is approximately 115 feet. The mean gradient along this flow path is approximately 71 feet per mile.

The straight-line distance from Vandeventer Karst Window to Vandeventer Spring is approximately 1,060 feet and the elevation loss is approximately 15 feet. The mean gradient along this flow path is approximately 75 feet per mile.

4.2.3 Trace 97-01. Fabish Sinkhole Trace

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced in the NE ¼ SE ¼ Section 30, T2S, R10W. The elevation of the dye introduction point is approximately 650 feet msl. The dye introduction was made on February 20, 1997 at 1415 hours. At the time of dye introduction water was entering the groundwater system at this location at an estimated rate of 12 gpm. The dye introduction location can be found on the Waterloo 7.5-minute quadrangle map.

Schnellbecher Spring was the only spring sampling station where fluorescein dye from the Fabish Sinkhole Trace was detected.

The straight-line distance from the Fabish sinkhole to Schnellbecher Spring is approximately 7,650 feet. The elevation loss is approximately 150 feet and the mean gradient is approximately 104 feet per mile.

4.2.4 Trace 97-03. Miller Sinkhole Trace.

Two pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole in the NW ¼ NW ¼ Section 32 T2S, R10W. The elevation of the dye introduction point is approximately 640 feet msl. The dye was introduced on February 20, 1997 at 1510 hours. At the time of dye introduction, water was entering the groundwater system at an estimated rate of approximately 11 gpm. The dye introduction location can be found on the Waterloo 7.5-minute quadrangle map.

Schnellbecher Spring was the only spring sampling station where rhodamine WT dye from the Miller Sinkhole Trace was detected.

The straight-line distance from the Miller sinkhole to Schnellbecher Spring is approximately 9,545 feet. The elevation loss is approximately 140 feet and the mean gradient is approximately 77 feet per mile.

4.2.5 Trace 97-04. Wednesday Sinkhole Trace.

Two pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced in the SW ¼ SW ¼ Section 28, T2S, R10W. The elevation of the dye introduction point is approximately 535 feet. The dye was introduced on February 20, 1997 at 1540 hours. At the time of dye introduction water was sinking into the groundwater system at this location at an estimated rate of 50 gallons per minute. The dye introduction site can be found on the Waterloo 7.5-minute quadrangle map.

Annbriar Spring was the only spring sampling station where eosine dye from Trace 97-04 was detected. Eosine dye was also detected in Fountain Creek downstream of the Annbriar Spring Complex. This trace demonstrates that Wednesday sink is within the Annbriar Spring recharge area.

No eosine from Trace 97-04 was detected at Dual Spring. Based upon the locations of the dye introduction point, Dual Spring, and Annbriar Spring, the absence of dye at Dual Spring is consistent with the interpretation that much of the flow of Dual Spring West is derived from waters that sink in the channel of Fountain Creek. This inference is supported by the results from Traces 96-03 and 97-11.

The straight-line distance from Wednesday sink to Annbriar Spring is approximately 7,580 feet and the elevation loss is approximately 100 feet. The mean gradient for this flow path is approximately 70 feet per mile. Dye first arrived at Annbriar Spring within three days of dye introduction. The velocity along this flow path under these conditions was approximately 2,525 feet per day.

4.2.6 Trace 97-09. Tuhro Sinkhole Trace.

One pound of fluorescein dye mixture was introduced in the NW ¼ SW ¼ Section 16, T2S, R10W. The elevation of the dye introduction point is 475 feet. The dye was introduced on July 8, 1997 at 2020 hours. At the time of dye introduction water was sinking into the groundwater system at this location at an estimated rate of 2 gallons per minute. The dye introduction site can be found on the Waterloo 7.5-minute quadrangle map.

Dye from Trace 97-09 was detected at a complex of three springs; they were Annbriar Spring, Spring Downstream of Annbriar, and Hidden Spring. Each of these springs is within 50 feet of the other two springs and are part of the Annbriar Spring Complex. Hidden Spring discharges from the north side of Fountain Creek, and the other two springs discharge from the south side of this stream. Based upon observations by Philip Moss on August 10, 1997, at least 90% of the flow from this complex of springs is discharged through Annbriar Spring. In view of the close proximity of the three springs, it is interesting that dye concentrations from activated carbon samplers at Hidden Spring were routinely greater than the concentrations at Annbriar. One possible explanation for the concentration differences may be that Hidden Spring receives recharge water from only a portion of the recharge area for Annbriar Spring, and that the area that contributes water to both Hidden and Annbriar Springs includes the dye introduction point for Trace 97-09. If this is the case, the dye discharging from Annbriar Spring receives more dilution than does the dye discharging from Hidden Spring.

The groundwater tracing work has demonstrated that Annbriar Spring receives some of its recharge water from the sinkhole plain area south of Fountain Creek (as shown by Trace 97-04). Annbriar Spring also receives some of its recharge water from the sinkhole plain area north of Fountain Creek (as shown by Trace 97-09).

Hidden Spring was not sampled during Trace 97-04 so there are no data to determine whether or not this spring received any dye from this trace.

Annbriar Spring, Hidden Spring, and Spring Downstream of Annbriar all contribute flow to Fountain Creek. Dye discharged from these springs was subsequently detected in Fountain Creek downstream of the Annbriar Spring Complex.

An unexpected fluorescein dye recovery was made at Bond Creek at HH Road. A subsequent trace, Trace 98-03, demonstrated that the Bond Creek detection was not from Trace 97-09.

4.2.7 Trace 97-10. Scheibe Trace.

One pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced in the SE ¼ SE ¼ Section 33, T2S, R10W. The dye introduction point is in a cave stream. The elevation of the dye introduction point is approximately 555 feet. The dye was introduced on July 9, 1997 at 1120 hours. At the time of dye introduction, there was an estimated flow of 15 gallons per minute. The dye introduction site can be found on the Waterloo 7.5-minute quadrangle map.

Dye from Trace 97-10 was detected at three groundwater sampling stations; Vandeventer Karst Window, Vandeventer Spring, and Dual Spring West. Based upon the results from Trace 96-03 and Trace 97-10, Vandeventer Karst Window is located in the natural conduit system that carries water to Vandeventer Spring. Ice Box Spring was a minor dye recovery site during Trace 96-03, but no dye from Trace 97-10 was detected at Ice Box Spring. There are two likely explanations for this difference.

The first possibility is related to differences in the characteristics of the tracer dyes. Eosine dye was used for Trace 96-03, and sulforhodamine B dye was used for Trace 97-10. Sulforhodamine B dye is more subject to adsorption onto earth materials than is eosine. The concentrations of eosine in activated carbon samplers from Ice Box Spring were more than an order of magnitude smaller than those at Vandeventer Spring and Karst Window; this may indicate that the waters discharging from Ice Box Spring are subject to more natural adsorption than the waters sampled at Vandeventer Spring and Karst Window.

The second possibility is that hydrologic interactions between Vandeventer Spring and Ice Box Spring may vary with the amount of water in the groundwater system; this is a common occurrence in karst groundwater systems. If this is the case, then the hydrologic interactions between Vandeventer Spring and Ice Box Spring were greater during Trace 96-03 than during Trace 97-10, and there may have been no hydrologic interactions between these two springs during Trace 97-10. It is the opinion of OUL that the second possibility is the more likely explanation for the observed differences between results for Trace 96-03 and 97-10. A subsequent trace, 00-306, demonstrated that Vandeventer Karst Window recharges both Ice Box Spring and Vandeventer Springs.

Dye from Trace 97-10 was detected at Dual Spring West during the sampling period from July 9 to 16, 1997. No dye was detected at this spring during any subsequent sampling periods, while sulforhodamine B dye was detectable at both the Vandeventer Karst Window and at Vandeventer Spring during two subsequent sampling periods. All of the tracer dyes, including sulforhodamine B, are subject to appreciable losses and degradation in surface waters; tracer dyes commonly persist longer at sampling stations in springs than at sampling stations on surface streams. Trace 97-11 (which will be discussed later) demonstrated that much of the flow of Dual Spring West is derived from waters that sink in the channel of Fountain Creek upstream of Annbriar Spring. The concentrations of sulforhodamine B at Fountain Creek Upstream of Annbriar Spring during Trace 97-10 were greater than those at Dual Spring West. It is the conclusion of OUL that the sulforhodamine B dye which discharged from Dual Spring West was derived from dye which had previously discharged from Vandeventer Spring, flowed a short distance down Fountain Creek, and then re-entered the groundwater system.

The straight-line distance from the dye introduction point to Vandeventer Spring is approximately 8,870 feet and the elevation loss is approximately 90 feet. The mean gradient is approximately 54 feet per mile. Dye first arrived in less than seven days at both the Vandeventer Karst Window and Spring. Groundwater velocity along this flow path under these conditions was greater than 1,420 feet per day.

The Scheibe Trace demonstrates that the cave stream it traced recharges Vandeventer Spring. Trace 00-312 demonstrated that Vandeventer Spring is the primary discharge point for the Pautler Cave system. Therefore, the area around the Scheibe dye introduction point is within the Pautler Cave system recharge area.

4.2.8 Trace 97-11. Fountain Creek Trace.

One-tenth of one pound of eosine dye mixture containing approximately 75% dye and 25% diluent dissolved in one quart of water was introduced in a sinking point in the channel of Fountain Creek between Vandeventer Spring and Annbriar Spring. The dye and water were introduced into a hole in the bedrock channel of the creek; a transmission fluid funnel was used to introduce the dye mixture and prevent any of the mixture from entering surface flow in Fountain Creek. The location of the dye introduction point was in the NW ¼ SE ¼ Section 21, T2S, R10W. The elevation of the dye introduction point is approximately 440 feet. The dye was introduced on August 14, 1997 at 1344 hours. The dye introduction site can be found on the Waterloo 7.5-minute quadrangle map.

Dye for this trace was introduced into a losing stream segment of Fountain Creek. Flow rate measurements were made of Fountain Creek on August 14, 1997 at two locations; one of these was upstream of the losing stream segment, and the other was downstream of the losing stream segment. The stream channel distance between these two stations is about 1,500 feet. The upstream sampling station was located about 1,000 feet downstream of Vandeventer Spring; the flow rate at this location on August 14, 1997 was approximately 1,300 gallons per minute. The downstream sampling station was located about 400 feet upstream of Annbriar Spring; the flow rate at this location on August 14, 1997 was approximately 1,080 gpm. The difference in flow rates at these two stations on August 14, 1997 was approximately 220 gallons per minute; most of this flow enters the groundwater system along a 150-foot stream segment that includes the point used for this dye introduction.

There is an estavelle located on the flood plain of Fountain Creek about 100 to 150 feet from the dye introduction point used for Trace 97-11. An estavelle is a karst feature through which water sometimes enters the groundwater system, but through which water sometimes discharges from the groundwater system. Changes in flow direction through estavelles are controlled by hydrologic conditions. The close proximity of this estavelle to the dye introduction point suggests that the dye introduction point may also be an estavelle.

Philip Moss observed a boil at the sink point on May 27, 2000. Previous observations were of a whirlpool. This change of appearance indicates that the dye introduction feature is an estavelle. Since this feature is in the channel of a flowing stream, for it to reverse flow, there has to be recharge to the Dual Spring groundwater system in addition to the estavelle. Trace 01-318 demonstrates recharge of Dual Spring West not derived from Fountain Creek .

Trace 97-11 demonstrates that about one-third of the base flow of Dual Spring West is derived from water that sinks in the channel of Fountain Creek in the losing stream segment described above. It is the opinion of OUL that all of the dyes detected at Dual Spring West from Traces 96-03 and 97-10 entered the groundwater system via the losing stream segment of Fountain Creek. Trace 97-09 suggests that there are no hydrologic interactions between Annbriar Spring and Dual Spring. As a result, Dual

Spring does not appear to have any groundwater recharge zone lying north of Fountain Creek other than the topographic basin contributing water to the losing segment of Fountain Creek that has been identified.

The straight-line distance from the dye introduction point to Dual Spring is approximately 690 feet and the elevation loss is approximately 10 feet. The mean gradient is approximately 77 feet per mile. Most of the dye was discharged from Dual Spring West within 24 hours following dye introduction. The groundwater velocity along this flow path under these flow conditions was greater than 700 feet per day.

It is noteworthy that this trace crosses the Annbriar Spring Recharge Area without any evidence of hydrologic interaction between the Dual Spring and Annbriar Spring groundwater systems.

4.2.9 Trace 98-03. Tuhro Replication Trace.

One-third of a pound of fluorescein dye was introduced in Tuhro Sinkhole on May 26, 1998 at 1650 hours. There was approximately 10 gpm flowing in the sinkhole at that time. The sinkhole can be found on the Waterloo Quadrangle and is located in the NW ¼ SW ¼ Section 16, Township 2 South, Range 10 West. The elevation of the injection is approximately 475 feet. This trace was designed to determine if an anomalous dye detection in Bond Creek was from Tuhro sink during Trace 97-09.

Fluorescein dye was detected at the same points in Fountain Creek as Trace 97-09, except not at the Annbriar Spring Complex, which was only sampled at Annbriar Spring. It is possible that dye was discharged from other outlets in Annbriar Spring Complex or that water flow in the system was not high enough to spill over into the Annbriar Spring Complex basin. On February 27, 2000, Illinois Speleological Survey cooperators, Philip Moss, Valerie Schmidt, Tony Schmitt, and Myron Mugele "discovered" and named Antler Spring. This is a major spring on the north side of Fountain Creek. Dye was detected in Fountain Creek downstream of both Antler and Annbriar Springs. Subsequent discovery of Antler Spring suggests that it is likely that dye from Trace 98-03 was discharged at Antler Spring and that dye was discharged from both the Annbriar Spring Complex and Antler Spring from Trace 97-09. Another trace needs to be done to confirm this interpretation.

No fluorescein dye was detected at Bond Creek at HH Road. This trace demonstrates that there is no flow path from Tuhro Sinkhole to Bond Creek. The most probable explanation for the failure to replicate the results of Trace 97-09 is that the dye detected at Bond Creek at HH Road was remobilized dye from Trace 97-01.

The straight-line distance from Tuhro sink to Antler Spring is approximately 1,900 feet and the elevation loss is approximately 30 feet. The mean gradient along this interpreted flow path is approximately 83 feet per mile.

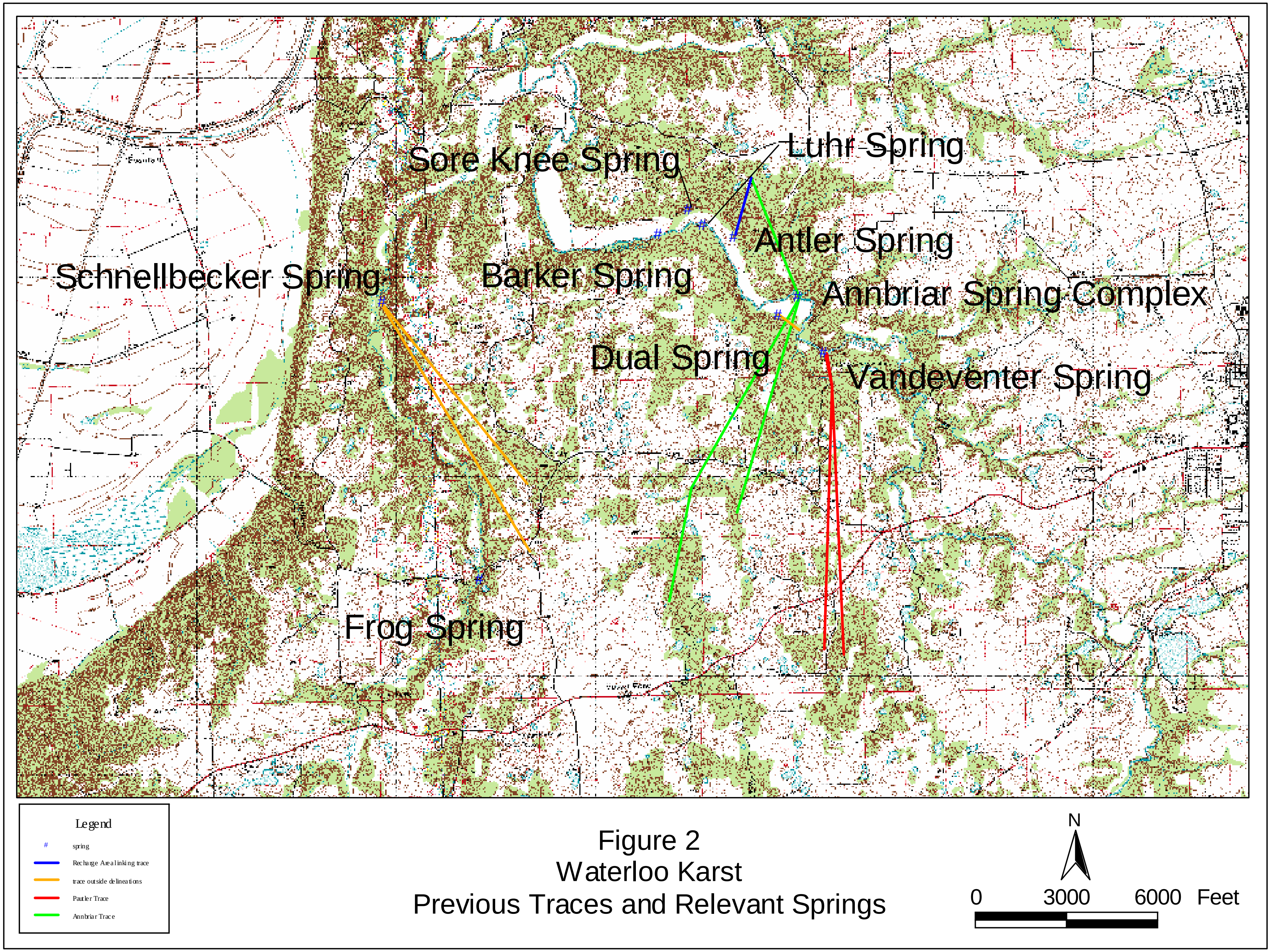


Figure 2
Waterloo Karst
Previous Traces and Relevant Springs

4.3 New Groundwater Tracing Results by Individual Traces

The dye tracing results initiated under contract with the Illinois Nature Preserves Commission are discussed in the following sections. A figure is included at the end of each dye trace's discussion that demonstrated a subsurface flow path (Figures 3 through 21). The figure shows the individual dye trace discussed and associated recharge area boundaries. The recharge area boundaries are discussed in detail in Section 4.4.

Dye concentrations for each sampling station where dye was detected are tabulated in the discussion of the relevant trace. The concentrations are reported in parts per billion (ppb). The data are from activated carbon samplers unless otherwise noted. The following notes may be found in the tables: "ND" means no dye was detected; "a" means this peak is out of the acceptable wavelength, but has been calculated as thought it were dye; "s" means the peak has an irregular shape, but has been calculated as though it were dye; "SH" indicates a shoulder that has a peak fluorescence, but has not been calculated as dye; and "dup" indicates a duplicate sample. "NS" means that there was no sample collected for the time interval.

Complete results are presented in Appendix A. In the table in Appendix A, there are columns attributing dye detections to a particular dye trace. In some cases, residual dye was present at a sampling station when a new dye pulse arrived. In such cases, the number of the trace providing the predominant dye concentration is listed as the source.

Graphs of all analyzed samples are presented in Appendix B. Appendix C is a copy of OUL's Procedures and Criteria document.

4.3.1 Trace 00-301: Dane's Overflow Trace

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a cave passage that receives overflow from an overflow passage in the Pautler Cave system as well as a small, locally derived flow. The dye was introduced on May 29, 2000 at 1430 hours. At the time of dye introduction there was approximately one-eighth gpm flowing through the passage. The elevation of the dye introduction point is approximately 480 feet msl and is in the SW ¼ NE ¼ Section 28 T2S R10W. The location can be found on the Waterloo 7.5-minute quadrangle map. The purpose of this trace was to determine if this cave stream resurges at the same springs as the main stream, believed to be the stream traced by the Scheibe Trace (97-10) and subsequently confirmed. It is notable that the cave stream was not discovered until March 26, 2000 by cooperators of the Illinois Speleological Survey Philip Moss, Lea Claycomb, Joe Sikorski, and Valerie Schmidt.

The stations sampled for this trace were: 301, 302, 303, 305, 306, 307, 308, 310, 311, 315, 316, 318, and 319 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-301 are listed below.

Station 309. Annbriar Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Rhodamine WT Dye Concentration (ppb)**
5/28 to 6/6/00	ND	ND
6/6 to 6/12/00	563.9	121
6/6 to 6/12/00 (duplicate)	563.0	20.3
6/12/00 (water)	ND	ND
6/12 to 6/16/00	563.0	17.8

Station 311. Fountain Creek at HH Road

Sampling Period	**Peak Emission Wavelength (nm)**	**Rhodamine WT Dye Concentration (ppb)**
5/28 to 6/7/00	ND	ND
6/7 to 6/12/00	562.4	4.72
6/12/00 (water)	570.0	0.474
6/12 to 6/20/00	562.8	2.11
6/20/00 (water)	ND	ND
6/20 to 7/5/00	ND	ND

Rhodamine WT dye from Trace 00-301 was detected at two sampling stations; Annbriar Spring and a station downstream (Station 311) which derived its dye from the Annbriar Spring Complex. The dye introduction point was in an overflow passage that receives water from the main stream of the Pautler Cave system under extremely high flow conditions. The passage has a minor amount of locally derived flow under normal flow conditions.

The Dane's Overflow Trace demonstrates a hydrologic link between the Pautler Cave system and the Annbriar groundwater system. This linkage provides a route for aquatic cave fauna to move between the Pautler Cave and Annbriar Spring groundwater systems. This is corroborated by the presence of the Illinois Cave Amphipod in both groundwater systems (Lewis et al., 1999). Figure 5 shows the groundwater flow paths schematically.

The straight-line distance is 4,150 feet and the elevation loss is approximately 45 feet. The mean gradient along this flow path is approximately 57 feet per mile. Dye first arrived at Annbriar Spring between eight and fourteen days after dye introduction. The mean velocity under these flow conditions was 300 to 500 feet per day.

The diagrammatic flow path for Trace 00-301 is shown bending to the west. The line is drawn in this manner to prevent the reader from believing that the flow path went under Fountain Creek.

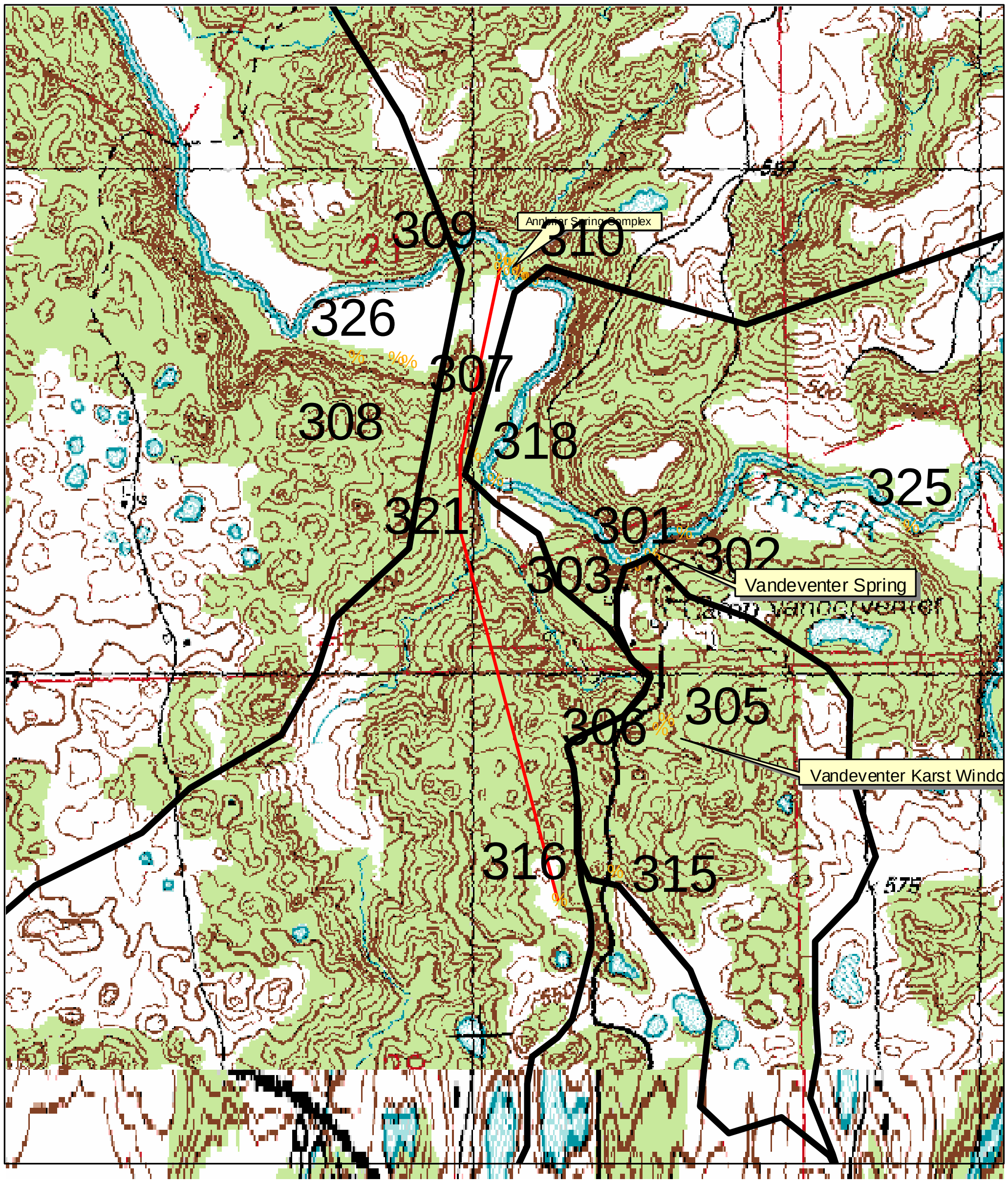


Figure 3
Trace 00-301
Dane's Overflow Trace

Ozark Underground Laboratory, 2001

4.3.2 Trace 00-302: Dane's Parallel Stream Trace

One-half pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a cave stream that receives overflow under very high flow conditions from the main stream in the Pautler Cave system as well as a small, locally derived flow. There was only the locally derived flow at the time of dye introduction. The dye was introduced on May 29, 2000 at 1500 hours. The elevation of the dye introduction point is approximately 485 feet msl and is in the SE ¼ NE ¼ Section 28 T2S R10W. At the time of dye introduction there was approximately two gpm flowing through the passage. The location can be found on the Waterloo 7.5-minute quadrangle map. The purpose of this trace was to determine if this recently discovered cave stream resurges at the same springs as the main stream.

The stations sampled for this trace were: 301, 302, 303, 305, 306, 307, 308, 309, 310, 311, 315, 316, 318, and 319 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-302 are listed below.

Station 301. Vandeventer Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
5/27 to 5/28/00	ND	ND
5/27 to 5/28/00 (Duplicate)	535.2	SH
5/28 to 6/6/00	538.7	93.2
6/6/00 (water)	532.6	1.49
6/6 to 6/12/00	538.6	101
6/12/00 (water)	532.0	0.253
6/12 to 6/20/00	538.6	33.0
6/20/00 (water)	ND	ND
6/20 to 7/5/00	ND	ND

Station 303. Ice Box Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
5/28/00 (water)	ND	ND
5/28 to 6/6/00	536.7	3.47
6/6/00 (water)	531.6	1.09
6/6 to 6/12/00	538.9	53.3
6/12/00 (water)	531.4	0.389
6/12 to 6/20/00	538.7	73.8
6/20/00 (water)	ND	ND
6/20 to 7/5/00	ND	ND

Station 305. Vandeventer Karst Window

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
5/28 to 6/6/00	539.0	85.9
6/6/00 (water)	532.0	1.55
6/6 to 6/12/00	538.6	80.8
6/12/00 (water)	531.5	0.277
6/12 to 6/20/00	538.9	55.9
6/20/00 (water)	ND	ND
6/20 to 7/5/00	ND	ND

Station 308. Dual Spring West

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
5/27 to 5/28/00	ND	ND
5/28 to 6/6/00	537.5	7.86
6/6/00 (water)	530.8	0.169
6/6 to 6/12/00	538.1	5.88
6/12/00 (water)	ND	ND
6/12 to 6/20/00	533.9	1.07
6/20/00 (water)	ND	ND
6/20 to 7/5/00	ND	ND

Station 309. Annbriar Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
5/27 to 5/28/00	ND	ND
5/28 to 6/6/00	537.5	5.70
6/6/00 (water)	533.6	SH
6/6 to 6/12/00	536.0	1.19
6/6 to 6/12/00 (duplicate)	535.7	0.787
6/12/00 (water)	ND	ND
6/12 to 6/16/00	534.9	0.674

Station 310. Fountain Creek upstream of Annbriar Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Eosine Dye Concentration (ppb)**
5/28/00 (water)	ND	ND
5/28 to 6/6/00	537.8	8.19
6/6/00 (water)	530.4	0.049
6/6 to 6/12/00	537.5	3.49
6/12/00 (water)	ND	ND
6/12 to 6/16/00	536.7	2.37
6/16/00 (water)	ND	ND
6/16 to 6/20/00	ND	ND

Station 318. Fountain Creek upstream Sink Point

Sampling Period	**Peak Emission Wavelength (nm)**	**Eosine Dye Concentration (ppb)**
6/6/00 (water)	531.4	0.241
6/6 to 6/12/00	538.3	12.2
6/12/00 (water)	ND	ND
6/12 to 6/20/00	536.2	3.08
6/20/00 (water)	ND	ND
6/20 to 7/17/00	ND	ND

Dye was detected from Trace 00-302 at seven sampling stations; Vandeventer Spring (301), Ice Box Spring (303), Vandeventer Karst Window (305), Dual Spring West (308), Annbriar Spring (309), Fountain Creek upstream of Annbriar Spring (310), and Fountain Creek upstream of sink point (318). Based on decreasing concentrations along the flow paths demonstrated by Traces 97-11 and 00-306, and the order of stations in Fountain Creek (Annbriar Spring rises in Fountain Creek), OUL interprets the flow path as follows. All the dye flowed through Vandeventer Karst Window, then most of the dye was discharged from Vandeventer Spring with some also being discharged from Ice Box Spring (Ice Box Spring has a much smaller discharge than Vandeventer Spring (Aley and Aley, 1998), then all the dye flowed down Fountain Creek to the sink point demonstrated by Trace 97-11, some of the dye re-entered the groundwater system and was discharged at Dual Spring West, while some of the dye continued down Fountain Creek where it was detected at Station 310 and at Annbriar Spring. OUL interprets the Annbriar Spring detection not as dye being discharged from the spring, but as dye flowing down Fountain Creek. The dye concentrations are slightly lower at Annbriar Spring than at Station 310 upstream. This is as expected if there were no dye being discharged from Annbriar Spring.

The straight-line distance from Dane's Parallel Stream to Vandeventer Karst Window is approximately 1,090 feet and the elevation loss is approximately 20 feet. The mean gradient is approximately 97 feet per mile. Dye first arrived at Vandeventer Spring in less than seven days. The groundwater velocity along this flow path is greater than 300 feet per day.

This trace demonstrates that the parallel stream in Dane's Cave flows through Vandeventer Karst Window as does the main cave system stream (Trace 97-10) and the Pautler Cave stream (Trace 00-312). Figure 4 shows the diagrammatic flow path for Trace 00-302. Ice Box Spring is the sampling station located about 140 feet west of Vandeventer Spring. Figure 5 shows the groundwater flow paths schematically.

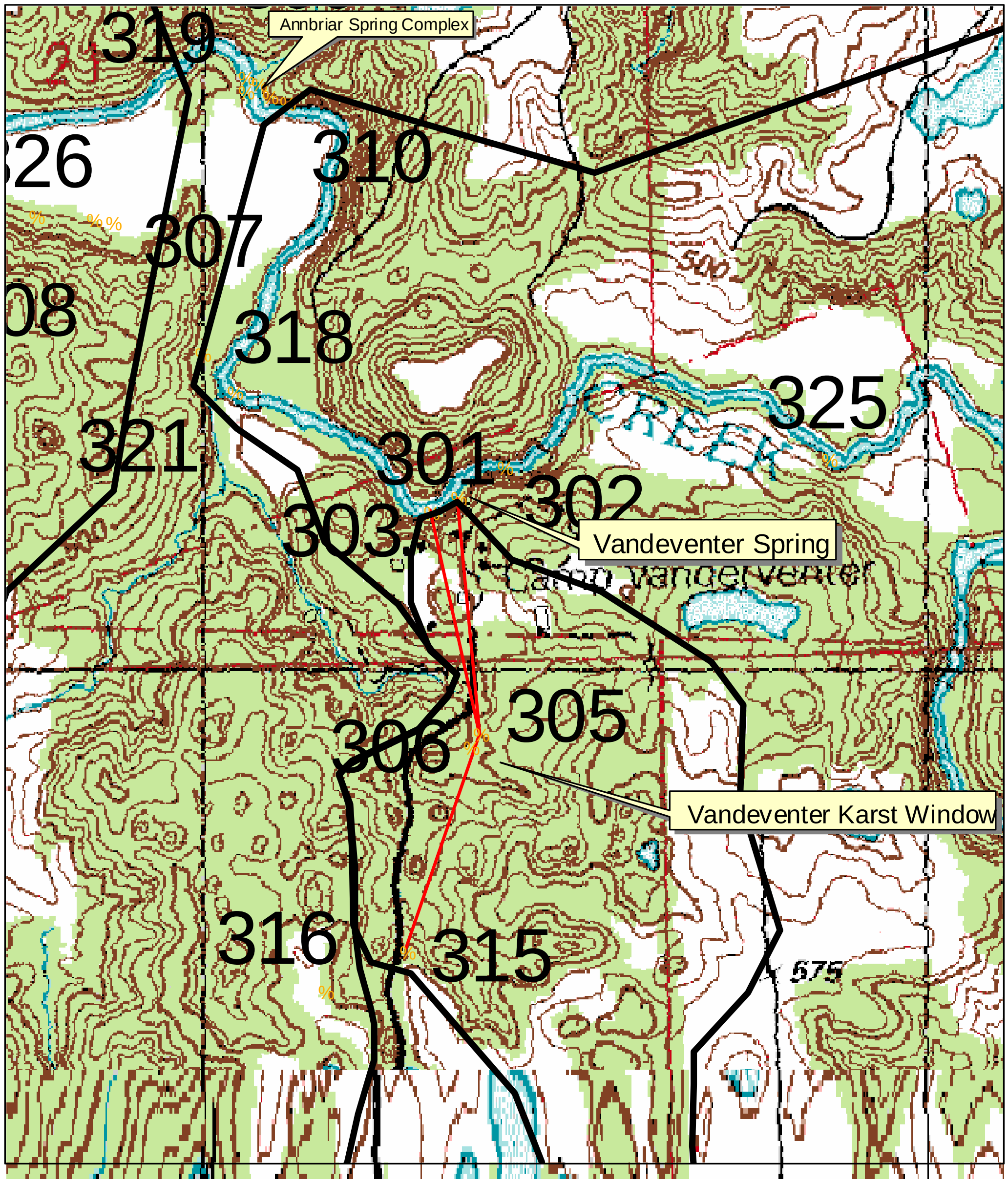


Figure 4
Trace 00-302
Dane's Parallel Stream Trace

N

0 1000 2000 Feet

Ozark Underground Laboratory, 2001

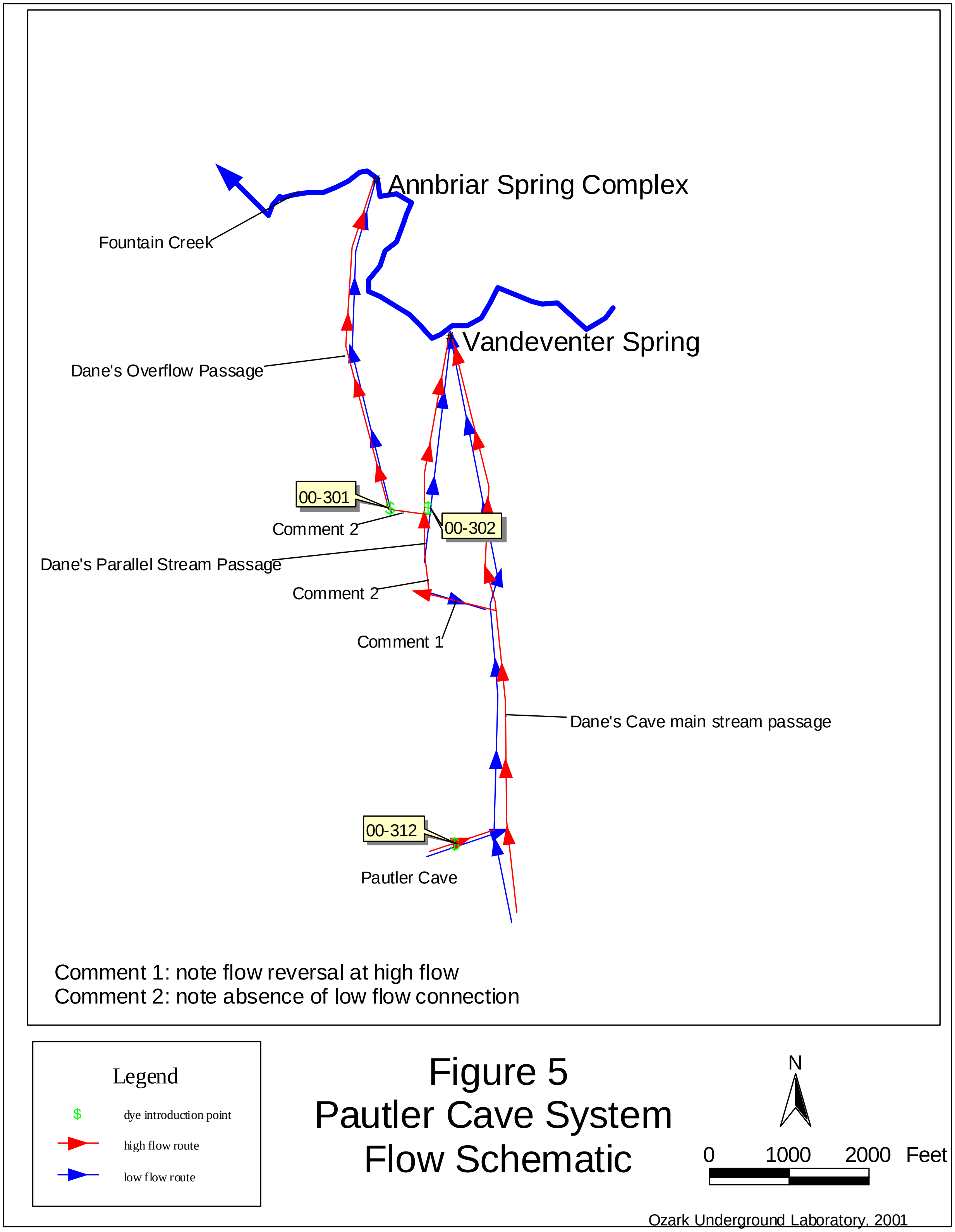


Figure 5
Pautler Cave System
Flow Schematic

4.3.3 Trace 00-303: Acorns Trace

One pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced into a small karst window on the Acorns Golf Course at 1257 hours on July 6, 2000. There was approximately 13 gpm flowing through the karst window at the time of dye introduction. The elevation of the dye introduction point is approximately 622 feet msl and is in the NW ¼ NW ¼ Section 10 T3S R10W. The location can be found on the Waterloo 7.5-minute quadrangle map. The purpose of this trace was to help define the southern boundary of the Pautler Cave system recharge area.

The stations sampled for this trace were: 301, 302, 303, 304, 305, 306, 307, 308, 310, 311, 312, 313, 317, 318, 319, 320, 321, 322, and 323 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-303 are listed below.

Station 301. Vandeventer Spring

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
6/20 to 7/5/00	ND	ND
7/5 to 7/17/00	575.4	49.8
7/17/00 (water)	ND	ND
7/17 to 7/29/00	ND	ND
7/29 to 8/14/00	571.4	3.18
8/14 (water)	ND	ND
8/14 to 8/14/00	ND	ND

Station 303. Ice Box Spring

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
6/20 to 7/5/00	ND	ND
7/5 to 7/17/00	575.5	56.2
7/17/00 (water)	ND	ND
7/17 to 7/29/00	ND	ND
7/29 to 8/14/00	574.0	2.55
8/14/00 (water)	ND	ND
8/14 to 8/14/00	ND	ND

Station 305. Vandeventer Karst Window

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
6/20 to 7/5/00	ND	ND
7/5 to 7/17/00	575.6	50.1
7/17/00 (water)	ND	ND
7/17 to 7/29/00	ND	ND
7/29 to 8/14/00	574.0	3.04

Station 308. Dual Spring West

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
6/20 to 7/5/00	ND	ND
7/5 to 7/17/00	573.8	2.90
7/17/00 (water)	ND	ND
7/17 to 7/29/00	ND	ND

Station 310. Fountain Creek upstream of Annbriar Spring

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
6/20 to 7/5/00	ND	ND
7/5 to 7/17/00	573.1	5.00
7/17/00 (water)	ND	ND
7/17 to 7/29/00	ND	ND

Station 311. Fountain Creek @ HH Rd.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
6/20 to 7/5/00	ND	ND
7/5 to 7/17/00	573.2	0.974
7/17 to 7/29/00	ND	ND

Station 318. Fountain Creek upstream of sink point

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
6/20 to 6/20/00	ND	ND
6/20 to 7/17/00	572.8	1.67
7/17 to 7/29/00	ND	ND

Station 319. Fountain Creek downstream Annbriar

Sampling Period	**Peak Emission Wavelength (nm)**	**Sulforhodamine B Dye Concentration (ppb)**
6/20 to 7/5/00	ND	ND
7/5 to 7/17/00	574.4	1.27
7/17 to 7/29/00	ND	ND

Station 322. Acorns Pond #6

Sampling Period	**Peak Emission Wavelength (nm)**	**Sulforhodamine B Dye Concentration (ppb)**
7/6 to 7/16/00	576.7	346
7/16 to 7/29/00	574.9	9.63
7/29/00 (water)	577.4	0.387
7/29 to 8/12/00	574.9	17.5
8/12/00 (water)	577.2	0.296
8/12 to 8/26/00	573.8	8.45
8/26/00 (water)	576.0 a	0.152
8/26 to 9/18/00	574.3	6.90
9/18/00 (water)	575.2 a	0.061
9/18 to 10/1/00	571.7	2.78
10/1/00 (water)	576.0 a	0.082
10/1 to 10/17/00	573.8	18.7
10/17/00 (water)	ND	ND
10/17 to 10/27/00	573.7	8.04
10/27/00 (water)	577.6	0.177
10/27 to 12/28/00	NS	
12/28/00 (water)	ND	ND

Station 323. Ebeler Cave

Sampling Period	**Peak Emission Wavelength (nm)**	**Sulforhodamine B Dye Concentration (ppb)**
7/6 to 7/16/00	574.6	11,200
7/16 to 7/29/00	575.7	127
7/29/00 (water)	577.9	2.21
7/29 to 8/12/00	575.3	203
8/12/00 (water)	578.8	3.53
8/12 to 8/26/00	575.1	157
8/26/00 (water)	577.9	1.58
8/26 to 9/18/00	575.7	64.2
9/18/00 (water)	578.0	0.584
9/18 to 10/1/00	575.5	39.8
10/1/00 (water)	578.6	17.8
10/1 to 10/17/00	575.3	157
10/17/00 (water)	ND	ND
10/17 to 10/27/00	574.9	54.6
10/27/00 (water)	578.2	0.910
10/27 to 11/22/00	575.1	162
11/22/00 (water)	578.0	0.484
11/22 to 12/28/00	574.7	29.4
12/28/00 (water)	ND	ND
12/28/00 to 2/6/01	574.6	8.74
2/6/01 (water)	576.4	0.718

Dye was detected at nine sampling stations from the Acorns Trace. From upstream to downstream they are: Ebeler Cave (323), Acorns Pond #6 (322)[this station samples a karst window about 1,000 feet northeast of the golf course], Vandeventer Karst Window (305), Vandeventer (301) and Ice Box Springs (303), Fountain Creek upstream of sink point (318), and then to Dual Spring West (308) and the stations sampling Fountain Creek upstream (310) and downstream (319) of Annbriar Spring, and at Fountain Creek at HH Road (311).

This trace demonstrates that Acorns Golf Course and the land that recharges its karst window contribute to the Pautler Cave groundwater system.

The straight-line distance from the Acorns karst window to Vandeventer Karst Window is approximately 17,825 feet and the elevation loss is approximately 172 feet. The mean gradient for this segment is approximately 51 feet per mile. Table 6 summarizes the lengths, elevation losses, and gradients for each segment of the dye trace. Dye first arrived at Vandeventer Spring between 29 and 41 days after introduction. Mean groundwater velocity for this flow path under these flow conditions was between 435 and 615 feet per day.

Within Appendix A, there is an isolated dye detection at Vandeventer Spring (301) attributed to this trace following a period of sulforhodamine B dye detection attributed to Trace 00-307. The data from Vandeventer Spring indicate that Trace 00-307 moved through the groundwater system fairly quickly. However, Acorns Pond #6 (322) and Ebeler Cave (323), which did not have dye from Trace 00-307 pass through them, had appreciable dye detected for about four months following the last detection of dye from Trace 00-307. It is most likely that the late detection at Vandeventer Spring is derived from the residual dye from Trace 00-303 rather than the later Trace 00-307.

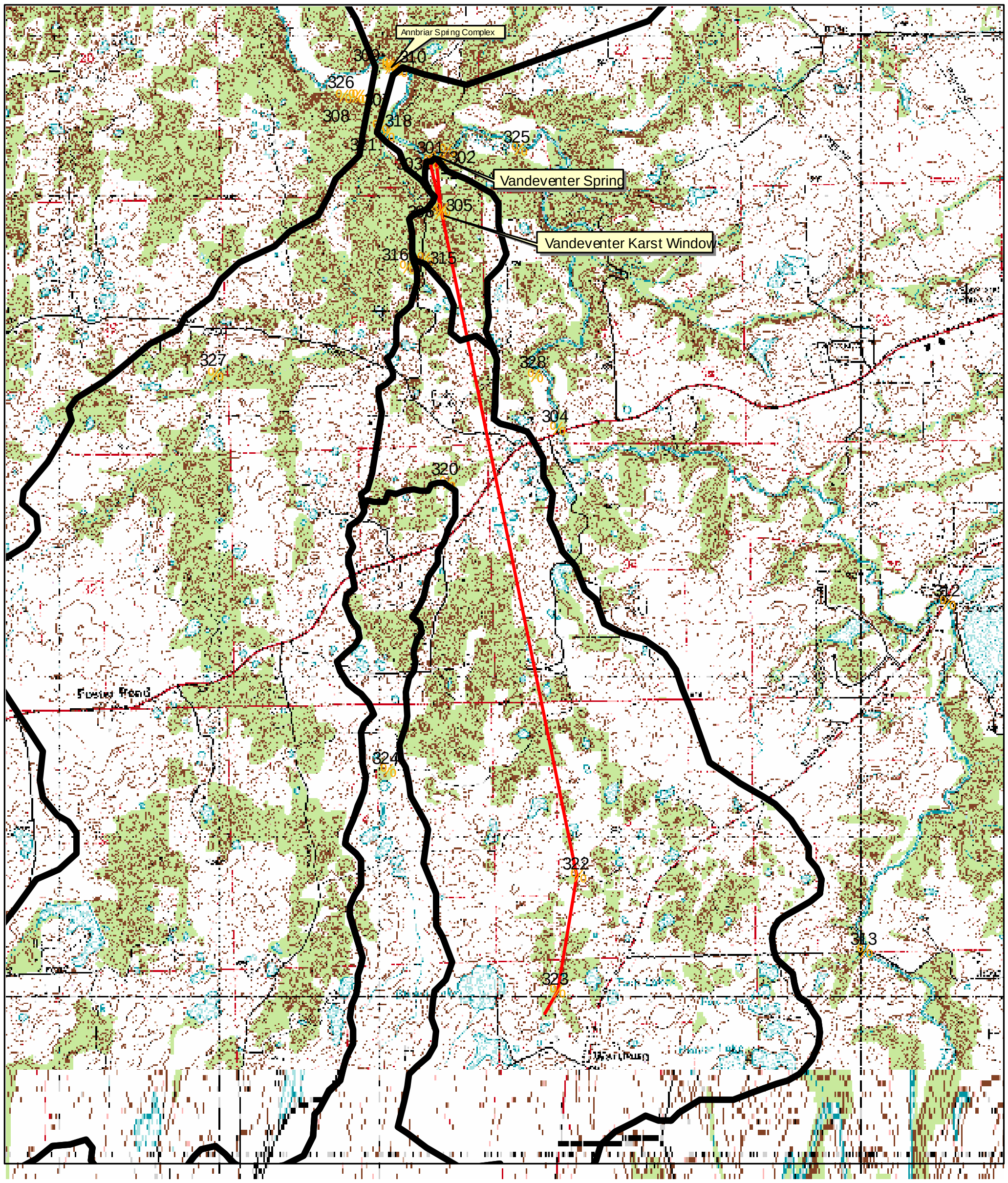


Figure 6
Trace 00-303
Acorns Trace

Ozark Underground Laboratory, 2001

4.3.4 Trace 00-304: Ritter Trace

Two pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into the Cedar Ridge Cave stream on July 17, 2000 at 1712 hours. There was an estimated 20 gpm flowing through the cave at the time of dye introduction. The elevation of the dye introduction is approximately 605 feet and is in the NE ¼ NE ¼ Section 5 T2S R10W. The location can be found on the Waterloo 7.5-minute quadrangle map. The purpose of this trace was to help define the western boundary of the Pautler Cave system recharge area. Additionally, this cave is a *Gammarus acherondytes* (Illinois Cave Amphipod) location (Lewis et al., 1999) and it is important to know in which groundwater system it lies.

The stations sampled for this trace were: 301, 302, 303, 304, 305, 306, 307, 308, 310, 311, 312, 313, 317, 318, 319, 320, 321, 322, and 323 (Table 1, page 17).

Data on the dye recovery location for Trace 00-304 is listed below.

Station 317. Tree Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Rhodamine WT Dye Concentration (ppb)**
7/5 to 7/17/00	ND	ND
7/17 to 7/29/00	564.8	54.2
7/29 to 8/14/00	562.4	SH
8/14 to 9/18/00	ND	ND

Dye from Trace 00-304 was only detected only at Tree Spring, which is about 100 feet from the part of Fountain Creek where there is perennial flow from the Annbriar Spring Complex. Tree Spring is an intermittent spring that we thought to be an overflow outlet for the Annbriar Spring Complex. Based on the dye traces detected in other parts of the Annbriar Spring Complex, OUL believes that dye from the Ritter Trace was also discharged from Annbriar Spring. The samplers downstream of Annbriar Spring for the relevant sampling period were buried under about one foot of gravel during a flood event and probably were not well exposed to dye. Also supporting the interpretation that Tree Spring cannot be the sole discharge point for Cedar Ridge Cave is that Cedar Ridge Cave has perennial flow, while Tree Spring does not. This trace indicates that Tree Spring is an overflow spring for the Annbriar Spring Complex. This dye detection along with other traces used to delineate the Annbriar Spring Recharge Area demonstrate that Cedar Ridge Cave is part of the Annbriar groundwater system.

The straight-line distance from Ritter sink to Tree Spring is approximately 14,950 feet and the elevation loss is approximately 173 feet. The mean gradient is approximately 61 feet per mile. Dye first arrived at Tree Spring within 12 days after dye introduction. The mean groundwater velocity for this trace is at least 1,270 feet per day. There was a storm event during this trace and most of the dye probably moved through the groundwater system during the flood.

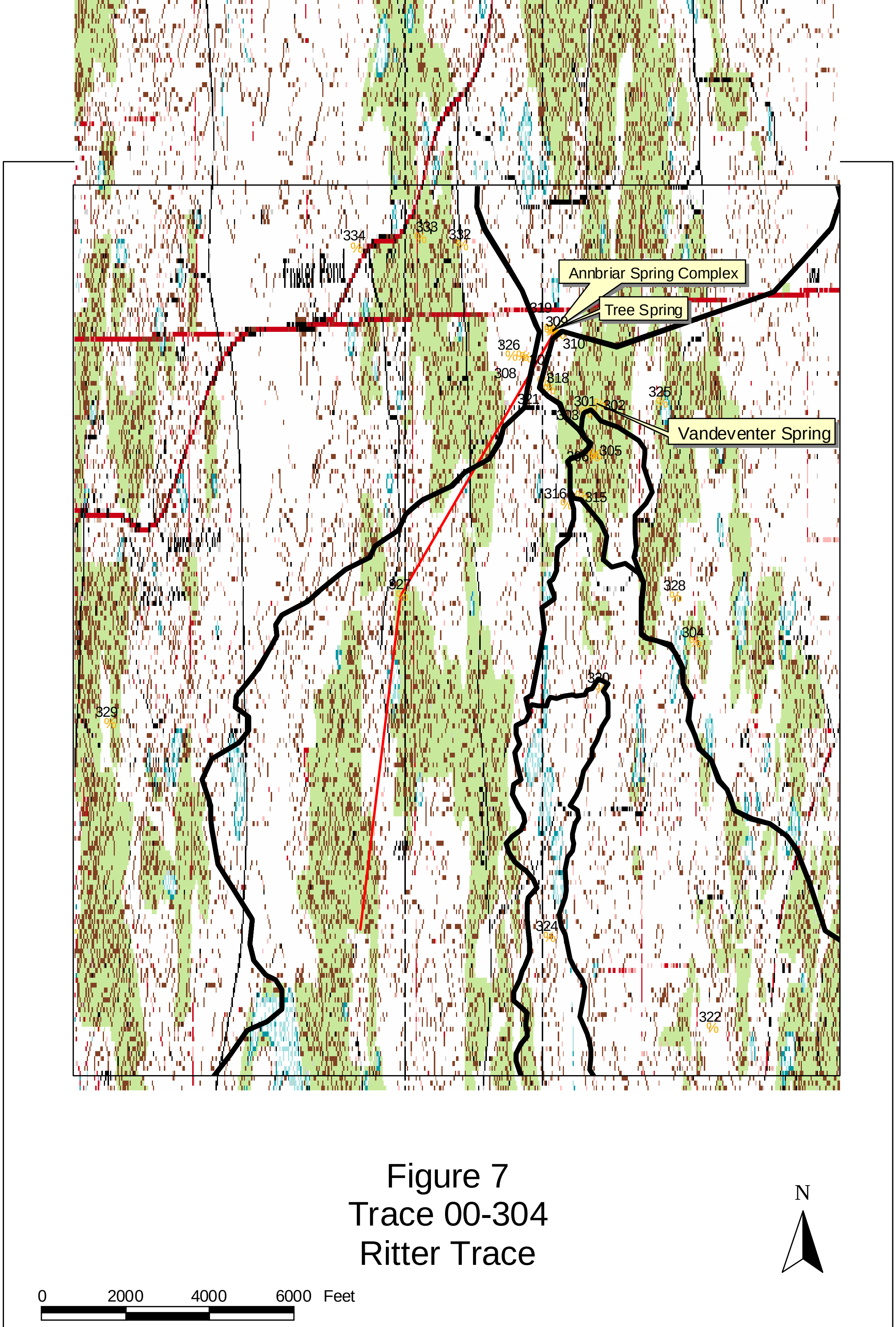


Figure 7
Trace 00-304
Ritter Trace

Ozark Underground Laboratory, 2001

4.3.5 Trace 00-305: Fountain Creek Trace

The Fountain Creek Trace had multiple eosine dye introduction points along Fountain Creek from the upstream end of the watershed downstream to where Maeystown Road crosses the creek near the water plant. All dye introductions associated with this trace were made on July 17, 2000. The eosine dye mixture contained approximately 75% dye and 25% diluent and was introduced at locations shown on Table 3. With the exception of Ahne Road, dye was introduced downstream of the nearest sampling station. The locations are shown on the Waterloo 7.5-minute quadrangle map. The purpose of this trace was to determine if Fountain Creek leaks into the Pautler Cave system.

Table 3. Fountain Creek Dye Introduction Locations

Location	Lbs. of eosine dye	Elevation	Time	Estimated flow (gpm)
Ahne Road	3	705	1748	8
Maeystown Road in Sec. 15	2	630	1800	300
JJ Road	2	565	1808	3,000
Maeystown Road near water plant	2	538	1819	5,000

All stations established prior to this trace were sampled, except for the discontinued station 309.

Data on the dye recovery locations for Trace 00-305 are listed below.

Station 302. Fountain Creek upstream Camp

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
7/5 to 7/17/00	ND	ND
7/17 to 7/29/00	538.2	59.5
7/29/00 (water)	ND	ND
7/29 to 8/14/00	ND	ND

Station 304. Fountain Creek at Route 156

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
7/5 to 7/17/00	ND	ND
7/17 to 7/29/00	538.3	479
7/29/00 (water)	ND	ND
7/29 to 8/14/00	ND	ND

Station 308. Dual Spring West

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
7/5 to 7/17/00	ND	ND
7/17 to 7/29/00	537.3	8.72
7/29/00 (water)	ND	ND
7/29 to 8/14/00	ND	ND

Station 310. Fountain Creek upstream Annbriar

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
7/5 to 7/17/00	ND	ND
7/17 to 7/29/00	538.2	56.5
7/29/00 (water)	ND	ND
7/29 to 8/14/00	ND	ND

Station 311. Fountain Creek at HH Road

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
7/5 to 7/17/00	ND	ND
7/17 to 7/29/00	537.8	24.7
7/29/00 (water)	ND	ND
7/29 to 8/14/00	ND	ND

Station 312. Fountain Creek near water plant

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
6/7 to 7/17/00	ND	ND
7/17 to 7/29/00	537.9	191
7/29/00 (water)	ND	ND
7/29 to 8/14/00	ND	ND

Station 313. Fountain Creek at JJ Road

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
6/20 to 7/17/00	ND	ND
7/17 to 7/29/00	537.1	11.8
7/29/00 (water)	ND	ND
7/29 to 8/14/00	ND	ND

Station 314. Fountain Creek at Maeystown Road in Section 15

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
6/20 to 7/17/00	ND	ND
7/17 to 7/29/00	537.7	24.8
7/29/00 (water)	533.2	SH
7/29 to 8/14/00	536.4	0.903
8/14/00 (water)	ND	ND
8/14 to 8/28/00	ND	ND

Station 317. Tree Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
7/5 to 7/17/00	ND	ND
7/17 to 7/29/00	535.6 s	0.366
7/29 to 8/14/00	ND	ND

Station 318. Fountain Creek upstream of sink point

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
6/20 to 7/17/00	ND	ND
7/17 to 7/29/00	538.1	76.2
7/17 to 7/29/00 (dup.)	538.5	76.2
7/29/00 (water)	ND	ND
7/29 to 8/14/00	ND	ND

Station 319. Fountain Creek downstream of Annbriar Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
7/5 to 7/17/00	ND	ND
7/17 to 7/29/00	538.6	105
7/29/00 (water)	ND	ND
7/29 to 8/14/00	ND	ND

Station 320. Pautler Cave

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
7/17 to 7/29/00	ND	ND
7/29 to 8/28/00	536.4	0.884
8/28 to 10/17/00	536.3	4.11
8/28 to 10/17/00 (verify)	536.4	3.60
10/17/00 (water)	ND	ND
10/17 to 10/27/00	ND	ND
10/17 to 10/27/00 (duplicate)	ND	ND
10/27/00 (water)	ND	ND
10/27 to 11/23/00	ND	ND
11/23/00 (water)	ND	ND
11/23 to 12/28/00	536.4	1.93
12/28/00 (water)	ND	ND
12/28/00 to 1/12/01	533.4	1.81
1/12/01 (water)	ND	ND
1/12 to 2/7/01	536.0	1.21
2/7/01 (water)	ND	ND
2/7 to 2/27/01	536.4	0.597
2/27/01 (water)	ND	ND
2/27 to 3/5/01	ND	ND
2/27 to 3/5/01 (duplicate)	ND	ND
3/5 to 3/21/01	534.0	1.01
3/21/01 (water)	ND	ND
3/21 to 4/23/01	534.8	2.24
3/21 to 4/23/01 (duplicate)	534.8	2.28
4/23/01 (water)	ND	ND
4/23 to 5/26/01	537.2	3.02
5/26/01 (water)	ND	ND

Dye was detected at twelve sampling stations; except for Dual Spring West, Tree Spring, and Pautler Cave, all sampled Fountain Creek. Dual Spring West derived its dye via Fountain Creek along the flow path demonstrated by Trace 97-11. Tree Spring was inundated during its sampling period by a flood on Fountain Creek and this poor detection at Tree Spring is probably derived from Fountain Creek.

This trace demonstrates that Pautler Cave is recharged by water leaking out of the upper reaches of Fountain Creek. Trace 00-312, the Pautler Trace (discussed later), demonstrated that Pautler Cave drains to Vandeventer and Ice Box Springs.

Philip Moss walked Fountain Creek from Ahne Road to LRC Road on February 26, 2001 looking for losing points in the creek. The most likely area (based on bedrock exposure in the creek bed) to contribute water to Pautler Cave based on those observations is circled on Figure 8. The diagrammatic flow route shown on Figure 8 is based on the supposition that the circled area is where Fountain Creek loses water into Pautler Cave. More dye introductions will need to be made to test this section of Fountain Creek.

The straight-line distance from the assumed sink point to Vandeventer Spring is approximately 22,535 feet. The elevation loss is approximately 185 feet and the mean gradient is approximately 43 feet per mile. The details of dye trace segment lengths, elevation losses, and gradients are presented in Table 6 (page 107). The dye first arrived at Pautler Cave between 12 and 42 days. The mean velocity for this flow path under these flow conditions was between 380 and 1,320 feet per day.

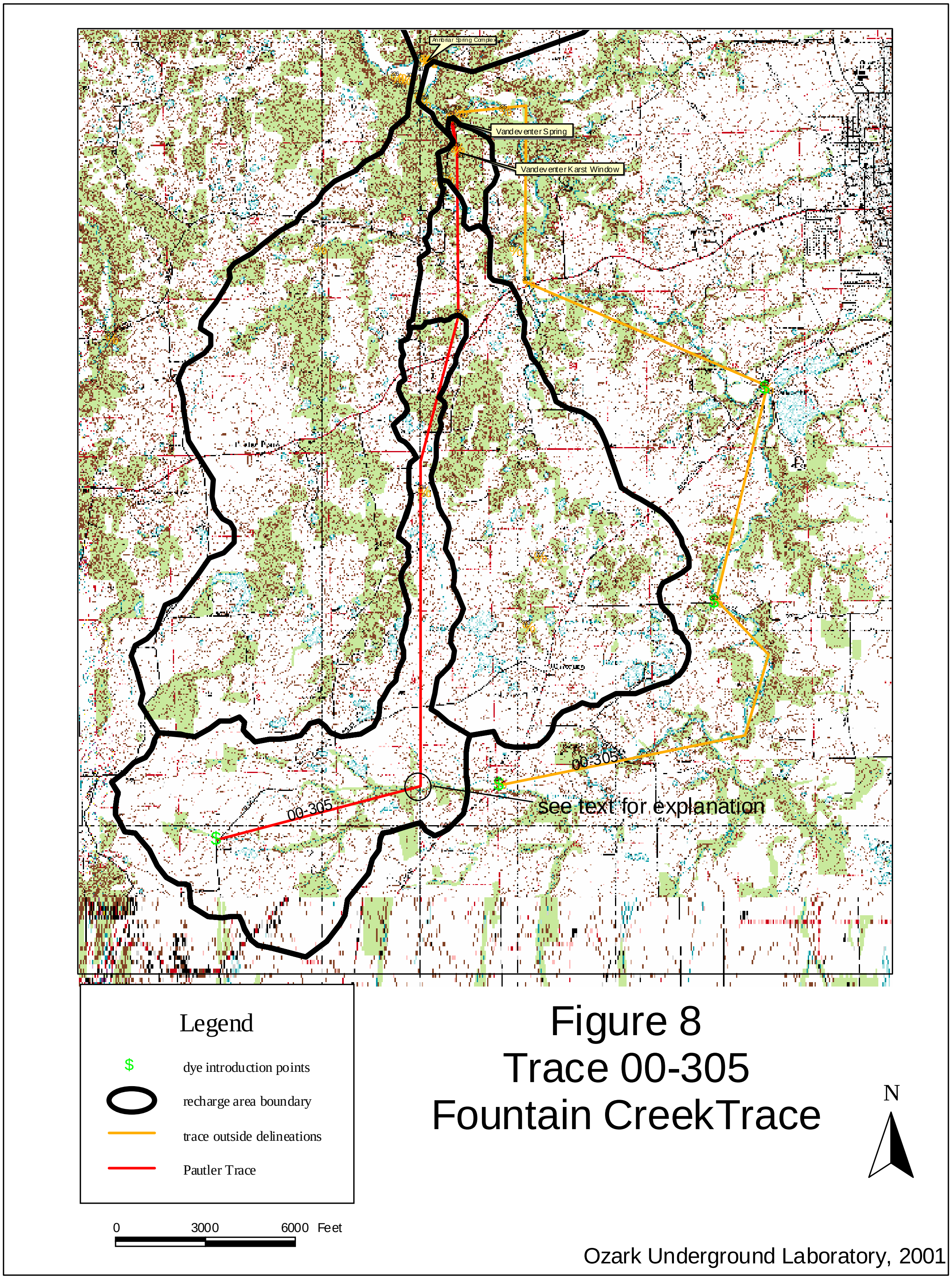


Figure 8
Trace 00-305
Fountain Creek Trace

Ozark Underground Laboratory, 2001

4.3.6 Trace 00-306: Vandeventer Trace

Two ounces of pyranine dye mixture containing 77% dye and 23% diluent was introduced into the Vandeventer Karst Window at 1214 hours on August 14, 2000. The elevation of the dye introduction point is approximately 465 feet msl and is in the NE¼ NE¼ Section 28 T2S R10W. There was approximately 450 gpm flow through the karst window at the time of dye introduction. The location can be found on the Waterloo 7.5-minute quadrangle map. The purpose of the trace was to determine whether the karst window discharges at Ice Box Spring as well as Vandeventer Spring.

The stations sampled for this trace were 301, 303, and 308 (Table 1, page 17).

Data on the recovery locations for Trace 00-306 are listed below.

Station 301. Vandeventer Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Pyranine Dye Concentration (ppb)**
7/29 to 8/14/00	ND	ND
8/14 to 8/14/00	502.4	1,440
8/14/00 (water)	501.6	1.83
8/14 to 8/28/00	ND	ND

Station 303. Ice Box Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Pyranine Dye Concentration (ppb)**
8/14 to 8/14/00	ND	ND
8/14 to 8/28/00	502.4	68.0
8/28/00 (water)	ND	ND
8/28 to 9/18/00	ND	ND

Station 308. Dual Spring West

Sampling Period	**Peak Emission Wavelength (nm)**	**Pyranine Dye Concentration (ppb)**
7/29 to 8/14/00	ND	ND
8/14 to 8/28/00	502.4	18.0
8/14 to 8/28/00 (duplicate)	502.8	17.0
8/28 to 9/18/00	ND	ND

Dye from Trace 00-306 was detected at three sampling stations; Vandeventer Spring, Ice Box Spring, and Dual Spring West. This trace demonstrates that Vandeventer Karst Window contributes water to both Ice Box and Vandeventer Springs. It is possible that there are other hydrologic connections between the two springs. Dual Spring West derived its dye via Fountain Creek along the flow path demonstrated by Trace 97-11. The trace also demonstrates that relatively small quantities of contaminants flowing through Camp Vandeventer could be detectable in water discharged from Dual Spring West.

The straight-line distance from Vandeventer Karst Window to Vandeventer Spring is approximately 1,060 feet and the elevation loss is approximately 15 feet. The mean gradient is approximately 75 feet per mile. Dye was first discharged from Vandeventer Spring in less than 5 hours following dye introduction. Comparison of the concentration of dye in the water sample (1.83 ppb) to the concentration of dye in the activated carbon sampler (1,440 ppb) indicates that most of the dye had been discharged from the groundwater system in less than five hours. Groundwater velocity along this flow path under these flow conditions was 5,000 to 15,000 feet per day.

Dye was first discharged from Ice Box Spring later than from Vandeventer Spring. Vandeventer Spring discharges about 200 times as much water as Ice Box Spring in base flow conditions. Dye was discharged at lower concentrations from Ice Box Spring than from Vandeventer Spring. The lower concentrations may reflect longer residence time and therefore greater losses from degradation. Another factor may be greater attenuation on the Ice Box Spring flow path.

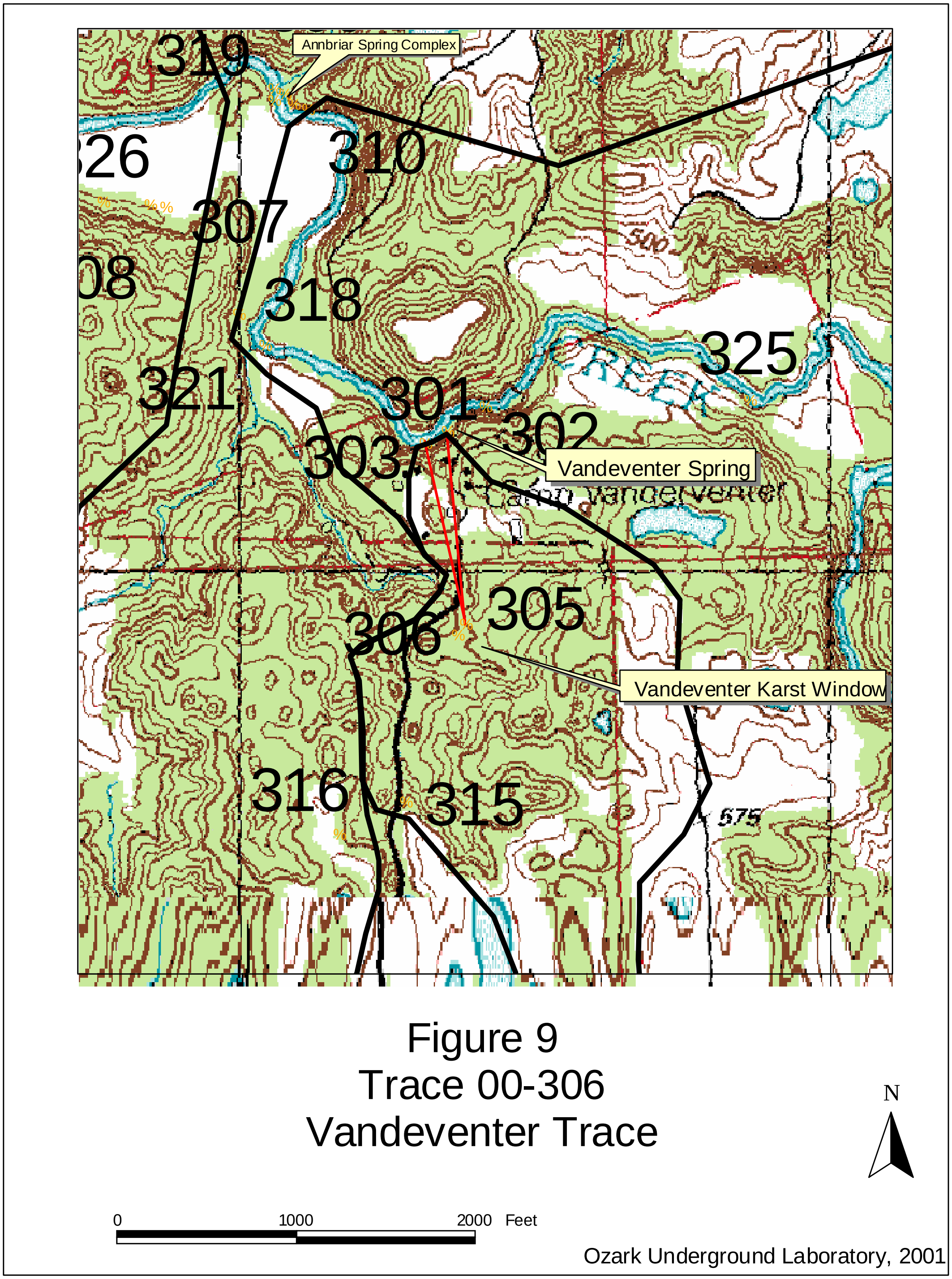


Figure 9
Trace 00-306
Vandeventer Trace

Ozark Underground Laboratory, 2001

4.3.7 Trace 00-307: Lenz Trace

Two pounds of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1411 hours on August 14, 2000. The elevation of the dye introduction point is approximately 620 feet msl and in the SE ¼ SE ¼ Section 3 T3S R10W. The dye was introduced using 3,200 gallons of potable water that were discharged into the sinkhole. Discharge of the water began at 1404 hours and at 1414 hours the first load of water (1,600 gallons) had been discharged. The second load of 1,600 gallons of water was discharged into the sinkhole from 1447 to 1454 hours. The dye introduction point can be found on the Waterloo 7.5-minute quadrangle map. The purpose of the trace was to help define the southeastern section of the recharge area boundary.

The stations sampled for this trace were: 301, 302, 303, 304, 305, 306, 310, 311, 312, 313, 314, 318, 319, 320, 321, 322, and 323 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-307 are listed below.

Station 301. Vandeventer Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Sulforhodamine B Dye Concentration (ppb)**
8/14 to 8/14/00	ND	ND
8/14 to 8/28/00	574.2	954
8/28/00 (water)	576.1 a	1.48
8/28 to 9/18/00	574.9	31.7
9/18/00 (water)	ND	ND
9/18 to 10/2/00	577.2	1.65
10/2/00 (water)	574.0	0.051
10/2 to 10/17/00	573.1	12.4
10/17/00 (water)	ND	ND
10/17 to 10/27/00	ND	ND

Station 303. Ice Box Spring

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
8/14 to 8/14/00	ND	ND
8/14 to 8/28/00	574.2	838
8/28/00 (water)	577.1	7.29
8/28 to 9/18/00	575.4	177
9/18/00 (water)	576.0 a	0.228
9/18 to 10/2/00	575.6	7.06
10/2/00 (water)	ND	ND
10/2 to 10/17/00	573.3	13.5
10/17/00 (water)	ND	ND
10/17 to 10/27/00	ND	ND

Station 305. Vandeventer Karst Window

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
8/14 to 8/28/00	574.3	945
8/28/00 (water)	576.9	1.47
8/28 to 9/18/00	574.6	22.6
9/18/00 (water)	ND	ND
9/18 to 10/2/00	574.8	1.25
10/2/00 (water)	574.4 a	0.039
10/2 to 10/17/00	573.0	12.2
10/2 to 10/17/00 (duplicate)	572.8	14.0
10/17/00 (water	ND	ND
10/17 to 10/27/00	ND	ND

Station 308. Dual Spring West

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
7/29 to 8/14/00	ND	ND
8/14 to 8/28/00	574.3	29.9
8/14 to 8/28/00 (duplicate)	574.3	14.0
8/28 to 9/18/00	ND	ND

Station 310. Fountain Creek upstream of Annbriar Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Sulforhodamine B Dye Concentration (ppb)**
7/29 to 8/14/00	ND	ND
8/14 to 8/28/00	574.3	39.8
8/28/00 (water)	576.8	0.218
8/28 to 9/18/00	574.8	1.68
9/18/00 (water)	ND	ND
9/18 to 10/2/00	ND	ND

Station 311. Fountain Creek at HH Road

Sampling Period	**Peak Emission Wavelength (nm)**	**Sulforhodamine B Dye Concentration (ppb)**
7/29 to 8/14/00	ND	ND
8/14 to 8/28/00	574.3	15.9
8/28/00 (water)	577.2	0.143
8/28 to 10/3/00	ND	ND

Station 318. Fountain Creek upstream of sink point

Sampling Period	**Peak Emission Wavelength (nm)**	**Sulforhodamine B Dye Concentration (ppb)**
7/29 to 8/14/00	ND	ND
8/14 to 8/28/00	574.5	48.6
8/28/00 (water)	578.8	0.227
8/28 to 9/18/00	572.4	2.85
9/18/00 (water)	ND	ND
9/18 to 10/2/00	ND	ND

Station 319. Fountain Creek downstream of Annbriar Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Sulforhodamine B Dye Concentration (ppb)**
7/29 to 8/14/00	ND	ND
8/14 to 8/28/00	573.2	30.1
8/28/00 (water)	ND	ND
8/28 to 10/2/00	ND	ND

Dye from the Lenz Trace was detected at eight sampling stations. They are: Vandeventer Spring (301), Ice Box Spring (303), Vandeventer Karst Window (305), Dual Spring West (308), Fountain Creek upstream of Annbriar Spring (310), Fountain Creek at HH Road (311), Fountain Creek upstream of sink point (318), and Fountain Creek downstream of Annbriar Spring (319). Only Vandeventer Spring, Ice Box Spring, and Vandeventer Karst Window derived their dye directly from groundwater flow paths. Dual

Spring West derived its dye via Fountain Creek along the flow path demonstrated by Trace 97-11.

Trace 00-307 demonstrates that the Lenz sink and portions of JJ Road are in the Pautler Cave system recharge area. The straight-line distance from the Lenz sink to Vandeventer Karst Window is approximately 16,030 feet and the elevation loss is approximately 155 feet. The mean gradient is approximately 51 feet per mile. Dye was still being discharged more than two months following dye introduction. The dye first arrived at Vandeventer Spring within 14 days of introduction. The mean groundwater velocity under these flow conditions was between 1,220 and 17,000 feet per day.

Two other stations had detections of sulforhodamine B dye following the Lenz Trace dye introduction; they are Acorns Pond #6 (322) and Ebeler Cave (323). These detections are not derived from the Lenz Trace, but are residual dye from the Acorns Trace (00-303). Appendix A shows that there was no increase in dye concentration at either of these sampling stations associated with the timing of the Lenz dye introduction.

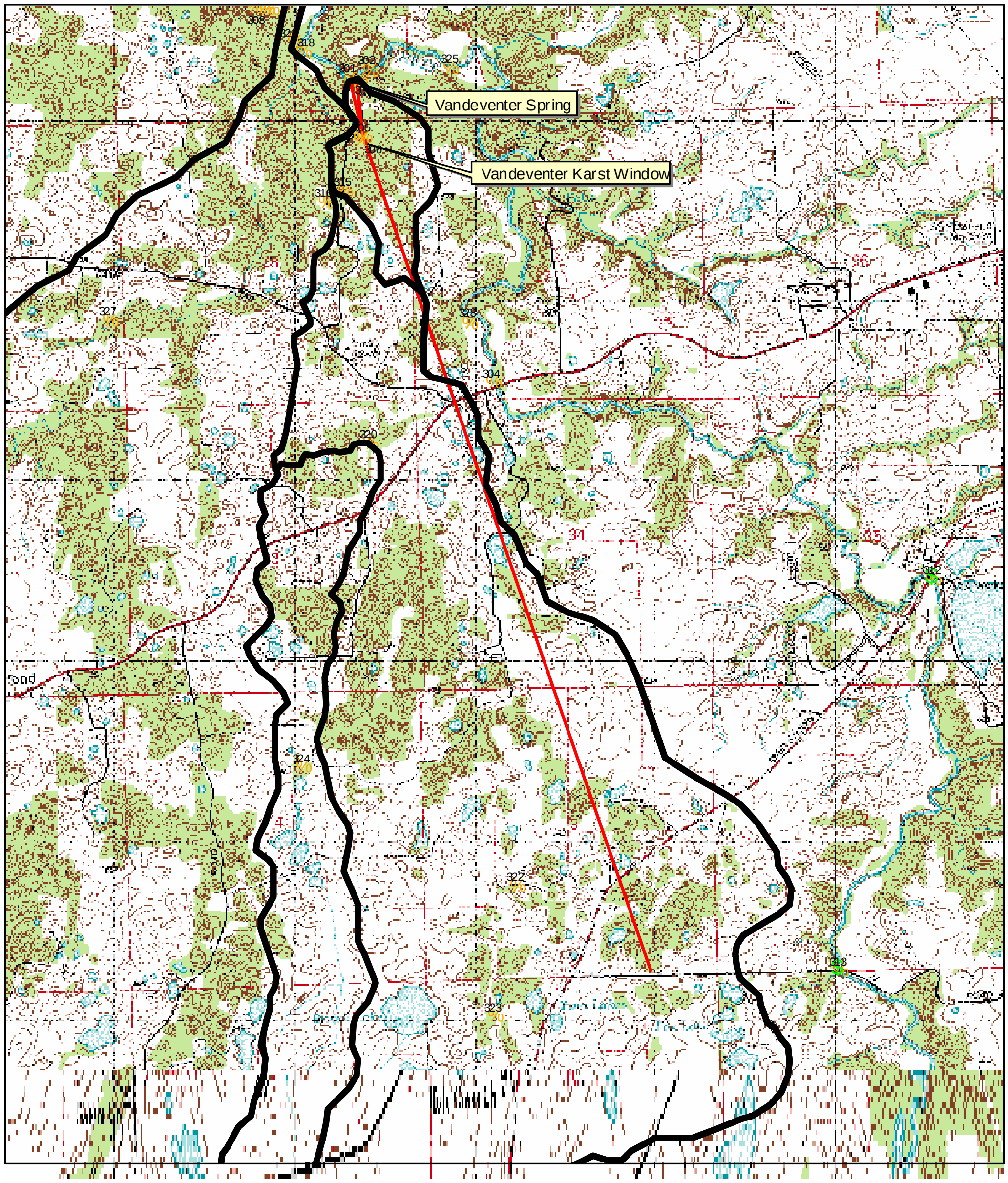


Figure 10
Trace 00-307
Lenz Trace

Ozark Underground Laboratory, 2001

4.3.8 Trace 00-308: Laurent Trace

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1705 hours on August 14, 2000. The elevation of the dye introduction point is approximately 665 feet msl and is in the SW ¼ NW ¼ Section 9 T3S R10W. The dye was introduced using water siphoned from a pond in the sinkhole. The water was siphoned at a rate of approximately 2.25 gpm. The siphon was started at 1653 hours and continued until about 1400 hours on August 15, 2000. Approximately 2,875 gallons of water was siphoned. The dye introduction point can be found on the Waterloo 7.5-minute quadrangle map. The purpose of the trace was to help define the recharge area boundary between the Pautler and Annbriar groundwater systems.

The stations sampled for this trace were: 301, 303, 305, 306, 307, 308, 310, 311, 317, 318, 319, 320, and 321 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-308 are listed below.

Station 311. Fountain Creek at HH Road

Sampling Period	**Peak Emission Wavelength (nm)**	**Fluorescein Dye Concentration (ppb)**
7/29 to 8/14/00	ND	ND
8/14 to 8/28/00	512.7	47.2
8/28/00 (water)	506.9	0.090
8/28 to 10/3/00	511.5	3.84
10/3/00 (water)	ND	ND
10/3 to 10/17/00	ND	ND

Station 319. Fountain Creek downstream of Annbriar Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Fluorescein Dye Concentration (ppb)**
7/29 to 8/14/00	ND	ND
8/14 to 8/28/00	513.5	174
8/28/00 (water)	507.4	0.351
8/28 to10/2/00	512.0	15.3
10/2/00 (water)	ND	ND
10/2 to 10/17/00	512.3	10.8
10/17/00 (water)	ND	ND

Station 327. Reverse Stream

Sampling Period	**Peak Emission Wavelength (nm)**	**Fluorescein Dye Concentration (ppb)**
10/29/00 (water)	ND	ND
10/29 to 11/1/00	510.8	0.793
11/1/00 (water)	ND	ND
11/1 to 11/22/00	511.1	2.32
11/22/00 (water)	ND	ND
11/22 to 11/27/00	510.4 a,s	1.26
11/27 to 12/28/00	510.9	1.69
12/28/00 (water)	ND	ND
12/28/00 to 1/12/01	ND	ND
1/12/01 (water)	ND	ND
1/12 to 2/6/01	511.7	1.88
2/6/01 (water)	ND	ND

Fluorescein dye was detected at three sampling stations from the Laurent Trace; Reverse Stream (327), which is karst window that was not added to the sampling routine until about six weeks after dye introduction, Fountain Creek downstream of Annbriar Spring (319), and the downstream station Fountain Creek at HH Road (311). In order to better detect dye that might be discharged from any outlet of the dynamic Annbriar Spring Complex, sampling was discontinued at Station 309 (Annbriar Spring) in mid-June 2000 and was begun at a replacement station (319), Fountain Creek downstream of the Annbriar Spring Complex. A comparison of the concentrations of a specific dye between the stations in Fountain Creek upstream and downstream of Annbriar Spring indicated whether dye was discharged from Annbriar Spring. In this case no dye was detected upstream of Annbriar Spring. Therefore, the fluorescein dye detected at Fountain Creek downstream of Annbriar Spring was discharged from the Annbriar Spring Complex. Thus, this trace demonstrates that the Laurent sink lies within the Annbriar Spring recharge area.

The straight-line distance from the Laurent sink to Annbriar sink is approximately 21,075 feet and the elevation loss is approximately 230 feet. The mean gradient is approximately 58 feet per mile. The dye first arrived at Annbriar Spring within two weeks following dye introduction. The groundwater velocity along this flow path under these flow conditions was at least 1,500 per day.

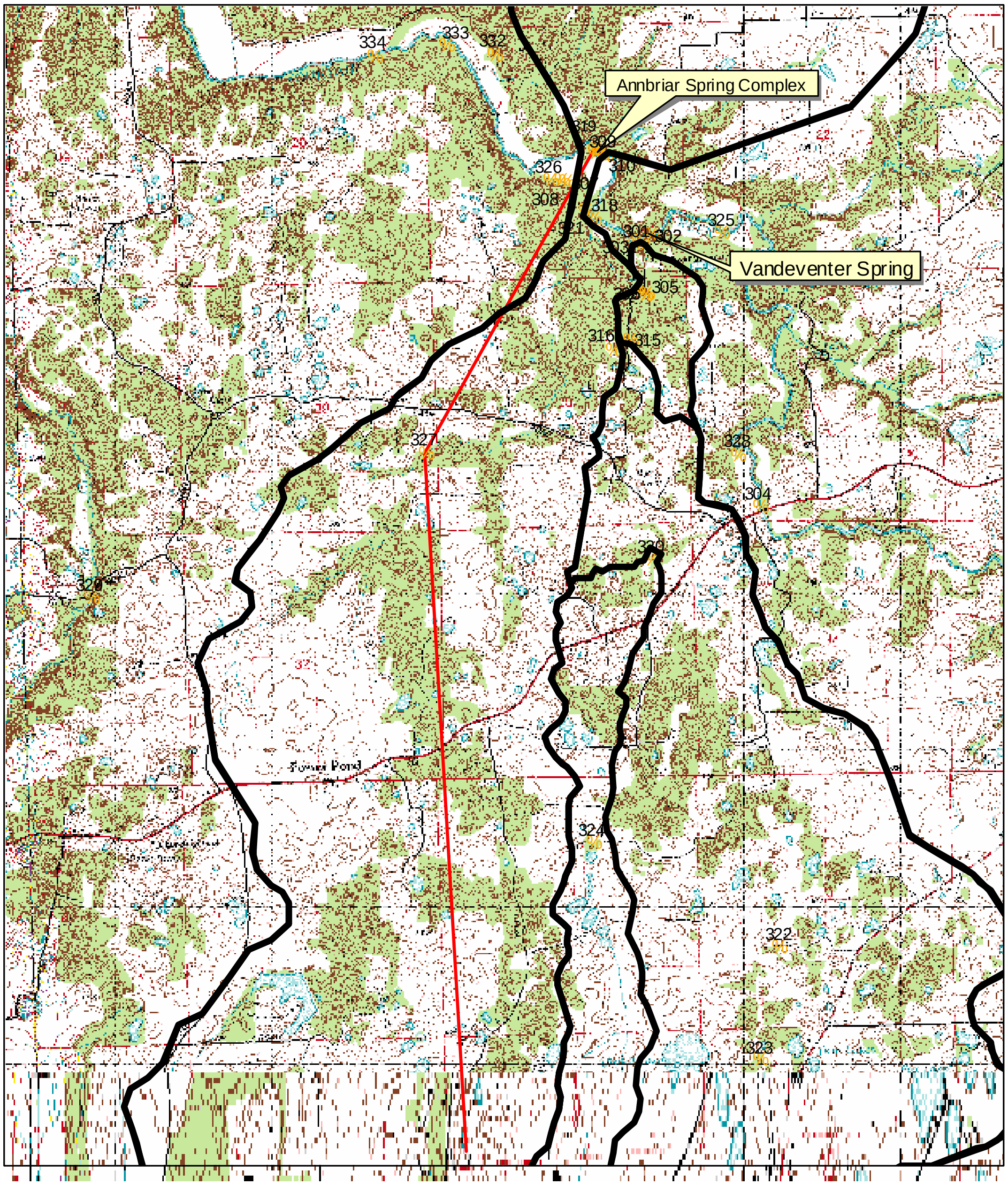


Figure11
Trace 00-308
Laurent Trace

Ozark Underground Laboratory, 2001

4.3.9 Trace 00-309: Woodpecker Trace

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into spring discharge that enters a sinkhole. The dye was introduced at 1905 hours on September 18, 2000 into a flow of approximately two gpm. The elevation of the dye introduction point is approximately 555 feet msl and is in the NE ¼ SW ¼ Section 34 T2S R10W. The dye introduction point can be found on the Waterloo 7.5-minute quadrangle map. The purpose of the trace was to help define the eastern boundary of the Pautler Cave system recharge area.

The stations sampled for this trace were: 301, 303, 305, 306, 307, 308, 310 311, 317, 318, 319, 320, and 321 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-309 are listed below.

Station 302. Fountain Creek upstream of Camp

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
8/28 to 9/18/00	ND	ND
9/18 to 10/2/00	535.1	5.45
10/2/00 (water)	ND	ND
10/2 to 10/17/00	ND	ND

Station 304. Fountain Creek at Route 156

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
8/28 to 9/18/00	ND	ND
9/18 to 10/2/00	537.5	59.6
10/2/00 (water)	531.6	0.224
10/2 to 10/17/00	537.4	10.9
10/17/00 (water)	ND	ND
10/17 to 10/27/00	ND	ND

Station 308. Dual Spring West

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
8/28 to 9/18/00	ND	ND
9/18 to 10/2/00	535.6	0.954
9/18 to 10/2/00 (duplicate)	ND	ND
10/2/00 (water)	ND	ND
10/2 to 10/17/00	ND	ND

Station 310. Fountain Creek upstream Annbriar

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
8/28 to 9/18/00	ND	ND
9/18 to 10/2/00	535.2	2.63
10/2/00 (water)	ND	ND
10/2 to 10/17/00	ND	ND

Station 318. Fountain Creek upstream Sink Point

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
8/28 to 9/18/00	ND	ND
9/18 to 10/2/00	536.1	6.51
10/2/00 (water)	ND	ND
10/2 to 10/17/00	ND	ND

Station 319. Fountain Creek downstream Annbriar

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
8/14 to 8/28/00	ND	ND
8/28 to 10/2/00	536.4	5.75
10/2/00 (water)	ND	ND
10/2 to 10/17/00	ND	ND

Eosine dye from Trace 00-309 was detected at six sampling stations; Fountain Creek upstream of Camp Vandeventer (302), Fountain Creek at Route 156 (304), Dual Spring West (308), Fountain Creek upstream of Annbriar (310), Fountain Creek upstream of sink point (318), and Fountain Creek downstream of Annbriar (319). Dual Spring West derived its dye via Fountain Creek along the flow path demonstrated by Trace 97-11. Fountain Creek at Route 156 is the most upstream detection point along this flow path. The Woodpecker Trace demonstrates that the Woodpecker sink discharges into Fountain Creek upstream of the Route 156 road crossing and does not recharge the Pautler Cave groundwater system.

During the winter of 2000, much of Fountain Creek was frozen. However, there was an unfrozen spot, apparently from spring discharge in Fountain Creek, about 140 feet upstream of the Route 156 bridge. It is this spring where the dye from this trace was likely discharged into Fountain Creek.

The straight-line distance for this trace is approximately 3,640 feet and the elevation loss is approximately 50 feet. The mean gradient is approximately 73 feet per mile. The dye first arrived at Fountain Creek at Route 156 within 14 days after introduction. The mean groundwater velocity under these flow conditions was 260 feet per day.

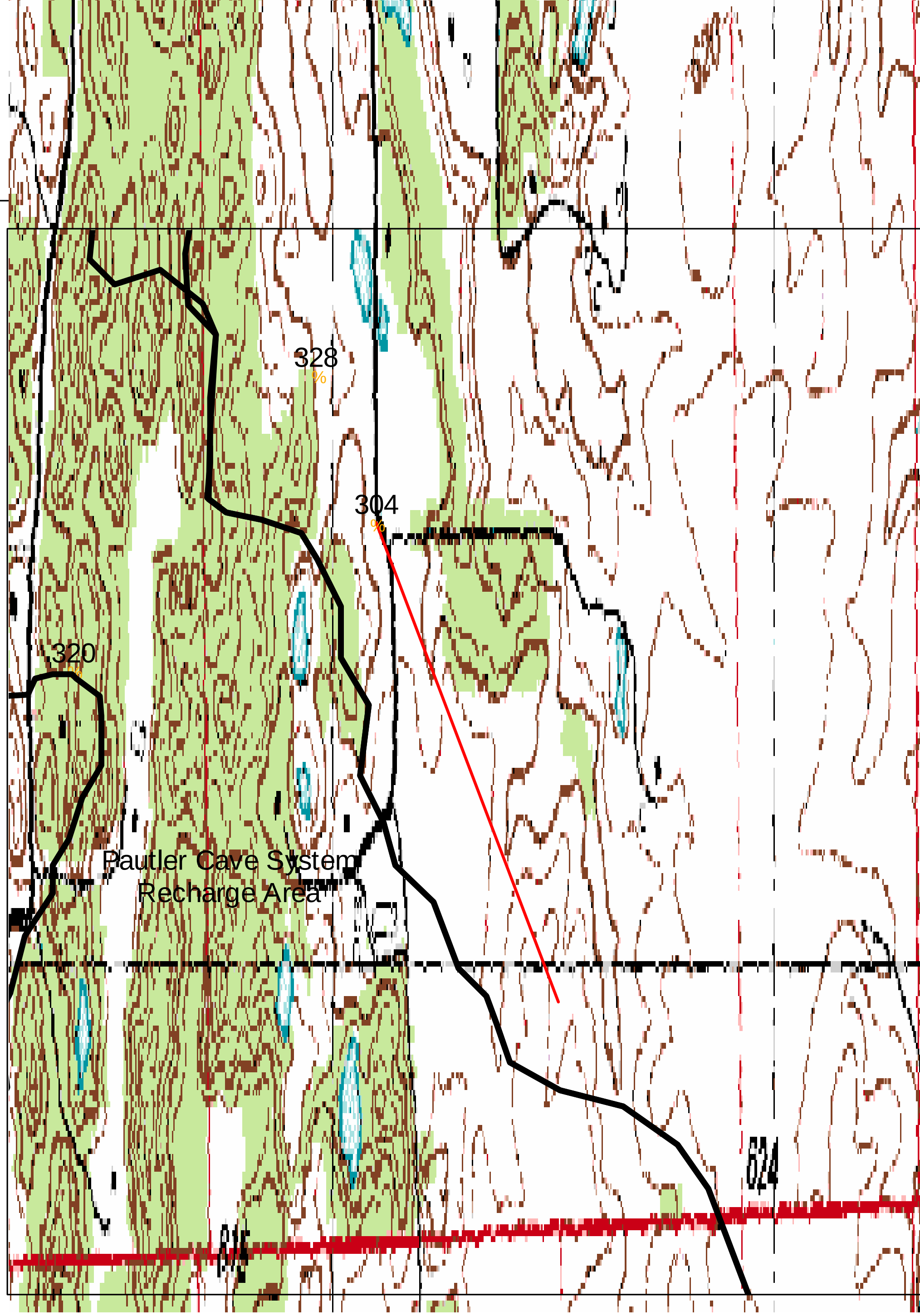


Figure 12
Trace 00-309
Woodpecker Trace

N

0 1000 2000 Feet

Ozark Underground Laboratory, 2001

4.3.10 Trace 00-310: Waddy Trace

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole in the SW ¼ SE ¼ Section 33 T2S R10W at 1721 hours on October 18, 2000. The elevation of the dye introduction point is approximately 595 feet msl. Water was siphoned from a nearby sinkhole pond to introduce the dye. The siphon was started at 1706 hours and was shut off the morning of October 20. The siphon was discharging approximately 1.9 gpm. The purpose of the trace was to help define the boundary between the Annbriar Spring recharge area and that of the Pautler Cave system. The trace can be found on the Waterloo 7.5-minute quadrangle map.

The stations sampled for this trace were: 301, 302, 303. 304, 305, 306, 307, 308, 310, 311, 317, 318, 319, 320, 321, and 324 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-310 are listed below.

Station 301. Vandeventer Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
10/2 to 10/17/00	ND	ND
10/17/00 (water)	ND	ND
10/17 to 10/27/00	562.7	13.2
10/27/00 (water)	569.6	0.062
10/27 to 11/1/00	ND	ND

Station 305. Vandeventer Karst Window

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
10/2 to 10/17/00	ND	ND
10/17/00 (water)	ND	ND
10/17 to 10/27/00	562.5	11.1
10/27/00 (water)	569.6	0.225
10/27 to 11/1/00	ND	ND

Station 320. Pautler Cave

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
8/28 to 10/17/00	ND	ND
10/17/00 (water)	ND	ND
10/17 to 10/27/00	563.9	578
10/17 to 10/27/00 (duplicate)	564.5	359
10/27/00 (water)	570.0	0.386
10/27 to 11/23/00	562.6	30.5
11/23/00 (water)	ND	ND
11/23 to 12/28/00	ND	ND

Rhodamine WT dye from the Waddy Trace was detected at three sampling stations. From upstream to downstream they were Pautler Cave, Vandeventer Karst Window, and Vandeventer Spring. All three sampling stations directly sample groundwater. This trace demonstrates that the Waddy sinkhole is in the Pautler Cave Recharge Area. It is notable that no dye from this trace was detected at Ice Box Spring; which is normally a discharge point for waters passing through Vandeventer Karst Window. Ice Box Spring typically has much lower dye concentrations detected than for the same trace at Vandeventer Spring. The concentration detected at Vandeventer Spring was low enough that it is possible that dye traveling through the Ice Box Spring flow path was lost to attenuation and degradation.

The straight-line distance from the Waddy sink to Vandeventer Spring through Pautler Cave and Vandeventer Karst Window is approximately 10,420 feet and the elevation loss is approximately 145 feet. Table 6 (page 107) provides details of dye trace segment lengths, elevation losses, and gradients. Dye from this trace first arrived at Vandeventer Spring between 29 and 39 days after introduction. The mean groundwater velocity under these flow conditions was between 270 and 360 feet per day.

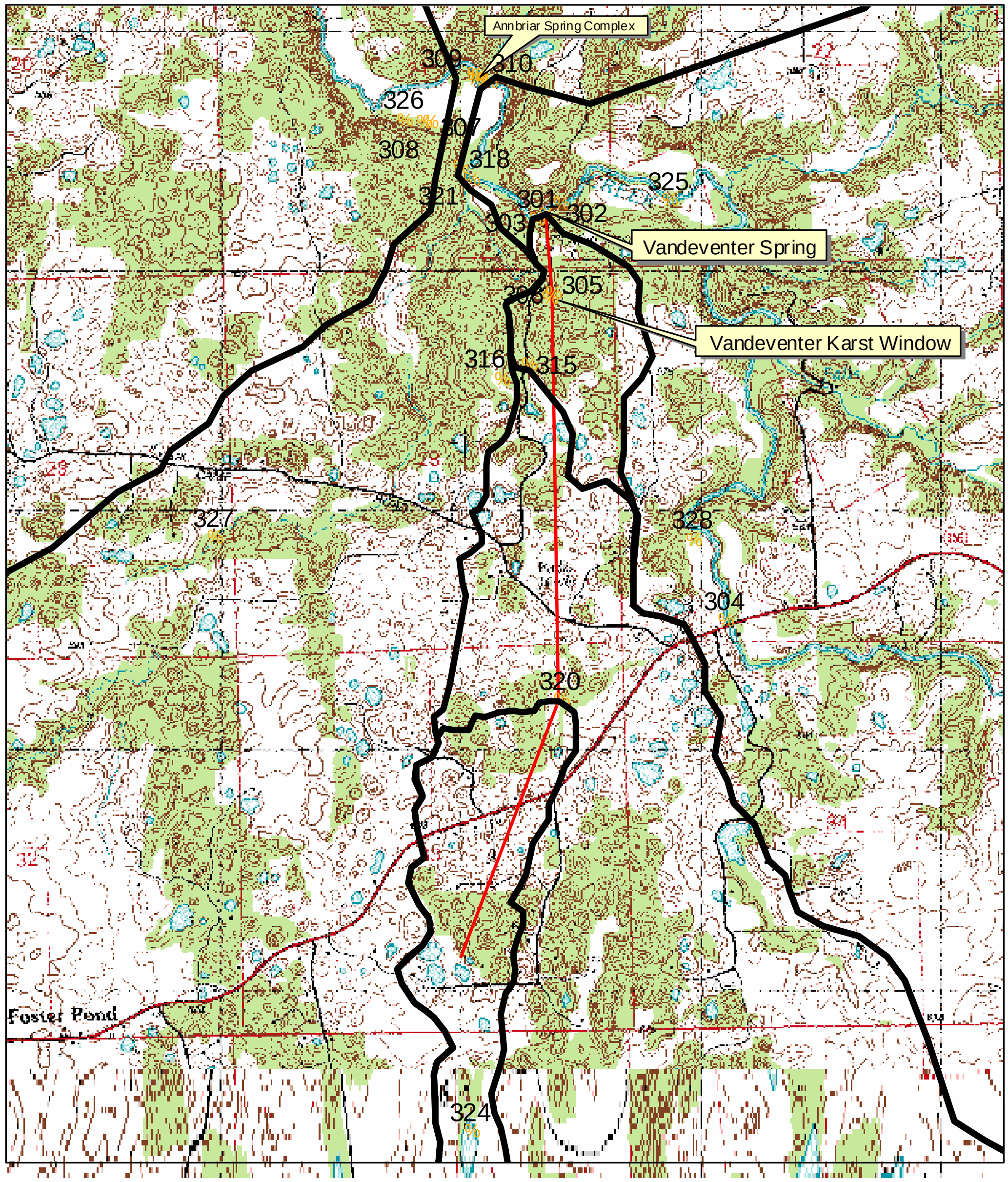


Figure 13
Trace 00-310
Waddy Trace

Ozark Underground Laboratory, 2001

4.3.11 Trace 00-311: Leber Trace

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole in the NW ¼ SE ¼ Section 4 T3S R10W at 1843 hours on October 18, 2000. The elevation of the dye introduction point is approximately 620 feet msl. This sinkhole receives water from a sinking stream that passes through some sinkhole ponds. The dye introduction point had a pool of water about ten feet across and was about four feet deep. Approximately 15 gpm were entering the sinkhole at the time of dye introduction. The purpose of this trace was to help define the boundary between the Annbriar Spring and Pautler Cave system recharge areas.

The stations sampled for this trace were: 301, 302, 303, 304, 305, 306, 307, 308, 310, 311, 317, 318, 319, 320, 321, and 324 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-311 are listed below.

Station 301. Vandeventer Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Fluorescein Dye Concentration (ppb)**
10/2 to 10/17/00	ND	ND
10/17 to 10/27/00	513.7	700
10/27/00 (water)	508.2	1.25
10/27 to 11/1/00	513.6	288
11/1/00 (water)	508.0	1.25
11/1 to 11/23/00	512.8	172
11/23/00 (water)	506.8	0.068
11/23 to 11/28/00	512.3	18.6
11/28/00 (water)	ND	ND
11/28 to 12/28/00	512.6	23.8
12/28/00 (water)	507.0	0.025
12/28/00 to 1/12/01	512.0	21.1
12/28/00 to 1/12/01 (duplicate)	512.3	22.5
1/12/01 (water)	505.6	0.075
1/12 to 2/5/01	512.3	13.8
1/12 to 2/5/01 (duplicate)	512.5	17.4
2/5/01 (water)	504.0 a,s	0.011
2/5 to 2/27/01	512.0	3.12
2/5 to 2/27/01 (duplicate)	511.4	2.91
2/27/00 (water)	ND	ND
2/27 to 3/20/01	511.1	3.06
2/27 to 3/20/01 (duplicate)	511.4	2.50
3/20/00 (water)	ND	ND

Station 303. Ice Box Spring

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
10/17 to 10/27/00	ND	ND
10/27 to 11/23/00	512.6	26.3
11/23/00 (water)	504.4 a,s	0.055
11/23 to 2/5/01	512.1	6.76
2/5/01 (water)	504.4 a,s	0.016

Station 305. Vandeventer Karst Window

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
10/2 to 10/17/00	ND	ND
10/17 to 10/27/00	513.7	805
10/27/00 (water)	507.8	1.16
10/27 to 11/1/00	513.2	371
11/1/00 (water)	508.0	1.11
11/1 to 11/23/00	514.0	204
11/23/00 (water)	507.1	0.070
11/23 to 11/28/00	512.3	17.0
11/28/00 (water)	ND	ND
11/28 to 12/28/00	512.6	25.6
12/28/00 (water)	506.5	0.026
12/28/00 to 1/12/01	512.4	20.4
1/12/01 (water)	505.2 a,s	0.075
1/12 to 2/5/01	512.4	14.7
2/5/01 (water)	504.8 a,s	0.013

Station 308. Dual Spring West

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
10/2 to 10/17/00	ND	ND
10/17 to 10/27/00	512.5	16.3
10/27/00 (water)	507.5	0.240
10/27 to 11/23/00	515.2	8.18
11/23/00 (water)	ND	ND
11/23 to 11/28/00	ND	ND
11/28 to 12/28/00	510.9 s	0.931
12/28/00 (water)	ND	ND
12/28/00 to 1/12/01	511.1	2.19
1/12/01 (water)	ND	ND
1/12 to 2/5/01	ND	ND

Station 310. Fountain Creek upstream of Annbriar Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Fluorescein Dye Concentration (ppb)**
10/2 to 10/17/00	ND	ND
10/17 to 10/27/00	512.6	42.8
10/27/00 (water)	505.6	0.093
10/27 to 11/23/00	514.4	10.8
11/23/00 (water)	ND	ND
11/23 to 11/28/00	510.6 a,s	1.61
11/28/00 (water)	ND	ND
11/28 to 12/28/00	511.2	3.21
12/28/00 (water)	ND	ND
12/28/00 to 1/12/01	511.8	3.90
1/12/01 (water)	ND	ND
1/12 to 2/5/01	512.1	4.41
2/5/01 (water)	ND	ND
2/5 to 2/27/01	ND	ND

Station 311. Fountain Creek at HH Road

Sampling Period	**Peak Emission Wavelength (nm)**	**Fluorescein Dye Concentration (ppb)**
10/3 to 10/17/00	ND	ND
10/17 to 10/27/00	511.1	7.57
10/27/00 (water)	506.0	0.167
10/27 to 11/22/00	512.0	5.33
11/22/00 (water)	ND	ND
11/22 to 12/16/00	ND	ND

Station 318. Fountain Creek upstream of sink point

Sampling Period	**Peak Emission Wavelength (nm)**	**Fluorescein Dye Concentration (ppb)**
10/2 to 10/17/00	ND	ND
10/17 to 10/27/00	512.9	48.4
10/27/00 (water)	507.4	0.187
10/27 to 11/23/00	512.8	13.0
11/23/00 (water)	ND	ND
11/23 to 11/28/00	510.7 s	2.05
11/28/00 (water)	ND	ND
11/28 to 12/28/00	511.4	3.21
12/28/00 (water)	ND	ND
12/28/00 to 1/12/01	511.6	4.51
1/12/01 (water)	504.4 a,s	0.015
1/12 to 2/5/01	511.8	4.06
2/5/01 (water)	ND	ND
2/5 to 2/27/01	ND	ND

Station 319. Fountain Creek downstream of Annbriar Spring *

Sampling Period	**Peak Emission Wavelength (nm)**	**Fluorescein Dye Concentration (ppb)**
10/17 to 10/27/00	512.6	17.9
10/27/00 (water)	505.6	0.057
10/27 to 11/23/00	513.0	8.88
11/23/00 (water)	ND	ND
11/23 to 11/28/00	510.9 s	2.16
11/28/00 (water)	ND	ND
11/28 to 12/28/00	511.3	3.10
11/28 to 12/28/00 (duplicate)	511.2	2.70
12/28/00 (water)	ND	ND
12/28/00 to 1/12/01	ND	ND
1/12/01 (water)	ND	ND
1/12 to 2/5/01	512.0	4.49
2/5/01 (water)	ND	ND

* This station, prior to the sampling periods presented in this table, was positive for fluorescein dye from Trace 00-308.

Station 320. Pautler Cave

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
8/28 to 10/17/00	ND	ND
10/17 to 10/27/00	511.3 s	2.26
10/17 to 10/27/00 (duplicate)	510.8 s	1.71
10/27/00 (water)	ND	ND
10/27 to 11/23/00	ND	ND

Station 324. Chantilly Spring

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
10/19/00 (water)	508.0	1,680
11/1/00 (water)	507.5	25.7
11/1 to 11/22/00	513.2	835
11/22/00 (water)	507.3	0.812
11/22 to 11/27/00	512.0	38.2
11/27/00 (water)	ND	ND
11/27 to 12/16/00	512.5	20.5
12/16/00 (water)	504.0 a,s	0.083
12/16 to 12/28/00	512.6	14.6
12/28/00 (water)	507.0	0.234
12/28/00 to 1/12/01	512.5	28.1
1/12/01 (water)	505.2 a,s	0.060
1/12 to 2/6/01	512.2	12.7
2/6/01 (water)	503.6 a,s	0.030
2/6 to 2/26/01	512.5	10.3
2/26/01 (water)	ND	ND
2/26 to 3/20/01	511.8	7.53
3/20/01 (water)	ND	ND

Fluorescein dye from the Leber Trace was detected at ten sampling stations. From upstream to downstream, they are: Chantilly Spring (324), Pautler Cave (320), Vandeventer Karst Window (305), Vandeventer Spring (301) and Ice Box Spring (303), Fountain Creek upstream of sink point (318), Dual Spring West (308) and Fountain Creek upstream of Annbriar Spring (310), Fountain Creek downstream of Annbriar Spring (319), and Fountain Creek at HH Road (311). The first five stations directly sample the groundwater flow path of this trace. Dual Spring derived its dye via Fountain Creek along the flow path demonstrated by Trace 97-11. The detection of this dye in Pautler Cave demonstrates that the sinking stream tested by the Leber Trace contributes water to the proposed Pautler Cave Nature Preserve and lies within the Pautler Cave System Recharge Area. However, a comparison of dye concentrations between the three downstream, groundwater sampling stations and that of Pautler Cave indicates that the majority of the dye did not pass through Pautler Cave under these flow conditions. The data indicate that there are two flow routes and the route through Pautler Cave is the minor route under these flow conditions. For clarity, a single flow path passing through Pautler Cave is shown on Figure 14.

OUL was not aware of Chantilly Spring until Mr. Ray Leber told us about it at the time he gave us permission to start a dye trace on his property. At that time, OUL added Chantilly Spring to the sampling routine.

The straight-line distance from the Leber sinking stream to Chantilly Spring is approximately 1,360 feet. The elevation loss is approximately 10 feet and the mean gradient is approximately 39 feet per mile. The details of dye trace segment lengths, elevation losses, and gradients can be found in Table 6 (page 107).

The dye first arrived at Vandeventer Spring between 29 and 39 days after introduction. The mean groundwater velocity under these flow conditions was between 360 and 480 feet per day.

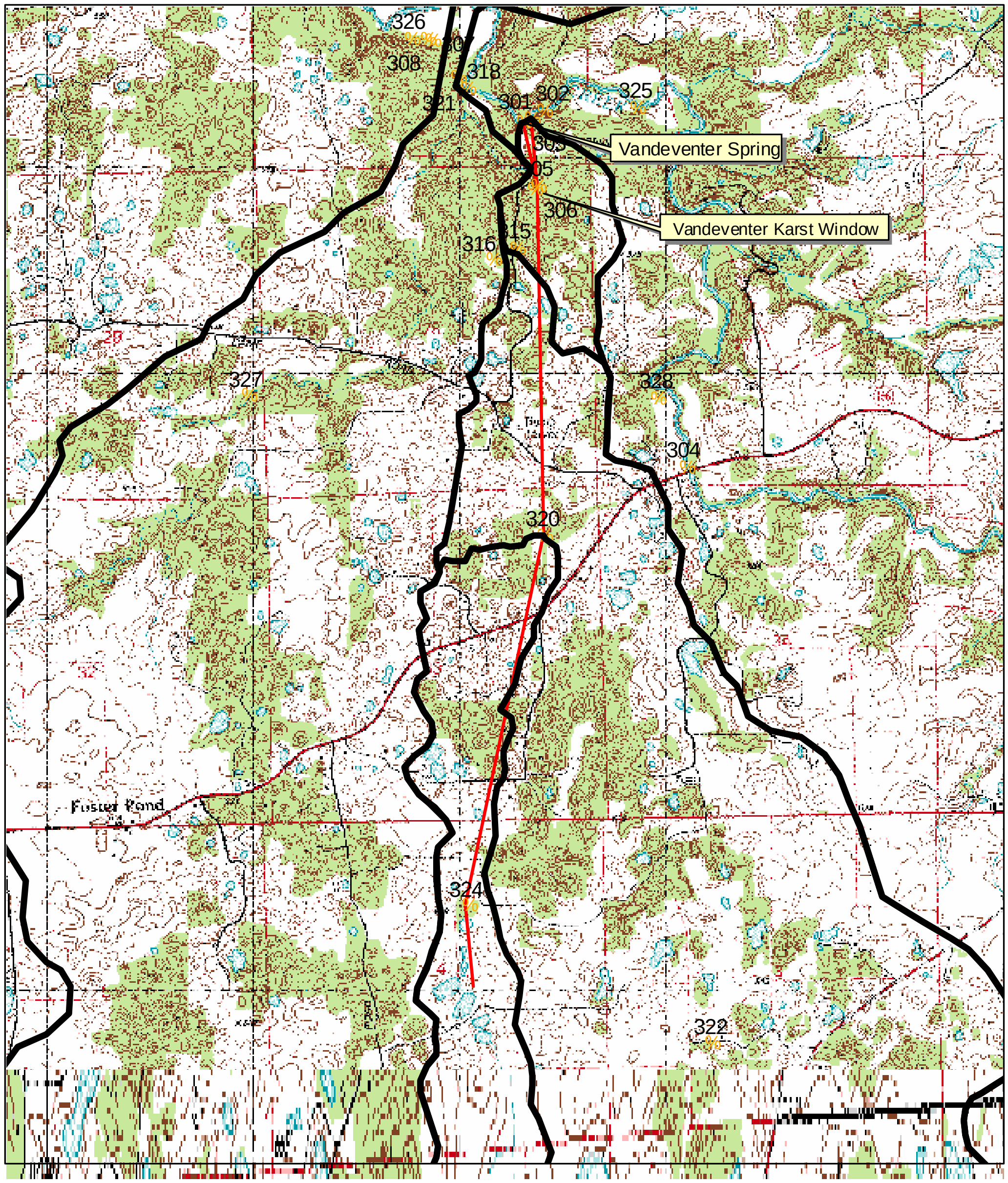


Figure 14
Trace 00-311
Leber Trace

N

0 3000 6000 Feet

Ozark Underground Laboratory, 2001

4.3.12 Trace 00-312: Pautler Trace

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into the Pautler Cave stream at 1909 hours on October 27, 2000. The elevation of the dye introduction point is approximately 530 feet and is located in the NE ¼ NE ¼ Section 33 T2S R10W. At the time of dye introduction, the flow was approximately 10 gpm. The dye introduction point can be found on the Waterloo 7.5-minute quadrangle map. The purpose of the trace was to demonstrate that Vandeventer Spring is the main discharge point for the Pautler Cave system.

The stations sampled for this trace were: 301, 302, 303, 305, 306, 307, 308, 310, 311, 318, 319, and 321 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-312 are listed below.

Station 301. Vandeventer Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Eosine Dye Concentration (ppb)**
10/17 to 10/27/00	ND	ND
10/27 to 11/1/00	538.2	4,970
11/1/00 (water)	532.6	74.9
11/1 to 11/23/00	538.2	2,430
11/23/00 (water)	ND	ND
11/23 to 11/28/00	535.6	3.79
11/28/00 (water)	ND	ND
11/28 to 12/28/00	536.0	5.25
12/28/00 (water)	ND	ND
12/28/00 to 1/12/01	ND	ND

Station 303. Ice Box Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Eosine Dye Concentration (ppb)**
10/17 to 10/27/00	ND	ND
10/27 to 11/23/00	536.8	5.64
11/23/00 (water)	ND	ND
11/23/00 to 2/5/01	536.0	2.42
2/5/01 (water)	ND	ND

Station 305. Vandeventer Karst Window

Sampling Period	**Peak Emission Wavelength (nm)**	**Eosine Dye Concentration (ppb)**
10/17 to 10/27/00	ND	ND
10/27 to 11/1/00	538.2	5,790
11/1/00 (water)	532.5	63.0
11/1 to 11/23/00	538.2	2,290
11/23/00 (water)	ND	ND
11/23 to 11/28/00	536.0	2.89
11/28/00 (water)	ND	ND
11/28 to 12/28/00	536.0	5.39
12/28/00 (water)	ND	ND
12/28/00 to 1/12/01	ND	ND

Station 308. Dual Spring West

Sampling Period	**Peak Emission Wavelength (nm)**	**Eosine Dye Concentration (ppb)**
10/17 to 10/27/00	ND	ND
10/27 to 11/23/00	537.9	75.2
11/23/00 (water)	ND	ND
11/23 to 11/28/00	ND	ND

Station 310. Fountain Creek upstream of Annbriar Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Eosine Dye Concentration (ppb)**
10/17 to 10/27/00	ND	ND
10/27 to 11/23/00	538.2	125
11/23/00 (water)	ND	ND
11/23 to 11/28/00	ND	ND

Station 311. Fountain Creek at HH Road

Sampling Period	**Peak Emission Wavelength (nm)**	**Eosine Dye Concentration (ppb)**
10/17 to 10/27/00	ND	ND
10/27 to 11/22/00	535.6	4.37
11/22/00 (water)	ND	ND
11/22 to 12/16/00	ND	ND

Station 318. Fountain Creek upstream of sink point

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
10/17 to 10/27/00	ND	ND
10/27 to 11/23/00	538.5	246
11/23/00 (water)	ND	ND
11/23 to 11/28/00	ND	ND

Station 319. Fountain Creek downstream Annbriar

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
10/17 to 10/27/00	ND	ND
10/27 to 11/23/00	537.0	23.5
11/23/00 (water)	ND	ND
11/23 to 11/28/00	ND	ND

Eosine dye from the Pautler Trace was detected at eight sampling stations. They were: Vandeventer Spring (301), Ice Box Spring (303), Vandeventer Karst Window (305), Dual Spring West (308), Fountain Creek upstream of Annbriar Spring (310), Fountain Creek at HH Road (311), Fountain Creek upstream of sink point (318), and Fountain Creek downstream of Annbriar (319). Only the first three sampling stations directly sample groundwater. Dual Spring West derived its dye via Fountain Creek along the flow path demonstrated by Trace 97-11. The other sampling stations also derive their dye from Vandeventer and Ice Box Springs via Fountain Creek. This trace demonstrates that under these flow conditions that the stream in Pautler Cave only discharges from Vandeventer and Ice Box Springs. It also demonstrates that any land recharging these springs is part of the Pautler Cave System Recharge Area.

The straight-line distance from Pautler Cave to Vandeventer Spring is approximately 7,060 feet. The elevation loss is approximately 95 feet and the mean gradient is approximately 71 feet per mile. The dye trace segment lengths, elevation losses, and gradients can be found in Table 6 (page 107). The dye first arrived at Vandeventer Spring within four days of introduction. The mean velocity under these flow conditions was between 1,770 feet and 7,000 feet per day.

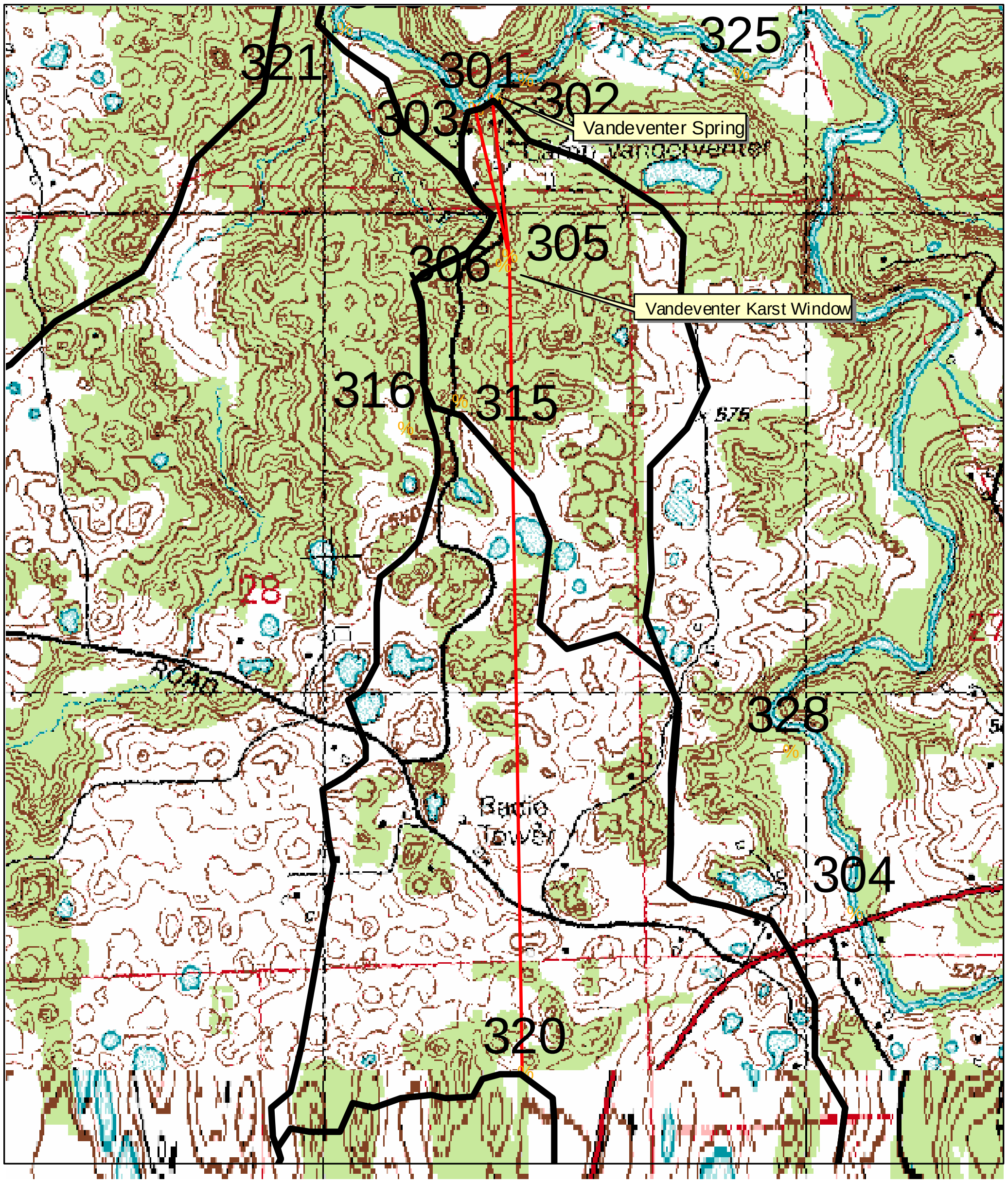


Figure 15
Trace 00-312
Pautler Trace

Ozark Underground Laboratory, 2001

4.3.13 Trace 00-313: Benitone Trace

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole at 1022 hours on November 1, 2000. The elevation of the dye introduction point is approximately 540 feet msl and is in the NW ¼ SW ¼ Section 27 T2S R10W. The dye was introduced using potable water hauled by truck to the sinkhole. The water was discharged 1015 to 1025 hours and a total of 2,500 gallons were discharged to the sink. The dye introduction point can be found on the Waterloo 7.5-minute quadrangle map. The purpose of the dye introduction was to help define the eastern boundary of the Pautler Cave system recharge area.

The stations sampled for this trace were: 301, 302, 303, 305, 306, 307, 308, 310, 311, 318, 319, 321, 325, and 328 (Table 1, page 17).

Data on the dye recovery location for Trace 00-313 is listed below.

Station 302. Fountain Creek upstream of Camp

Sampling Period	**Peak Emission Wavelength (nm)**	**Rhodamine WT Dye Concentration (ppb)**
10/17 to 10/27/00	ND	ND
10/27 to 11/23/00	562.3	10.3
11/23/00 (water)	ND	ND
11/23 to 11/28/00	ND	ND

Rhodamine WT dye from the Benitone Trace was only detected at one sampling point; Fountain Creek upstream of Camp (Vandeventer). This trace demonstrates that the Benitone sink lies outside the Pautler Cave System Recharge Area. The implication of this result is that there was an unsampled spring between Fountain Creek at Route 156 (Station 304) and Fountain Creek upstream of Camp (Station 302). Two springs (Orange and Culvert Springs) on this section of Fountain Creek were added to the sampling routine for this trace, but dye was not detected at either of them.

Figure 16 shows a diagrammatic flow path of the trace. The line representing the trace has been drawn to curve around the Pautler Cave System Recharge Area. The trace probably flowed east to Fountain Creek and it is highly unlikely that it crossed the Pautler Cave System Recharge Area boundary.

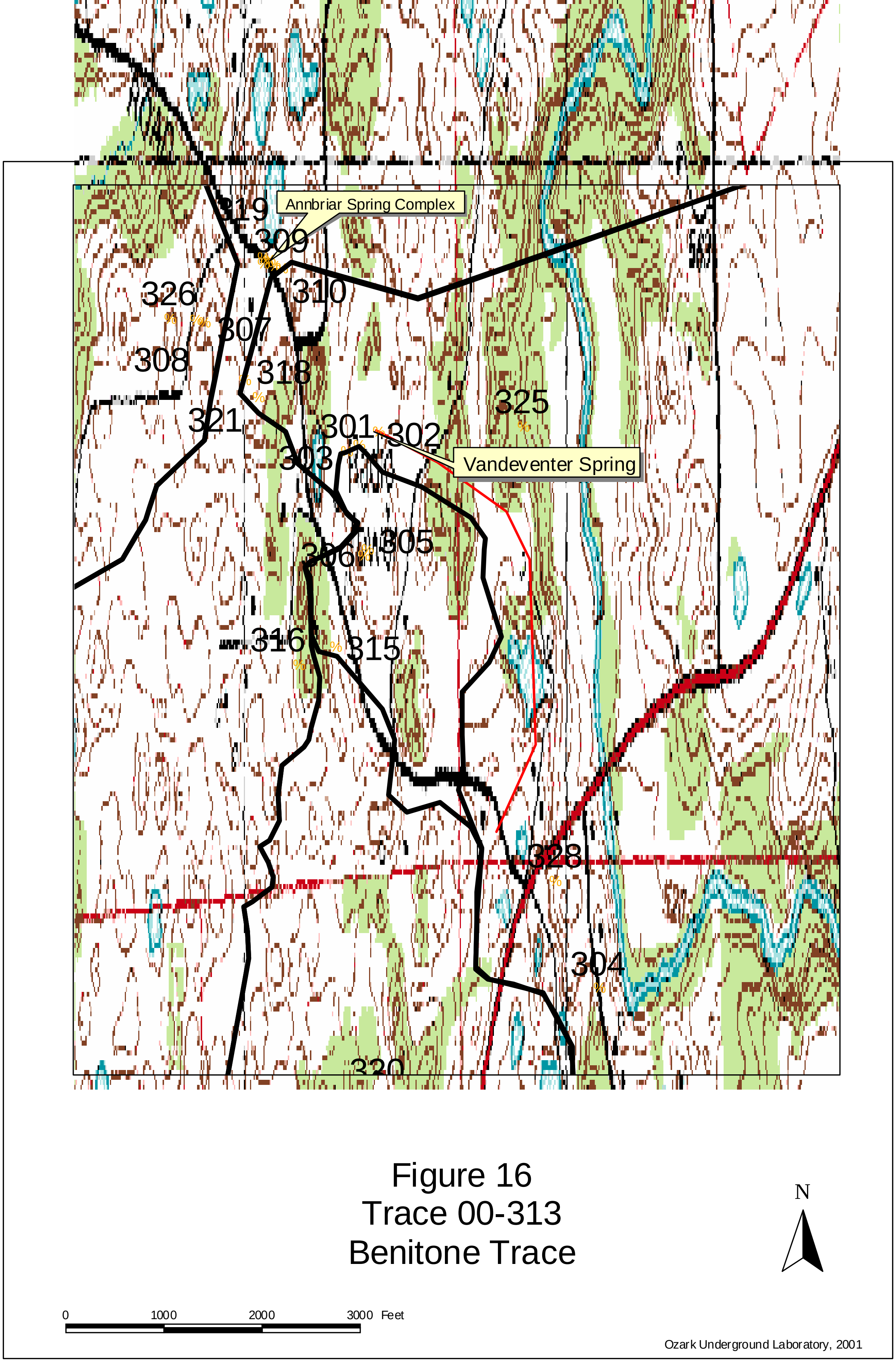


Figure 16
Trace 00-313
Benitone Trace

4.3.14 Trace 00-314: Stumpf Trace

One pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1300 hours on November 25, 2000. The elevation of the dye introduction point is approximately 640 feet msl and is in the NW ¼ SW ¼ Section 31 T2S R10W. There was approximately 75 gpm of storm runoff entering the sinkhole, chiefly through a field tile from an adjacent sinkhole. The dye introduction point can be found on the Waterloo 7.5-minute quadrangle map. The purpose of the trace was to help define the eastern boundary of the Annbriar Spring groundwater system.

The stations sampled for this trace were: 319, 321, 326, 327, 329, 330, 331, 333, 334, and 335 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-314 are listed below.

Station 329. Frog Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Sulforhodamine B Dye Concentration (ppb)**
11/22/00 (water)	ND	ND
11/26/00 (water)	577.7	222
11/22 to 11/27/00	575.2	134
11/27/00 (water)	575.9 a	2.92
11/27 to 12/28/00	574.1	62.9
12/28/00 (water)	ND	ND
12/28/00 to 1/12/01	573.8	11.5
1/12/01 (water)	ND	ND
1/12 to 2/6/01	573.2	2.61
2/6/01 (water)	ND	ND

Station 331. Bond Creek at HH Road

Sampling Period	**Peak Emission Wavelength (nm)**	**Sulforhodamine B Dye Concentration (ppb)**
11/22/00 (water)	ND	ND
11/22 to 12/16/00	574.4	13.4
12/16/00 (water)	ND	ND
12/16/00 to 1/12/01	575.2	1.07
1/12 to 2/6/01	ND	ND

Station 335. Bond Creek upstream of Schnellbecher Spring

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
11/26/00 (water)	ND	ND
11/26 to 12/16/00	575.3	88.8
12/16/00 (water)	ND	ND

Sulforhodamine B dye from the Stumpf Trace was detected at three sampling stations. From upstream to downstream they were: Frog Spring (329), Bond Creek upstream of Schnellbecher Spring (335), and Bond Creek at HH Road (331). Only Frog Spring directly samples groundwater and the other two stations derived their dye from Frog Spring.

This is the first groundwater trace to be detected at Frog Spring and demonstrates that the Stumpf sinkhole lies within the Frog Spring Recharge Area. Frog Spring is an important spring since its groundwater system provides habitat for the Illinois Cave Amphipod (Lewis et al., 1999). It is also a relatively large spring with a base flow discharge of approximately 316 gpm (Aley and Aley, 1998). This discharge is comparable with that of the Krueger – Dry Run Cave System (Aley et al., 2000)

Mr. Louis Stumpf informed OUL that a drain tile connects the next sinkhole to the north-northeast with the one in which dye was introduced. The bottom of the tiled sinkhole is about 900 feet away from the dye introduction point. In fact, much of the water entering the groundwater system at the time of dye introduction was being discharged from the drain tile. This information requires inclusion of that sinkhole in the Frog Spring Recharge Area.

The straight-line distance from the Stumpf sink to Frog Spring is approximately 2,730 feet. The elevation loss is approximately 140 feet and the mean gradient is approximately 271 feet per mile. Dye first arrived at Frog Spring within 20 hours. The mean groundwater velocity under these flow conditions is at least 3,300 feet per day.

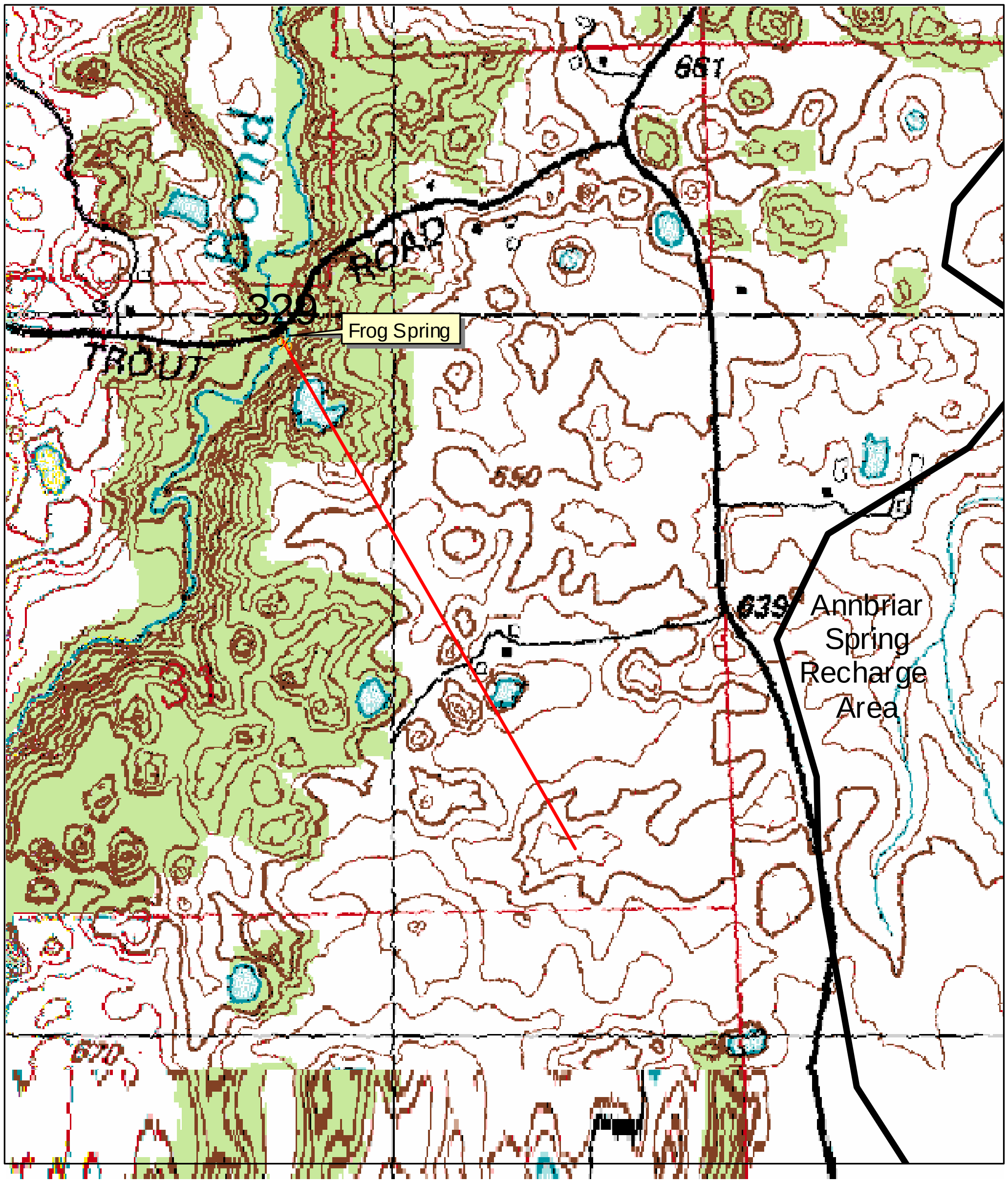


Figure 17
Trace 00-314
Stumpf Trace

N

0 500 1000 1500 Feet

Ozark Underground Laboratory, 2001

4.3.15 Trace 00-315: Acorns Pond #6 Trace

One-half pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole at 1325 hours on December 28, 2000. The elevation of the dye introduction point is approximately 630 feet msl and is in the SW ¼ SW ¼ Section 3 T3S R10W. There were approximately 25 gpm entering the groundwater system at the time of dye introduction. This trace was done at the request of Bill Ebeler (owner of Acorns Golf Course), who wanted to know if this pond leaked to the karst window that is being sampled by Station 322, Acorns Pond #6. This trace is included in this report for completeness. The dye introduction point can be found on the Waterloo 7.5-minute quadrangle map.

The stations sampled for this trace were: 301, 303, 305, 322, and 323 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-315 are listed below.

Station 301. Vandeventer Spring

Sampling Period	**Peak Emission Wavelength (nm)**	**Rhodamine WT Dye Concentration (ppb)**
11/28 to 12/28/00	ND	ND
12/28/00 to 1/12/01	564.8	755
12/28/00 to 1/12/01 (duplicate)	565.1	914
1/12/01 (water)	ND	ND
1/12 to 2/5/01	567.2	1.67
1/12 to 2/5/01 (duplicate)	566.4	1.22
2/5/01 (water)	ND	ND
2/5 to 2/27/01	ND	ND

Station 305. Vandeventer Karst Window

Sampling Period	**Peak Emission Wavelength (nm)**	**Rhodamine WT Dye Concentration (ppb)**
11/28 to 12/28/00	ND	ND
12/28/00 to 1/12/01	564.5	665
1/12/01 (water)	ND	ND
1/12 to 2/5/01	ND	ND

Station 308. Dual Spring West

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
11/28 to 12/28/00	ND	ND
12/28/00 to 1/12/01	563.0	13.0
1/12/01 (water)	ND	ND
1/12 to 2/5/01	ND	ND

Station 310. Fountain Creek upstream Annbriar Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
11/28 to 12/28/00	ND	ND
12/28/00 to 1/12/01	563.1	22.6
1/12/01 (water)	ND	ND
1/12 to 2/5/01	ND	ND

Station 318. Fountain Creek upstream of sink point

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
11/28 to 12/28/00	ND	ND
12/28/00 to 1/12/01	563.1	24.5
1/12/01 (water)	ND	ND
1/12 to 2/5/01	ND	ND

Station 322. Acorns Pond #6

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
10/17 to 10/27	ND	ND
10/27 to 12/28/00	NS	
12/28/00 to 1/11/01	562.5	9,190
1/11/01 (water)	572.0	0.124
1/11 to 2/6/01	564.8	19.7

Rhodamine WT dye from the Acorns Pond #6 Trace was detected at six sampling stations. They were: Vandeventer Spring (301), Vandeventer Karst Window (305), Dual Spring West (308), Fountain Creek upstream of Annbriar Spring (310), Fountain Creek upstream of sink point (318), and Acorns Pond #6 (322). Stations 301, 305, and 322 sampled the groundwater flow path directly. The other sampling stations derived their dye from Vandeventer Spring. Dual Spring West derived its dye via Fountain Creek along the flow path demonstrated by Trace 97-11. These data demonstrate that Acorns Pond #6 overflow lies within the Pautler Cave System Recharge Area. Further, it demonstrates that the pond overflow drains to the Haegle karst window (sampled as Acorns Pond #6) along the flow path to Vandeventer Spring.

Dye concentrations may have been affected by some recirculation of the dye during this trace. Acorns Pond #6 was leaking and was being kept full by water pumped from Haegle karst window (Bill Ebeler, personal communication, 2000). At high flow, the pond overflows into the dye introduction sink. Both pond leakage and overflow would allow dye to recirculate between the karst window and the pond while the karst window was being pumped.

It is notable that under these flow conditions that no dye was detected at Ice Box Spring. However, on January 12, the sampler was not exposed to liquid water at Ice Box Spring since the samplers were encapsulated in an ice mass. Only ice was observed at that time so no water sample could be collected. Sampling at Ice Box Spring was discontinued after February 5, 2001. It is possible that dye from this trace was discharged from Ice Box Spring after sampling was discontinued.

The straight-line distance from the dye introduction point to Vandeventer Spring is approximately 16,080 feet. The elevation loss is approximately 185 feet and the mean gradient is approximately 61 feet per mile. Dye first arrived at Vandeventer Spring within 15 days of introduction. The mean groundwater velocity under these flow conditions was at least 1,100 feet per day.

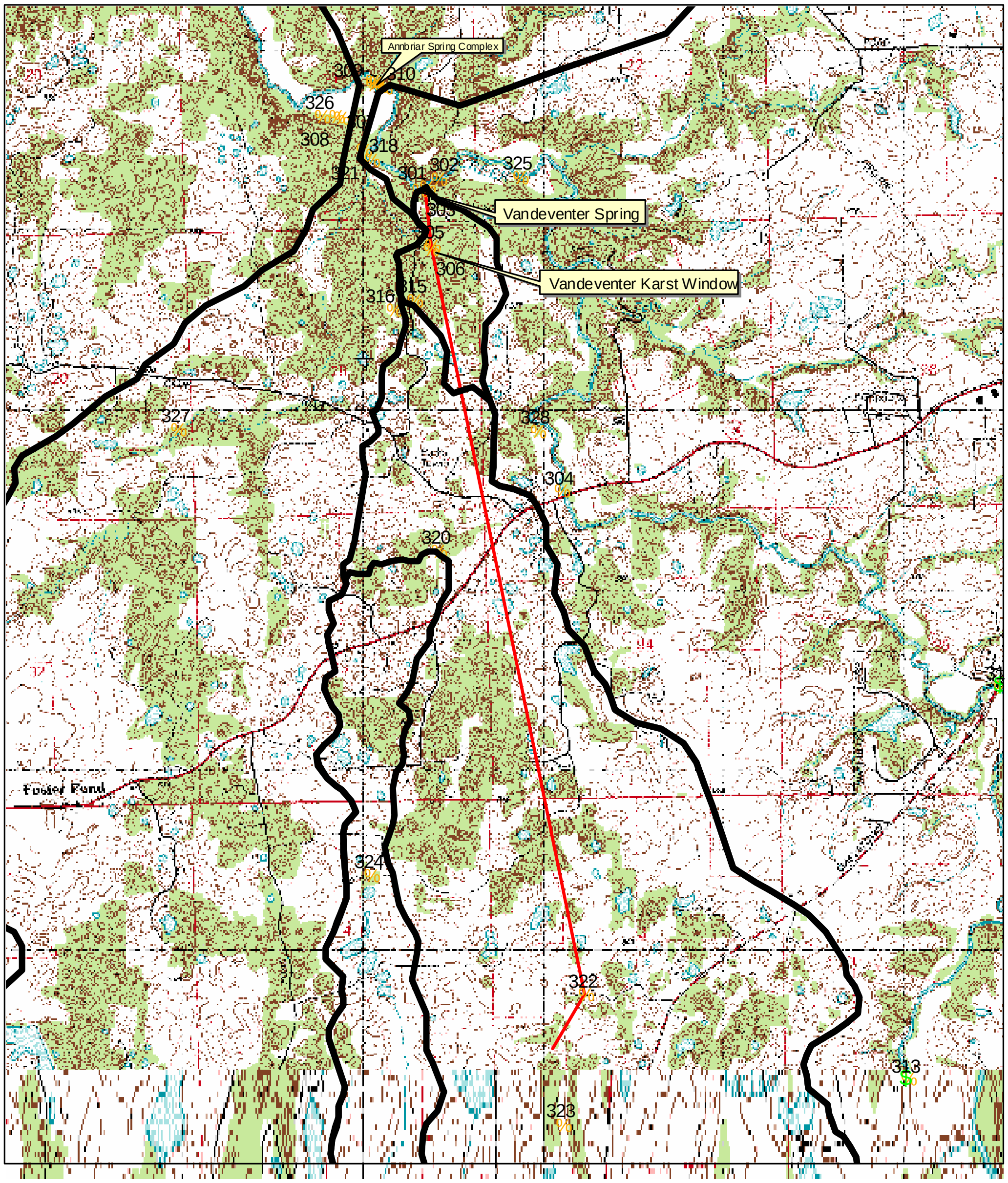
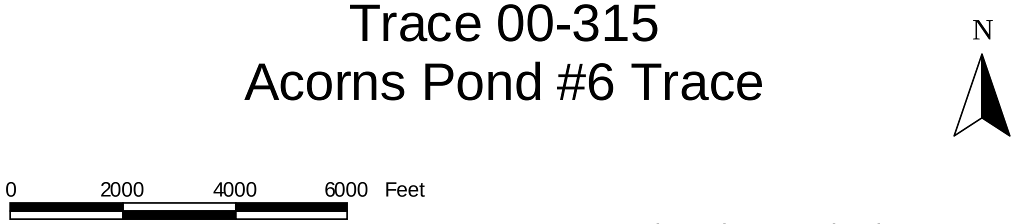


Figure 18
Trace 00-315
Acorns Pond #6 Trace



Ozark Underground Laboratory, 2001

4.3.16 Trace 00-316: Chantilly Trace

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1400 hours on December 28, 2000. The elevation of the dye introduction point is approximately 620 feet msl and is in the NE ¼ SW ¼ Section 4 T3S R10W. The flow at the time of dye introduction was approximately 40 gpm. The purpose of this dye trace was to help define the recharge area boundary between the Annbriar Spring recharge area and the Pautler Cave recharge area. The dye introduction point can be found on the Waterloo 7.5-minute quadrangle map.

The stations sampled for this trace were: 301, 303, 305, 307, 308, 310, 319, 320, 324, 326, 327, and 332 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-316 are listed below.

Station 311. Fountain Creek at HH Road

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
11/22 to 12/16/01	ND	ND
12/16/00 to 1/12/01	536.0	26.5
1/12/01 (water)	534.4	0.040
1/12 to 2/6/01	539.6	1.47
2/6/01 (water)	ND	ND
2/6 to 2/26/01	ND	ND

Station 319. Fountain Creek downstream of Annbriar Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
11/28 to 12/28/00	ND	ND
12/28/00 to 1/12/01	537.7	926
1/12/01 (water)	530.7	0.219
1/12 to 2/5/01	536.4	2.35
2/5/01 (water)	ND	ND

Station 327. Reverse Stream

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
11/27 to 12/28/00	ND	ND
12/28/00 to 1/12/01	537.7	2,170
1/12/01 (water)	531.7	0.172
1/12 to 2/6/01	536.0	6.30
2/6/01 (water)	ND	ND

Station 332. Antler Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
11/22 to 12/16/00	ND	ND
12/16/00 to 2/6/01	537.4	91.0
2/6/00 (water)	ND	ND
2/6 to 6/5/00	ND	ND

Eosine dye from the Chantilly Trace was detected at four sampling stations; Fountain Creek at HH Road (311), Fountain Creek downstream of Annbriar Spring (319), Reverse Stream (327), and Antler Spring (332). The non-detection of eosine dye at Fountain Creek upstream of Annbriar Spring (310) demonstrates that the dye was discharged from the Annbriar Spring Complex. That in turn, demonstrates that the Chantilly sink lies within the Annbriar Spring Recharge Area. It is worth noting that the only connection between Chantilly Spring and the Chantilly Trace dye introduction point is that they are both located in a subdivision called Chantilly Village.

Antler Spring is on the north side of Fountain Creek. All dye introductions for this study were on the south side of Fountain Creek. Some previous dye introductions were on the north side of Fountain Creek. Stations were added to the sampling routine when the contract was extended at the end of November 2000 to include the Annbriar Spring delineation. Antler Spring was added to the sampling routine based on previous investigations (Aley and Aley, 1998) that showed that Annbriar Spring is recharged from both sides of Fountain Creek. It is unclear from these data whether Antler Spring received dye from flow under Fountain Creek or whether Antler Spring is recharged by water leaking out of Fountain Creek. Suggested additional studies are discussed in Section 4.5.

The straight-line distance from the Chantilly sink to Annbriar Spring is approximately 17,140 feet. The elevation loss is approximately 180 feet and the mean gradient is approximately 55 feet. Dye first arrived at Annbriar Spring within 15 days of dye introduction. The mean groundwater velocity under these flow conditions was 1,150 feet per day.

If there were a flow path to Antler Spring under Fountain Creek, the straight-line distance from Chantilly sink to Antler Spring would be approximately 18,420 feet, the elevation loss approximately 180 feet, and the mean gradient approximately 52 feet per mile.

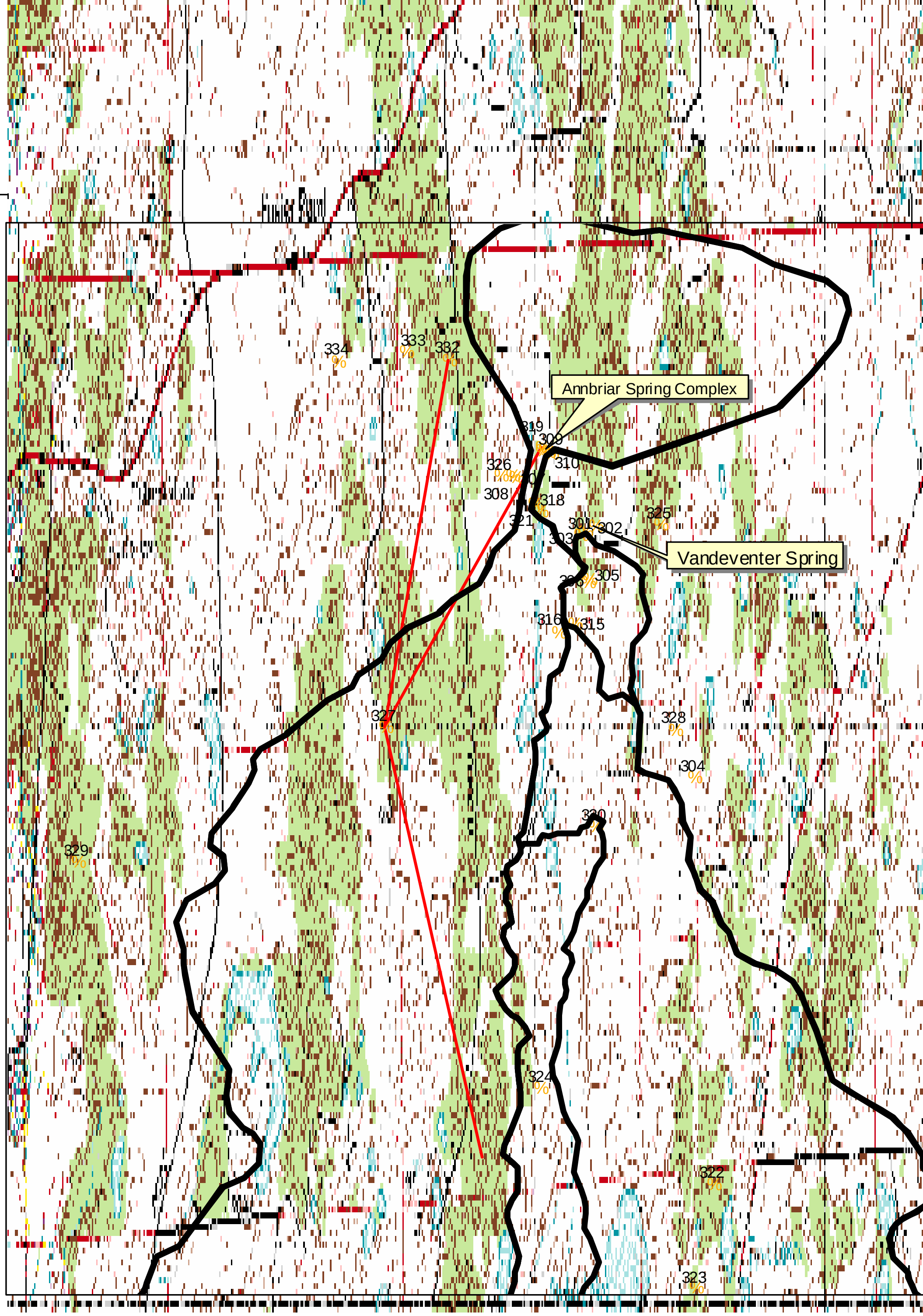


Figure 19
Trace 00-316
Chantilly Trace

0 2000 4000 6000 Feet

N

Ozark Underground Laboratory, 2001

4.3.17 Trace 00-317: Pumphouse Trace

One-half pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1445 hours on December 28, 2000. The elevation of the dye introduction point is approximately 500 feet msl and is in the SW ¼ NW ¼ Section 21 T2S R10W. The flow at the time of dye introduction was approximately 15 gpm. The purpose of this dye trace was to help define the boundary between the Annbriar Spring and nearby groundwater system recharge areas. The dye introduction point can be found on the Waterloo 7.5-minute quadrangle map. The trace appears near the left margin of Figure 20 to show its location relative to Annbriar Spring.

The stations sampled for this trace were: 307, 308, 311, 319, 326, 332, 333, and 334 (Table 1, page 17).

Data on the dye recovery locations for Trace 00-317 are listed below.

Station 311. Fountain Creek at HH Road

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
11/22 to 12/16/00	ND	ND
12/16/00 to 1/12/01	512.9	54.0
1/12/01 (water)	ND	ND
1/12 to 2/6/01	511.1	3.50
2/6/01 (water)	ND	ND
2/6 to 2/26/01	ND	ND

Station 333. Luhr Spring

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
11/22 to 12/16/00	ND	ND
12/16/00 to 1/12/01	513.9	9,910
1/12/01 (water)	507.7	0.406
1/12 to 2/6/01	512.9	48.7
2/6/01 (water)	504.4 a,s	0.014

Fluorescein dye from Trace 00-317, the Pumphouse Trace, was detected at two sampling stations; Fountain Creek at HH Road (311) and Luhr Spring (333). Station 311 derived its dye from Luhr Spring. This trace demonstrates that under these flow conditions Pumphouse sinkhole lies within the Luhr Spring Recharge Area and does not contribute water to Annbriar or Vandeventer Springs.

Luhr Spring has a moderate-sized discharge that was measured under base flow conditions in 1997 at approximately 112 gpm (Aley and Aley, 1998). The Luhr Spring groundwater system is now known to provide habitat for the Illinois Cave Amphipod (Lewis, 2001, personal communication).

The straight-line distance from Pumphouse sink to Luhr Spring is approximately 2,050 feet. The elevation loss is approximately 55 feet and the mean gradient is approximately 142 feet per mile. Dye first arrived at Luhr Spring within 15 days of introduction. The mean groundwater velocity under these flow conditions is at least 150 feet per day.

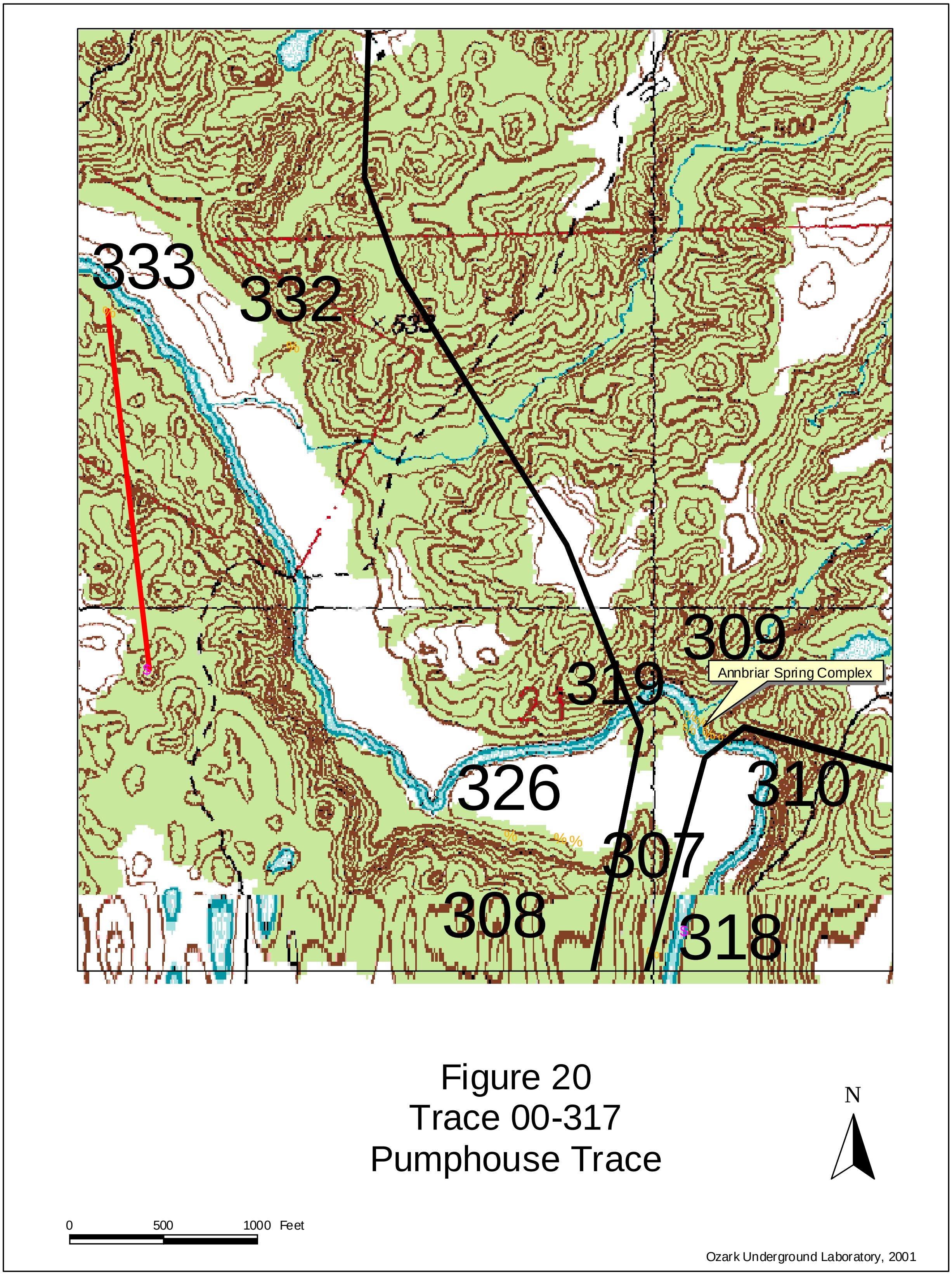


Figure 20
Trace 00-317
Pumphouse Trace

4.3.18 Trace 01-318: Snow White Trace

One-half pound of pyranine dye mixture containing 77% dye and 23% diluent was introduced into a sinkhole at 1628 hours on January 12, 2001. The elevation of the dye introduction point is approximately 480 feet msl and in the NE ¼ NW ¼ Section 18 T2S R10W. The flow at the time of introduction was approximately 25 gpm. The purpose of this trace was to help define the boundary between the Dual Spring and Annbriar Spring recharge areas. The dye introduction point can be found on the Waterloo 7.5-minute quadrangle map.

The stations sampled for this trace were: 307, 308, 310, 311, 317, 318, 319, 326, 332, 333, and 334 (Table 1, page 17).

Data on the dye recovery location for Trace 01-318 is listed below.

Station 308. Dual Spring West

Sampling Period	**Peak Emission Wavelength (nm)**	**Pyranine Dye Concentration (ppb)**
12/28/00 to 1/12/01	ND	ND
1/12 to 2/5/01	502.1	159
2/5/01 (water)	ND	ND
2/5 to 2/27/01	ND	ND

Pyranine dye from Trace 01-318, the Snow White Trace, was detected only at Dual Spring West (308). This trace demonstrates that the Snow White sink lies within the Dual Spring Recharge Area and under these flow conditions does not contribute water to either Annbriar or Vandeventer Springs. This is the first trace that was detected at Dual Spring West that did not pass through Fountain Creek. This trace is especially important since we now know that the Dual Spring groundwater system provides habitat for the Illinois Cave Amphipod (Lewis, 2001, personal communication).

Dual Spring East has no discharge to the surface under normal flow conditions. During the winter of 2000, the Dual Spring East rise pool was frozen for an extended period of time while the rise pool for Dual Spring West was not frozen and was discharging a few hundred gallons per minute. The failure to detect dye at Dual Spring East from any trace during this and previous investigations, suggests that Dual Spring East rarely flows.

The straight-line distance from Snow White sink to Dual Spring West is approximately 2,200 feet. The elevation loss is approximately 45 feet and the mean gradient is approximately 108 feet per mile. The dye first arrived at Dual Spring West within 24 days of introduction. The mean groundwater velocity under these flow conditions was approximately 100 feet per day.

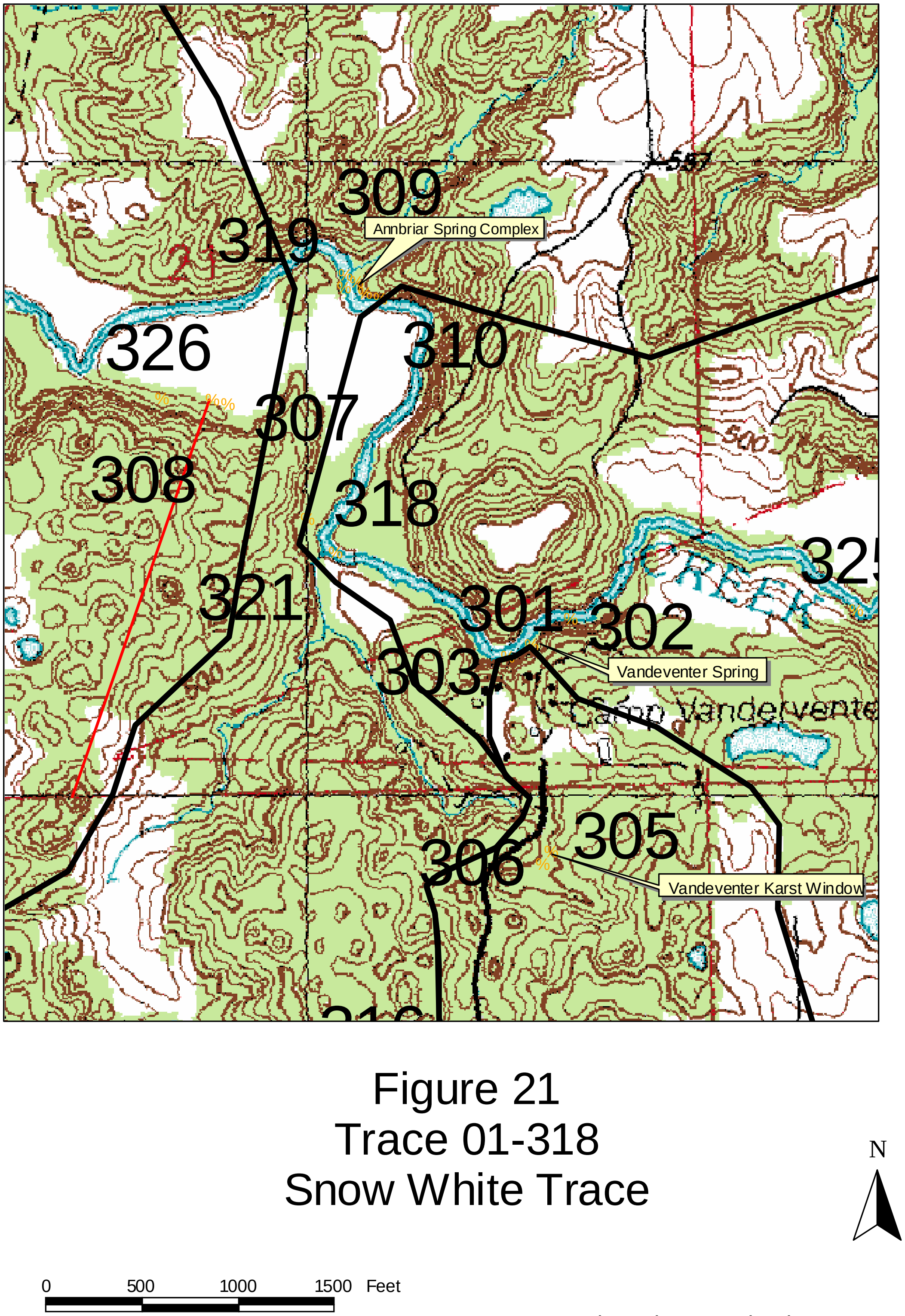


Figure 21
Trace 01-318
Snow White Trace

Ozark Underground Laboratory, 2001

4.3.19 Trace 01-319: Maeystown Road Trace

Four pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into Fountain Creek just downstream of the Maeystown Road bridge at 1817 hours on March 5, 2001. The flow was estimated to be 200 gpm at the time of dye introduction. The elevation of the dye introduction point is approximately 630 feet and is in the NW ¼ NW ¼ Section 15 T3S R10W. The dye introduction point can be found on the Waterloo 7.5-minute quadrangle map.

The purpose of this trace was to test whether Fountain Creek is losing water upstream or downstream of this dye introduction point. A previous trace, Trace 00-305, demonstrated that Fountain Creek loses some water into Pautler Cave. However, that trace did not yield any data regarding what section of Fountain Creek is losing water into the Pautler groundwater system.

The stations sampled for this trace were: 304, 312, 313, 314, and 320.

Data on the dye recovery locations for Trace 01-319 are listed below.

Station 312. Fountain Creek near water plant

Sampling Period	**Peak Emission Wavelength (nm)**	**Eosine Dye Concentration (ppb)**
10/2 to 2/26/01	ND	ND
2/26 to 3/20/01	536.2	1.71
3/20/01 (water)	ND	ND

Station 313. Fountain Creek at JJ Road

Sampling Period	**Peak Emission Wavelength (nm)**	**Eosine Dye Concentration (ppb)**
8/28 to 2/26/01	ND	ND
2/26 to 3/20/01	538.2	7.12
3/20/01 (water)	ND	ND

Eosine dye from the Maeystown Road Trace was detected at two sampling stations, both of which are downstream in Fountain Creek from the dye introduction point. No dye from the Maeystown Road Trace was detected in Pautler Cave. This trace demonstrates that the section of Fountain Creek that contributes water to Pautler Cave is upstream of the Maeystown Road bridge. No figure has been provided showing this trace since it did not contribute water to the groundwater system.

Philip Moss walked Fountain Creek from Ahne Road to LRC Road on February 26, 2001 looking for losing points in the creek. The most likely area (based on bedrock exposure in the creek bed) to contribute water to Pautler Cave based on those observations is circled on Figure 8 (page 56). More dye introductions will need to be made to test this section of Fountain Creek.

Table 4. Dye Introduction Data.

Trace #	Trace Name	Dye Type & Amt. Used	Date Dye Introd.	Where Dye Introduced	Quad	Legal Description	Approx Elev. (ft msl)	Approx Flow (gpm)
96-01	Shivery Slither Trace	rhodamine WT, 3 lbs.	7/29/96	sinkhole	Waterloo	SE ¼ NE ¼ Section 32 T2S R10W	580	20
96-03	Schneider Sinkhole Trace	eosine, 3 lbs.	7/30/96	sinkhole	Waterloo	NE ¼ SE ¼ Section 33 T2S R10W	580	3,200*
97-01	Fabish Sinkhole Trace	fluorescein, 1 lb.	2/20/97	sinkhole	Waterloo	NE ¼ SE ¼ Section 30 T2S R10W	650	10
97-03	Miller Sinkhole Trace	rhodamine WT, 2 lbs.	2/20/97	sinkhole	Waterloo	NW ¼ NW ¼ Section 32 T2S R10W	640	10
97-04	Wednesday Sinkhole Trace	eosine, 2 lbs.	2/20/97	sinkhole	Waterloo	SW ¼ SW ¼ Section 28 T2S R10W	535	50
97-09	Tuhro Sinkhole Trace	fluorescein, 1 lb	7/8/97	sinkhole	Waterloo	NW ¼ SW ¼ Section 16 T2S 10W	475	2
97-10	Scheibe Trace	sulforhodamine B, 1 lb.	7/9/97	cave stream	Waterloo	SE ¼ SE ¼ Section 33 T2S R10W	555	15
97-11	Fountain Creek Trace	eosine, 0.1 lb.	8/14/97	losing point in creek	Waterloo	NW ¼ SE ¼ Section 21 T2S R10W	440	220
98-03	Tuhro Replication Trace	eosine, 1 lb.	5/26/98	sinkhole	Waterloo	NW ¼ SW ¼ Section 16 T2S 10W	475	10
00-301	Dane's Overflow Trace	rhodamine WT, 1 lb.	5/29/00	cave stream	Waterloo	SW ¼ NE ¼ Section 28 T2S R10W	480	0.125
00-302	Dane's Parallel Stream Trace	eosine, 0.5 lb.	5/29/00	cave stream	Waterloo	SE ¼ NE ¼ Section 28 T2S R10W	485	2
00-303	Acorns Trace	sulforhodamine B, 1 lb.	7/6/00	karst window	Waterloo	NW ¼ NW ¼ Section 10 T3S R10W	622	13
00-304	Ritter Trace	rhodamine WT, 2 lbs.	7/17/00	cave stream	Waterloo	NE ¼ NE ¼ Section 5 T2S R10W	605	20
00-305	Fountain Creek Trace	eosine, 9 lbs.	7/17/00	creek	Waterloo	multiple introduction points, see Table 3	538-705	8-5,000
00-306	Vandeventer Trace	pyranine, 0.125 lb.	8/14/00	karst window	Waterloo	NE¼ NE¼ Section 28 T2S R10W	465	450
00-307	Lenz Trace	sulforhodamine B, 2 lbs.	8/14/00	sinkhole	Waterloo	SE ¼ SE ¼ Section 3 T3S R10W	620	3,200*

(Continued)

Table 4 (Continued). Dye Introduction Data.

Trace #	Trace Name	Dye Type & Amt. Used	Date Dye Introd.	Where Dye Introduced	Quad	Legal Description	Approx Elev. (ft msl)	Approx Flow (gpm)
00-308	Laurent Trace	fluorescein, 1 lb.	8/14/00	sinkhole	Waterloo	SW ¼ NW ¼ Section 9 T3S R10W	665	2.25
00-309	Woodpecker Trace	eosine, 1 lb.	9/18/00	karst window	Waterloo	NE ¼ SW ¼ Section 34 T2S R10W	555	2
00-310	Waddy Trace	rhodamine WT, 1lb.	10/18/00	sinkhole	Waterloo	SW ¼ SE ¼ Section 33 T2S R10W	595	1.9
00-311	Leber Trace	fluorescein, 1 lb.	10/18/00	sinking stream	Waterloo	NW ¼ SE ¼ Section 4 T3S R10W	620	15
00-312	Pautler Trace	eosine, 1 lb.	10/27/00	cave stream	Waterloo	NE ¼ NE ¼ Section 33 T2S R10W	530	10
00-313	Benitone Trace	rhodamine WT, 1lb.	11/1/00	sinkhole	Waterloo	NW ¼ SW ¼ Section 27 T2S R10W	540	2,500*
00-314	Stumpf Trace	sulforhodamine B, 1 lb.	11/25/00	sinkhole	Waterloo	NW ¼ SW ¼ Section 31 T2S R10W	640	75
00-315	Acorns Pond #6 Trace	rhodamine WT, 0.5 lb.	12/28/00	pond overflow/sinkhole	Waterloo	SW ¼ SW ¼ Section 3 T3S R10W	630	25
00-316	Chantilly Trace	eosine, 1 lb.	12/28/00	sinkhole	Waterloo	NE ¼ SW ¼ Section 4 T3S R10W	620	40
00-317	Pumphouse Trace	fluorescein, 0.5 lb.	12/28/00	sinkhole	Waterloo	SW ¼ NW ¼ Section 21 T2S R10W	500	15
01-318	Snow White Trace	pyranine, 0.5 lb.	1/12/01	sinkhole	Waterloo	NE ¼ NW ¼ Section 18 T2S R10W	480	25
01-319	Maeystown Road Trace	eosine, 4 lbs.	3/5/01	creek	Waterloo	NW ¼ NW ¼ Section 15 T3S R10W	630	200

* Gallons of water hauled and introduced with the dye, i.e. 3,200 gallons of water were introduced with Trace 96-03.

Table 5. Summary of Dye Trace Lengths, Elevation Loss, and Gradients

Trace Number	From	To	Distance (feet)	Elevation loss (feet)	Gradient (feet/mile)
96-01	Shivery Slither sink	Annbriar Spring	10,500	145	73
96-03	Schneider sink	Vandeventer Spring	9,660	130	71
97-01	Fabish sink	Schnellbecher Spring	7,650	150	104
97-03	Miller sink	Schnellbecher Spring	9,545	140	77
97-04	Wednesday sink	Annbriar Spring	7,580	100	70
97-09	Tuhro sink	Annbriar Spring	4,200	40	50
97-10	Scheibe cave stream	Vandeventer Spring	9,930	105	56
97-11	Fountain Creek sink point	Dual Spring	690	10	77
98-03	Tuhro sink	Antler Spring	1,900	35	97
00-301	Dane's Overflow cave stream	Annbriar Spring	4,160	45	57
00-302	Dane's Parallel cave stream	Vandeventer Spring	2,150	35	86
00-303	Acorn's karst window	Vandeventer Spring	17,825	172	51
00-304	Ritter cave stream	Annbriar Spring	15,210	263	91
00-305	Fountain Creek road crossing	Vandeventer Spring	22,535	185	43
00-306	Vandeventer karst window	Vandeventer Spring	1,060	15	75
00-307	Lenz sink	Vandeventer Spring	17,060	170	53
00-308	Laurent sink	Annbriar Spring	21,790	320	78
00-309	Woodpecker springbranch	Fountain Creek at Route 156	3,640	50	73
00-310	Waddy sink	Vandeventer Spring	10,420	160	81
00-311	Leber sinking stream	Vandeventer Spring	13,980	185	70
00-312	Pautler cave stream	Vandeventer Spring	7,060	95	71
00-313	Benitone sink	Fountain Creek upstream of Camp	600 - 4,220	60 - 85	75 - 750
00-314	Stumpf sink	Frog Spring	2,730	140	271
00-315	Acorn's Pond #6 sink	Vandeventer Spring	16,080	185	61
00-316	Chantilly sink	Annbriar Spring	17,140	180	55
00-316	Chantilly sink	Antler Spring	18,420	180	52
00-317	Pumphouse sink	Luhr Spring	2,050	55	142
01-318	Snow White sink	Dual Spring	2,200	45	108
01-319	Fountain Creek at Maeystown Road	not applicable, no groundwater flow path			

Table 6. Summary of Dye Trace Segment Lengths, Elevation Loss, and Gradients

From	To	Distance (feet)	Elevation loss (feet)	Gradient (feet/mile)	Trace number associated w/segment
Annbriar system					
Shivery Slither sink	Reverse Stream Karst Window	3,360	55	86	96-01
Reverse Stream Karst Window	Annbriar Spring	7,140	90	67	96-01
Wednesday sink	Annbriar Spring	7,580	100	70	97-04
Dane's overflow passage	Annbriar Spring	4,160	45	57	00-301
Ritter sink	Reverse Stream Karst Window	8,070	173	113	00-304
Reverse Stream Karst Window	Tree Spring	7,240	93	68	00-304
Laurent sink	Reverse Stream Karst Window	14,650	230	83	00-308
Tuhro sink	Annbriar Spring	4,200	40	50	97-09
Chantilly sink	Reverse Stream Karst Window	10,000	90	48	00-316
Tuhro sink	Antler Spring	1,900	35	97	98-03
Reverse Stream Karst Window	Antler Spring	8,420	90	56	00-316
Pautler Cave system					
Schneider sink	Vandeventer Karst Window	8,600	115	71	96-03
Vandeventer Karst Window	Vandeventer Spring	1,060	15	75	00-306
Scheibe cave stream	Vandeventer Karst Window	8,870	90	54	97-10
Dane's parallel stream	Vandeventer Karst Window	1,090	20	97	00-302
Acorns karst window	Ebeler Cave	480	26	286	00-303
Ebeler Cave	Acorns Pond #6	2,385	57	126	00-303
Acorns Pond #6	Vandeventer Karst Window	13,900	69	26	00-303
Lenz sink	Vandeventer Karst Window	16,030	155	51	00-307
Waddy Sink	Pautler Cave	3,800	65	90	00-310
Leber sinking stream	Chantilly Spring	1,360	10	39	00-311
Chantilly Spring	Pautler Cave	6,000	80	70	00-311
Pautler Cave	Vandeventer Karst Window	5,560	80	76	00-312
Acorns Pond #6 overflow	Acorns Pond #6 (Haegele Karst Window)	1,120	101	476	00-315
Fountain Creek	Pautler Cave	15,860	70	23	00-305
Other groundwater systems					
Fountain Creek	Dual Spring	690	10	77	97-11
Snow White sink	Dual Spring	2,200	45	108	01-318
Woodpecker Spring	Fountain Creek at Rt. 156	3,640	50	73	00-309
Benitone Trace	unknown spring on Fountain Creek	unknown			00-313
Stumpf sink	Frog Spring	2,730	140	271	00-314
Pumphouse sink	Luhr Spring	2,050	55	142	00-317
Fountain Creek					
Ahne Road	Maeystown Road in Sec. 15	9,560	75	41	00-305
Maeystown Road in Sec. 15	JJ Road	9,450	65	36	00-305
JJ Road	Maeystown Road near water plant	7,370	27	19	00-305
Maeystown Road near water plant	Fountain Creek at Rt. 156	8,760	33	20	00-305
Fountain Creek at Rt. 156	Fountain Creek upstream of Camp	6,125	50	43	00-305
Fountain Creek upstream of Camp	Fountain Creek upstream of sink point	1,350	18	70	00-305

4.4 Recharge Area Delineation

Recharge area delineation is essential for protection and management of important cave systems where the caves contain streams. Protection and management cannot be conducted unless one has a basic understanding of where the relevant lands are located. This is precisely the basic information which recharge area delineation provides.

As we use the term in this report, a recharge area for a cave or spring is the surface land area which contributes water under some or all conditions to that particular cave or spring. Unless otherwise noted, the recharge area for a cave includes both lands upstream of the known cave passages plus other lands which contribute water to the spring or springs through which water from the cave discharges.

As explained earlier, we commonly refer to the groundwater system associated with a particular cave. The lateral boundaries of a cave's groundwater system are identical with the lateral boundaries of the cave's recharge area. The difference in the terms is that "recharge area" is related to the land's surface and "groundwater system" is related to the subsurface.

Shared recharge areas provide water to two or more cave systems. Such areas are typically located near recharge area boundaries. Shared recharge areas and their associated shared groundwater systems are undoubtedly important in explaining the subsurface distribution of aquatic cave fauna. Where we have sufficient data we have discussed and delineated shared recharge areas in this report.

Under Illinois law, three classes of groundwater are recognized. Class I is groundwater that is used for human consumption. Class II is general resource groundwater. Class III is special resource groundwater. The water recharging dedicated Illinois Nature Preserves is special resource groundwater under the Illinois Groundwater Protection Act (35 IL Admin. Code 620.230(b)). Since fieldwork was completed on this project, the Pautler Cave entrance, owned by The Karst Conservancy of Illinois, was dedicated as an Illinois Nature Preserve.

OUL has provided two delineations for Pautler Cave. The first delineation is the recharge area for that portion of the cave system that contributes water to the Pautler Nature Preserve. The second delineation is for the entire cave system, including the springs that ultimately discharge water from the Pautler Cave groundwater system. The recharge area delineation has been developed also for Annbriar Spring identified in the contract extension. These system delineations will be useful to the IDNR consultation process, local management and educational efforts, and to biologists and others concerned with the aquatic biota of these groundwater systems. In particular, the U.S. Fish and Wildlife Service will be able to use the delineations in designing and implementing a recovery plan for the Illinois Cave Amphipod.

The recharge area delineations are generally interpolations between dye introduction points. The lines have been drawn according to the best information available. That information includes the dye traces, topographic features, flow rate measurements, and cave maps. The lines delineating the recharge area boundaries should generally be considered as a region having some width and some uncertainty as distinguished from a finite line. In view of this, site-specific issues at locations near the recharge area boundaries we have drawn will often need site-specific dye tracing investigations to refine boundaries in the local area. Furthermore, areas near recharge area boundaries sometimes contribute recharge water to both of the associated groundwater systems. Some of these shared recharge areas have been identified in our studies, and more such areas probably exist. Finally, some areas may share recharge waters between different groundwater systems only under high flow conditions.

Not all lands within a delineated recharge area pose equal risks of introducing contaminants into the associated groundwater system. Existing and potential land uses and practices are an obvious variable. Another variable is the manner in which water moves from the surface into the groundwater system.

The movement of water from the surface of the land into the groundwater system is called groundwater recharge. Two types of groundwater recharge are recognized in conceptual models for karst hydrology; these are discrete recharge and diffuse recharge. Discrete recharge is the movement of water through localized, preferential flow routes. Diffuse recharge is dispersed flow which seeps and oozes through the soil and rock to enter the groundwater system. Sinkholes and losing streams are common regional examples of discrete recharge zones.

Discrete recharge provides much less effective natural cleansing than does diffuse recharge. This is because discrete recharge seldom provides effective natural cleansing through processes such as filtration and adsorption onto soil particles. Furthermore, discrete recharge waters commonly enter cave systems rapidly which results in short-duration (but highly concentrated) pulses of contaminants. Finally, the rapid travel rates through discrete recharge zones commonly provide insufficient time for the natural die-off of pathogens to occur. The net result is that the risks and problems associated with contaminant introduction through discrete recharge zones is often much greater than when contaminants are introduced through diffuse recharge pathways.

Contaminants which are introduced into the groundwater system of a significant cave and then follow a long flow path through the cave are likely to have greater impacts on the associated aquatic fauna than contaminants which follow a shorter flow path. While the contaminant pulse from the longer flow path source is likely to be more attenuated than is the case with the shorter flow path, more of the cave habitat is impacted by the contaminant that follows the longer flow path.

In most of the sinkhole plain areas of the Southwestern Illinois karst, essentially all of the runoff water passes through the karst groundwater system. In contrast, in areas where sinkholes are less abundant or locally absent, some of the runoff water remains on the surface and never enters the karst groundwater system. Areas near major springs often yield runoff both to surface and groundwater flow. As a result, on a per acre basis, areas which yield all of their runoff to the groundwater system are likely to have a greater impact on associated cave systems than areas which yield only part of their runoff to the groundwater system.

4.4.1 Pautler Cave System Recharge Area

The Pautler Cave system has several caves within it. Of greatest known biological importance are Pautler Cave and Rose Hole (Lewis et al., 1999). Lewis et al. (1999) also lists Dane's Cave as part of the Pautler Cave system, however, it has been physically connected to Pautler Cave and is considered to be part of a single cave known as Pautler Cave. Over five miles of cave passage has been mapped in the system to date and exploration continues (Moss, 1999, 2000a, 2000b, 2000c). This investigation verified that Vandeventer Spring is the principle discharge point for the Pautler Cave system. Ice Box Spring discharges a small portion of the Pautler Cave system water. At very high flow conditions, water from the Pautler Cave system can overflow into a cave passage which discharges at Annbriar Spring. However, these very high flow events probably occur very infrequently. It is unlikely due to elevation differences that there is ever flow from the Annbriar Spring groundwater system into the Pautler Cave system along this overflow route.

The Pautler Cave System Recharge Area is shown on Figure 22 (page 115). The areas marked 1, 2, and 3 on Figure 22 recharge the Pautler Cave groundwater system. The recharge area of the Pautler Cave system is approximately 6.3 square miles. Area 1 is the only area that cannot contribute water to the Annbriar Spring groundwater system. Areas 2 and 3 can overflow into the Annbriar Spring groundwater system and are thus shared recharge areas (at very high flows) with Annbriar Spring. Area 3 is the recharge area for the proposed Pautler Nature Preserve and is discussed more specifically in the next section.

Based on dye concentrations detected in Pautler Cave, only a fraction of the Fountain Creek flow leaks into Pautler Cave. In the densely sinkholed parts of the recharge area, nearly all the runoff enters the groundwater system. It is clear that not all sections of the recharge area contribute the same volume of water per unit area.

Delineation Rationale (Areas 1, 2, and 3)

The northern boundary of the Pautler Cave System Recharge Area is defined by the Fountain Creek valley along with Vandeventer and Ice Box Springs. The boundary has been drawn far enough east to include the entire sinkhole in which Vandeventer Karst Window is located. The boundary has been drawn west of the Benitone Trace dye introduction point (00-313), which lies east of the Pautler Cave System Recharge Area.

Where the eastern recharge area boundary crosses Route 156, there is a small cave system (Illinois Speleological Survey, 2000) through which the Woodpecker Trace probably flowed. The boundary has been drawn to exclude this small cave system and the Woodpecker Trace dye introduction point.

The boundary has been drawn to the southeast from the Woodpecker Trace dye introduction point following the Fountain Creek topographic basin divide and including the majority of the sinkholes. The boundary then follows the Fountain Creek topographic basin divide to the west until it crosses Maeystown Road. The boundary then crosses Fountain Creek to the south to include the section of Fountain Creek that recharges Pautler Cave (Trace 00-305). The boundary wraps around the western end of the Fountain Creek topographic basin including all of the Fountain Creek topographic basin upstream of the losing stream reach.

The boundary then has been drawn north to include the topographic basin of the Leber sinking stream west of Bissel Lake and shown to be in the Pautler Cave Recharge Area by Trace 00-311. The boundary has been drawn to exclude the Chantilly Trace (00-316), which lies within the Annbriar Spring Recharge Area. The boundary includes Chantilly Spring, which was shown by Trace 00-311 to lie in the Pautler Cave Recharge Area. The only connection between Chantilly Spring and the Chantilly Trace dye introduction point is that they are both located in a subdivision called Chantilly Village. The boundary in this area was not drawn evenly between dye introduction points in the Annbriar Spring and Pautler Cave Recharge Areas. The reason is there is relatively little flow through this section of Pautler Cave and that influenced where the boundary was drawn. The boundary does include Rose Hole, which is west of and tributary to Pautler Cave (Moss, 1999, 2000b).

The boundary has been drawn roughly north from the Pautler Cave area (Station 320) to separate the dye introduction points for Traces 00-301 and 00-302. Trace 00-301 lies within the Annbriar Spring Recharge Area, while Trace 00-302 lies within the Pautler Cave System Recharge Area. The boundary then continues north, while wrapping around a losing stream topographic basin, to Ice Box Spring completing the loop.

Areas 2 and 3 are in the Pautler Cave System Recharge Area exclusively at normal flow levels. However, under very high flow conditions, there is a cave passage that carries overflow through the dye introduction point tested by Trace 00-301 (Figure 5). This water flows to Annbriar Spring. The boundary between areas 1 and 2 is based on cave mapping (Moss, 2000a).

4.4.1.1 Pautler Nature Preserve Recharge Area

Pautler Cave has been dedicated as an Illinois Nature Preserve. Groundwater recharging the Nature Preserve can be designated Class III groundwater. In support of that possibility, OUL delineated the recharge area for Pautler Cave upstream of the Nature Preserve. This recharge area is shown on Figure 22 (page115) as area 3.

The recharge area of the Pautler Nature Preserve is approximately 2.9 square miles. Based on dye concentrations detected in Pautler Cave, only a fraction of the Fountain Creek flow leaks into Pautler Cave. In areas with high sinkhole density, nearly all the runoff enters the groundwater system. It is clear that not all sections of the recharge area contribute the same volume of water per unit area.

Delineation Rationale (Area 3)

The northern boundary of the Pautler Cave Nature Preserve Recharge Area boundary is defined by the proposed Nature Preserve property boundary. It has been drawn to the east to exclude the main stream of Dane's Cave based on cave mapping (Moss, 2000a, 2000b). The boundary has been drawn southerly to exclude the Schneider Trace (96-03) which OUL has interpreted to have not passed through Pautler Cave based on cave mapping (Moss, 2000a). The boundary has been drawn further south continuing to exclude Dane's Cave but including the topographic basin of the Leber sinking stream. The Leber sinking stream was shown to recharge Pautler Cave by Trace 00-311.

The boundary is drawn southeast to include the topographic basin of Fountain Creek that recharges Pautler Cave (Trace 00-305). The boundary wraps around the western end of the Fountain Creek topographic basin including all of the Fountain Creek topographic basin upstream of the losing stream reach.

The boundary then has been drawn north to include the topographic basin of the Leber sinking stream west of Bissel Lake and demonstrated to be in the Pautler Cave Recharge Area by Trace 00-311. The boundary has been drawn to exclude the dye introduction point for the Chantilly Trace (00-316), which lies within the Annbriar Spring Recharge Area. The boundary includes Chantilly Spring (Station 324), which was shown by Trace 00-311 to lie in the Pautler Cave Recharge Area. The boundary in this area was not drawn evenly between dye introduction points in the Annbriar Spring and Pautler Cave Recharge Areas. The reason is there is relatively little flow through this section of Pautler Cave and that influenced where the boundary was drawn. The boundary does include Rose Hole, which is west of and tributary to Pautler Cave (Moss, 1999, 2000b). The boundary is then drawn easterly to close the loop.

4.4.2 Annbriar Spring Recharge Area

The Annbriar Spring Complex is recharged from both the north and south sides of Fountain Creek (Aley and Aley, 1998). Figure 22 (page 115) shows the Annbriar Spring Recharge Area. Area 4 on Figure 22 is the normal flow condition recharge area south of Fountain Creek and area 5 is the portion of the Annbriar Spring Recharge Area north of Fountain Creek (Aley and Aley, 1998). In very high flow conditions, areas 2 and 3 contribute water to Annbriar Spring via the flow path demonstrated by cave mapping and Trace 00-301.

Area 4 on Figure 22 has two caves within it that have been shown to provide habitat for an important ecosystem that includes the Federally listed endangered Illinois Cave Amphipod. These two caves are Cedar Ridge and Wednesday Caves (Lewis et al., 1999). It is not known whether Illinois Cave Amphipod is present in area 5.

The recharge area of Annbriar Spring varies considerably between normal flow and high flow conditions. The low flow recharge area is approximately 6.0 square miles. However, at high flows most of the Pautler Cave groundwater system can overflow to Annbriar Spring making the high flow recharge area approximately 12.1 square miles.

Delineation Rationale (Area 5)

The portion of the Annbriar Spring Recharge Area north of Fountain Creek is discussed in this section. The recharge area boundary has been drawn to include Annbriar Spring. From Annbriar Spring, the boundary has been drawn to the northwest to exclude Antler Spring (Station 332) and to include Tuhro sink (Trace 97-09). There are no other traces on the north side of Fountain Creek and south of Andys Run (Aley and Aley, 1998). There are three sinking streams shown on the topographic map. There are no other known springs that could receive recharge from the sinking streams in area 5. OUL has therefore included the topographic basins of these sinking streams in the Annbriar Recharge Area. The boundary wraps around the sinking streams' topographic basins and comes nearly to a close near Annbriar Spring. However, it has been drawn southerly and crosses Fountain Creek into area 4 discussed in the next section.

Delineation Rationale (Area 4)

The portion of the Annbriar Spring Recharge Area south of Fountain Creek is discussed in this section. Starting from Annbriar Spring, the boundary has been drawn to the south crossing Fountain Creek and its floodplain. It has been drawn to the southwest to include a sinking stream that receives overflow from Reverse Stream karst window and excluding the dye introduction point for the Snow White Trace (01-318), which was detected at Dual Spring West.

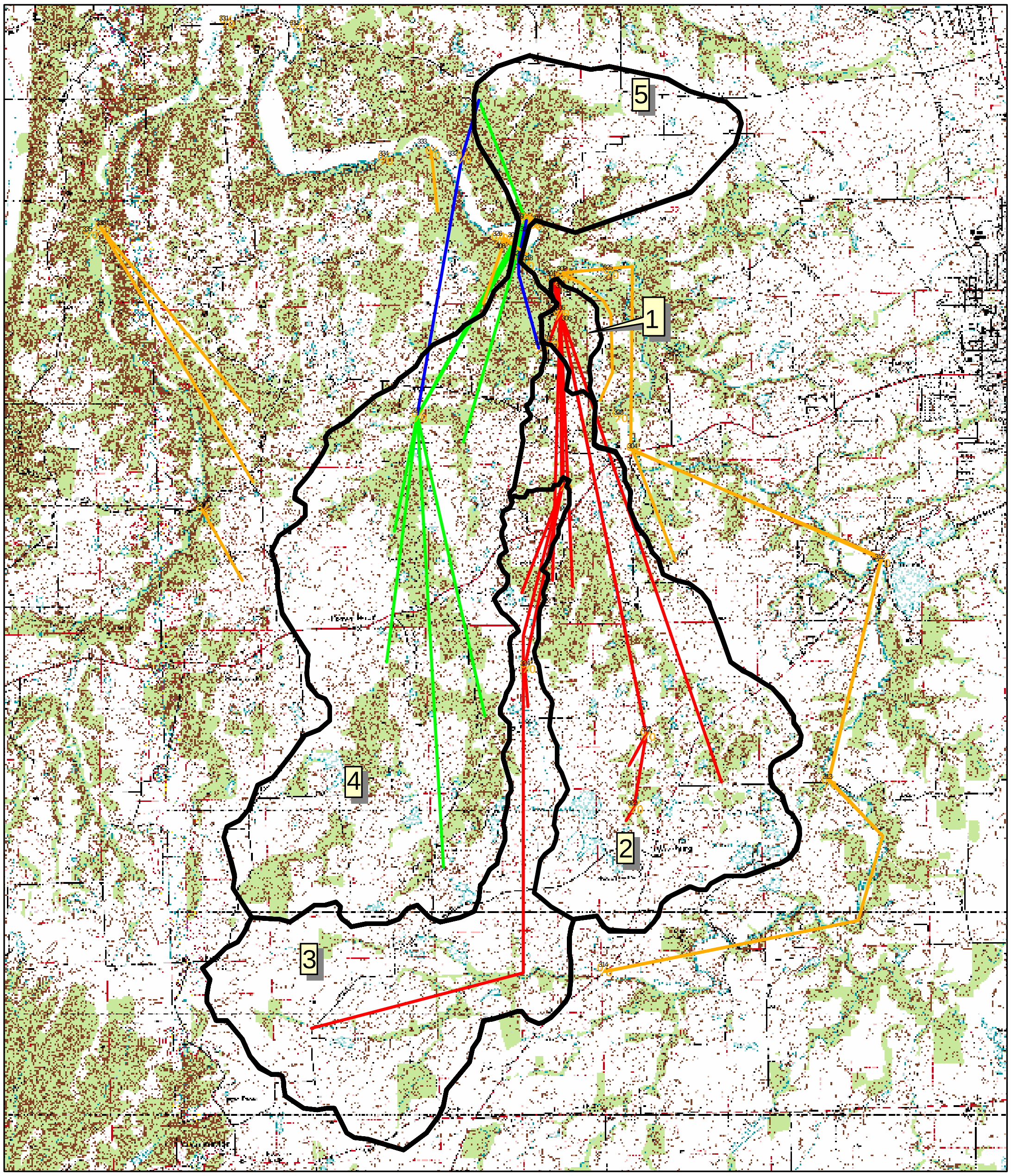
The boundary continues to the southwest including Reverse Stream (Station 327) and an area of high sinkhole density that is proximate to the stream channel in which Reverse Stream lies. The boundary has been drawn to exclude the Fabish Trace (97-01) and the Miller Trace (97-03). The boundary continues roughly parallel to and including the topographic basin containing the losing stream in which Reverse Stream lies. From there, the boundary is drawn southerly to exclude the Stumpf sink and its associated drain-tiled sinkhole (Trace 00-314).

The boundary has been drawn to the southeast but including the large, compound sinkhole in where the Ritter Trace (00-304) dye was introduced. The boundary has then been drawn to the southwest to include the topographic basin for a sinking stream that has not been dye traced. The boundary has then been drawn southerly to the Fountain Creek basin topographic divide, since the basin contributes water to Pautler Cave.

The boundary then has been drawn north to exclude the topographic basin of the Leber sinking stream west of Bissel Lake and demonstrated to be in the Pautler Cave Recharge Area by Trace 00-311. The boundary has been drawn to include the Chantilly

Trace (00-316), which lies within the Annbriar Spring Recharge Area. The boundary excludes Chantilly Spring (Station 324), which was shown by Trace 00-311 to lie in the Pautler Cave Recharge Area. The boundary in this area was not drawn evenly between dye introduction points in the Annbriar Spring and Pautler Cave Recharge Areas. The reason is there is relatively little flow through this section of Pautler Cave and that influenced where the boundary was drawn. The boundary excludes Rose Hole, which is west of and tributary to Pautler Cave (Moss, 1999, 2000b).

The boundary has been drawn roughly north from the area near Station 320 to separate the dye introduction points for Traces 00-301 and 00-302. Trace 00-301 lies within the Annbriar Spring Recharge Area, while Trace 00-302 lies within the Pautler Cave System Recharge Area. The boundary has then been drawn northerly, wrapping around a losing stream topographic basin, and continuing northwesterly excluding much of the floodplain, which is part of the Dual Spring Recharge Area as shown by Trace 97-11. The boundary then crosses Fountain Creek and its floodplain closing the loop with area 5.



Legend
recharge area boundary
$ dye introduction point
% sampling station
Recharge Area linking trace
trace outside delineations
Pautler Trace
Annbriar Trace

Figure 22
Pautler and Annbriar Recharge Areas, Sampling Stations, Dye Introduction Points, and Diagrammatic Flow Routes

1, 2, 3, 4, 5 - see section 4.4.1 and 4.4.2 for explanation

N

0 5000 10000 Feet

Ozark Underground Laboratory, 2001

4.5 Potential Refining Investigations

In any investigation, there are questions that may warrant further investigation. Every study has its practical limitations; those of focus, time, and money. More traces were initiated for this project than were required by the contract. However, some details were not resolved. A list of potential dye traces and other investigations is presented below with some brief discussion of the understanding that might be gained from them.

Antler Spring

It is unclear whether Antler Spring is recharged by water leaking from Fountain Creek. This could be tested by introducing one dye into Fountain Creek downstream of the Annbriar Spring Complex, and a second dye into Reverse Stream karst window. The combined results of either one dye or two dyes detected at Antler Spring, would demonstrate whether any of the recharge comes from Fountain Creek or if there is a flow path under Fountain Creek.

While OUL has assumed that Traces 97-09 and 98-03 flowed to Antler Spring, this has not been proven. Another replication from the Tuhro sink would resolve this question.

Annbriar Recharge Area

The delineation of the Annbriar Spring Recharge Area resulted from greater than expected economic efficiency during the Pautler Cave Recharge Area delineation. The budget remaining was used to start delineating the adjacent Annbriar Spring Recharge Area. A few dye traces should be conducted north of Fountain Creek to empirically define that part of the recharge area. Much of the western boundary in area 4 shown on Figure 22 (page115) is not as well defined as the delineations provided for Pautler Cave and the delineations presented by the most recent previous study (Aley et al., 2000). A few more traces along this boundary would provide that detail.

Frog Spring Recharge Area

The Frog Spring Recharge Area delineation was not identified as an objective of this contract study. However, it provides habitat for the Illinois Cave Amphipod and other important fauna (Lewis et al., 1999). Only very limited data on its recharge area has been developed. Delineating its recharge area would better define the Annbriar Spring Recharge Area as well as other adjacent recharge areas.

Luhr Spring Recharge Area

The Luhr Spring Recharge Area delineation was not identified as an objective of this contract study. However, it provides habitat for the Illinois Cave Amphipod and other important fauna (Lewis, 2001, personal communication). Only very limited data on its recharge area has been developed. Delineating its recharge area would better define the

Annbriar Spring Recharge Area as well as other adjacent recharge areas, including that of Dual Spring.

Dual Spring Recharge Area

The Dual Spring Recharge Area delineation was not identified as an objective of this contract study. However, it provides habitat for the Illinois Cave Amphipod and other important fauna (Lewis, 2001, personal communication). Only very limited data on its recharge area has been developed. Delineating its recharge area would better define the Annbriar Spring Recharge Area as well as other adjacent recharge areas, including that of Luhr Spring.

Illinois Cave Amphipod

Additional efforts should be made to determine if there are undiscovered populations of the Illinois Cave Amphipod. In a study funded through The Nature Conservancy of Illinois, new populations were found throughout the fieldwork period (Lewis et al., 1999), implying that not all populations have been discovered. Additional fieldwork by Lewis (2001, personal communication) demonstrated previously unknown populations in the Luhr Spring and Dual Spring groundwater systems.

5.0 SUMMARY AND CONCLUSIONS

5.1 Contract Requirements

In the contract with the INPC, work was permitted to begin on May 15, 2000 and must be completed by December 1, 2000. However, the contract was extended to June 30, 2001 to permit additional delineation of Annbriar Spring. The contract required a minimum of 12 dye traces using about 15 sampling stations, a final report, and Arc Info compatible maps at 1:24,000 scale.

This final report summarizes all data gathered and the interpretation of that data in the form of recharge area delineation maps and discussion of all dye traces used for these delineations. Arc View 3.2 themes accompany this report. These themes show all the dye traces as diagrammatic lines, the recharge areas of two groundwater systems, and the recharge areas of a proposed Illinois Nature Preserve. This report completes the delineation study and satisfies the requirements of the contracts with the INPC.

5.2 Character and Purpose of the Delineations

The INPC published a Request for Proposal for delineation of the groundwater recharge area for Pautler Cave. The cave system is part of an important karst ecosystem and provides habitat for the Federally endangered Illinois Cave Amphipod (*Gammarus acherondytes*). In order to best manage the ecosystems, it is necessary to understand which lands provide recharge to the cave systems.

It should be noted that the delineations are generally interpolations between dye introduction points. The lines have been drawn according to the best information available to OUL. The lines delineating the recharge area boundaries should generally be considered as a region having some width as distinguished from a finite line having no width. OUL recommends, for use in the IDNR Consultation process, that proposals dealing with areas that lie close to a recharge area boundary have site specific dye tracing conducted to determine a more exact location of the recharge area boundaries.

Dye can be considered a surrogate for contaminants that are mobile in water. Since dye often was detectable at sampling stations for only a few days, an effective monitoring program for the karst systems examined needs to have samples collected frequently for comprehensive detection of episodic inputs of contaminants. Since travel times are hours or days from potential source areas to natural areas, a pre-planned spill response is desirable for effective mitigation of contaminant pulses.

5.3 Results

The direction of groundwater flow in karst is often dramatically different from that of surface runoff. Water that sinks in one surface valley may flow beneath a surface ridge and discharge from springs in a different valley. Groundwater tracing with fluorescent dyes permits mapping of the groundwater flow system using data that are technically defensible.

The study involved 19 new dye introductions that were detected at 25 sampling stations. A total of thirty-six sampling stations were established.

The recharge areas were delineated primarily through dye tracing, but OUL also drew upon its knowledge of the caves involved, flow rate measurements of springs, and hydrogeological considerations. Both of these biologically significant groundwater systems are in the Salem Plateau, which in Illinois is an intensely karstified sinkhole plain area.

Conducting the groundwater tracing studies led to several important discoveries; these include:

1) There is intermittent hydrologic interaction between the Pautler Cave and Annbriar Spring groundwater systems. This interaction is in the form of the Pautler Cave groundwater system overflowing to Annbriar Spring under very high flow conditions.

2) An upstream portion of Fountain Creek is losing water into the groundwater system. In the Salem Plateau Karst, surface streams shown on the USGS topographic maps may lose some or all of their flow into the karst groundwater system.

3) There is either flow passing under Fountain Creek between Reverse Stream and Antler Spring, or there is another losing section of Fountain Creek downstream of Annbriar Spring recharging Antler Spring.

4) Cedar Ridge Cave, an Illinois Cave Amphipod site, has been determined to be part of the Annbriar Spring groundwater system. Previous to this investigation, it was unclear whether it was part of the Pautler Cave system or part of the Annbriar system.

5) Groundwater in the Salem Plateau Karst can travel great distances. Two traces were detected over four miles from the dye introduction points (Table 5, page 106).

6) Mean groundwater gradients in this study range from 26 to 286 feet per mile, with 45 to 75 feet per mile being typical.

7) The persistence of dye pulses ranges from a few days to several months. Even in high flow systems, contaminants may not flush out quickly. Conversely, sampling for a contaminant pulse from some source areas may need to be conducted daily.

8) Runoff and spills from Route 156 and Maeystown Road have the potential to impact at least two populations of the Illinois Cave Amphipod.

5.4 Identification of Recharge Areas and Associated Springs

Pautler Cave Recharge Area

The total size of the recharge area is approximately 6.3 square miles. Under normal flow conditions, groundwater in this system flows through Vandeventer Karst Window and is primarily discharged at Vandeventer Spring along with minor discharge from Ice Box Spring. Under very high flow conditions, most of the recharge area can overflow to Annbriar Spring. Figure 5 shows this hydrologic interaction.

Annbriar Spring Recharge Area

The size of this recharge area at normal flow is approximately 6.0 square miles. However, under high flow conditions approximately 12.1 square miles contribute water to Annbriar Spring. Most of the normal level recharge from the south side of Fountain Creek flows through Reverse Stream karst window. However, there is an appreciable portion of the recharge area on the north side of Fountain Creek. Further, groundwater overflowing from the Pautler Cave groundwater system does not flow through Reverse Stream karst window.

6.0 RECOMMENDATIONS

1. A great deal of effort has gone into the groundwater tracing work to delineate the recharge areas for the four cave systems and associated nearby springs. These data need to be made available to public health, land use planning, agricultural services, and other relevant entities. Furthermore, these entities should be encouraged to incorporate the recharge area delineation results in their work in the region. Data left on the shelf do not help to enhance or protect public health or natural resources.

2. Site-specific groundwater tracing will be needed to assess particular issues, especially in areas near recharge area boundaries or in areas outside of the areas included in this study.

3. More detailed groundwater tracing should be conducted in areas that are receiving suburban land development pressures. More detailed groundwater tracing is also appropriate where other land uses which could significantly impact water resources are proposed or planned.

4. Vulnerability mapping should be conducted for the delineated recharge areas. As briefly mentioned in this report, the vulnerability of a cave groundwater system to contamination is not equal for all parcels of land within the recharge area. Tailoring of land uses to site suitability is a prudent and effective strategy for minimizing adverse impacts on groundwater and cave resources. Vulnerability mapping, which assesses the relative risks of groundwater contamination from land uses, is a valuable land management and land use planning tool. Vulnerability mapping typically identifies areas where the groundwater contamination risks to the associated groundwater system are high, where they are moderate, and where they are low.

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