DELINEATION OF RECHARGE AREAS FOR FOUR BIOLOGICALLY SIGNIFICANT CAVE SYSTEMS IN MONROE AND ST. CLAIR COUNTIES, ILLINOIS

FINAL REPORT

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A Contract Study for the Illinois Nature Preserves Commission
and the Monroe County Soil and Water Conservation District
with funding from the Illinois Department of Natural Resources
Conservation 2000 Program

1.0 EXECUTIVE SUMMARY

This study was designed to delineate the recharge areas for four biologically significant cave systems in Monroe and St. Clair Counties, Illinois. The recharge area for a cave is the land area which contributes water to that cave and the streams which flow through the cave. The four cave systems are Fogelpole Cave, Illinois Caverns, Krueger Cave System, and Stemler Cave. Portions of these cave systems are within various state Nature Preserves and a state Natural Area. The cave fauna in the caves 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 State of Illinois through the Illinois Nature Preserves Commission, Department of Natural Resources and with additional funding from the Monroe County Soil and Water Conservation District.

The recharge area delineations are 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 two-year period and involved 55 new dye introductions that were recovered at 53 sampling stations. A total of 87 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 delineations. Recharge areas were also delineated for Collier Spring and Lantz Spring because of proximity to the studied cave systems.

A number of important discoveries were made during the study; these included:

1) Stemler Cave has a much larger recharge area than previously suggested by a preliminary Illinois Department of Natural Resources delineation. The Stemler Cave Recharge Area includes the Illinois Route 158 highway corridor. As a result, highway runoff and spills have the potential to degrade water quality in the Stemler Cave Nature Preserve.

2) Fogelpole Cave and Illinois Caverns have significantly smaller recharge areas than previously suggested by a preliminary Illinois Department of Natural Resources delineation.

3) Groundwater in the studied areas can travel great distances; some traces went over five miles straight-line distance. Groundwater velocities demonstrated by the tracer dyes were commonly hundreds to thousands of feet per day.

4) The persistence of dye pulses at springs ranged from about a day to more than a year. This indicates that contaminants may or may not flush out of the groundwater system quickly. This is important information for designing sampling approaches for

detecting and assessing groundwater contaminants.

The following information summarizes the recharge areas which were delineated during this study and identifies their associated springs.

Fogelpole Cave Recharge Area

The total size of this recharge area is 7.14 square miles. The portion of the recharge area which is located in or tributary to the Fogelpole Cave Nature Preserve is 5.13 square miles. These values include lands which function as shared recharge areas and yield waters to other delineated groundwater systems. The Fogelpole Cave Recharge Area includes some lands where the recharge water is shared with the Illinois Caverns groundwater system and with the Collier Spring groundwater system. The Fogelpole Cave Recharge Area borders recharge areas for Collier Spring, Illinois Caverns, the Krueger Cave System, Lantz Spring, and probably some other small springs.

Aside from shared recharge areas, the Fogelpole Cave Recharge Area discharges groundwater only at Tierce Spring under low flow conditions. Under moderate flow conditions the recharge area discharges groundwater at Tierce Spring and at Indian Hole (also called Indian Hole Spring). In contrast, the shared recharge area discharges at Collier Spring under low flow. At high flows, the shared recharge area overflows to Tierce Spring and Indian Hole. All three of these springs are located in relatively close proximity to one another. Figure 59 shows the flow paths in Fogelpole Cave schematically under various flow conditions. On Figure 59, it should be noted that at higher flows, the normal flow routes are also followed. The high and extremely high flow routes are overflow routes.

Collier Spring Recharge Area

The total size of this recharge area is 7.90 square miles. There are no currently established nature preserves which are associated with Collier Spring. The recharge area size includes lands which function as shared recharge areas and yield waters to other delineated groundwater systems. The Collier Spring Recharge Area includes some lands where the recharge water is shared with the Fogelpole Cave groundwater system. Further, the Sunfish Passage of Fogelpole Cave drains to Collier Spring. The flow paths of Fogelpole Cave, including the Sunfish Passage, at various flow conditions are shown schematically on Figure 59. On Figure 59, it should be noted that at higher flows, the normal flow routes are also followed. The high and extremely high flow routes are overflow routes.

Under high flow conditions, the Collier Spring groundwater system overflows into the Fogelpole Cave system and discharges at Tierce Spring and Indian Hole as well as Collier Spring.

Under low flow conditions the Collier Spring Recharge Area borders recharge areas for Fogelpole Cave, the Krueger Cave System, the Renault Cave System and probably some smaller springs.

Illinois Caverns Recharge Area

The total size of this recharge area is 2.10 square miles. The portion of the recharge area which is located in or tributary to the designated Illinois Caverns Natural Area is 0.65 square miles. These values include lands that function as shared recharge areas and yield waters to other delineated groundwater systems. The Illinois Caverns Recharge Area includes some lands where the recharge water is shared with the Fogelpole Cave Recharge Area and other areas where the recharge water is shared with the Krueger Cave System. The Illinois Caverns Recharge Area borders recharge areas for Fogelpole Cave, the Krueger Cave System, Lantz Spring, Curran Spring, and probably some other small springs.

Aside from shared recharge areas, the Illinois Caverns Recharge Area discharges groundwater at Dye Spring, Walsh Spring, and Walsh Cave. Walsh Cave and Walsh Spring are located about 250 feet apart; both of these features are about 3,000 feet from Dye Spring. Dye Spring receives most of the flow from Illinois Caverns under low flow conditions. Walsh Cave receives most of the flow from Illinois Caverns under high flow conditions. Walsh Spring and Walsh Cave are closely connected hydrologically.

Krueger Cave System Recharge Area

This cave system includes Krueger Cave, Dry Run Cave, Spider Cave, Half-Mile Cave, and Kelly Spring Cave. Krueger Cave, Half-Mile, and Dry Run Caves have all been physically connected by cavers. The total size of this recharge area is 5.40 square miles. The portion of the recharge area that is located in or tributary to the Armin Krueger Speleological Nature Preserve is 5.38 square miles. These values include lands that function as shared recharge areas and yield waters to other delineated groundwater systems. The Krueger Cave System Recharge Area includes some lands where the recharge water is shared with the Illinois Caverns, Collier Spring, Fogelpole Cave, and Curran Spring groundwater systems and probably some other small springs.

Aside from shared recharge areas, the Krueger Cave System Recharge Area discharges all of its groundwater at Kelly Spring.

Lantz Spring Recharge Area

The total size of this recharge area is 1.86 square miles. There is no Nature Preserve associated with this spring or its recharge area. Our groundwater tracing studies did not identify any areas which function as shared recharge areas and yield waters to other delineated groundwater system. Lantz Spring appears to be the only discharge point for groundwater from the Lantz Spring Recharge Area. The Lantz Spring Recharge Area borders recharge areas for Fogelpole Cave, Illinois Caverns, and probably some other small springs.

Stemler Cave Recharge Area

The total size of this recharge area is 7.14 square miles. The portion of the recharge area that is located in or tributary to the Stemler Cave Nature Preserve is 3.93 square miles. There are no identified lands which we have determined function as shared recharge areas and yield waters to other delineated groundwater systems. The Stemler Cave Recharge Area borders recharge areas for Falling Spring, Ritter Spring, Haney Spring, and a number of other small springs. The Stemler Cave Recharge Area discharges groundwater only at Sparrow Spring.

The report makes the following 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 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 (such as that conducted along the western border of the Stemler Cave Recharge Area) should be conducted in areas which 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 delineation of groundwater recharge areas for four biologically significant cave systems in Monroe and St. Clair Counties, Illinois. Within these cave systems lie the Armin Krueger Speleological Nature Preserve, Stemler Cave Woods Nature Preserve, Stemler Cave Nature Preserve, Fogelpole Cave Nature Preserve, and the Illinois Caverns Natural Area. In the future, additional Nature Preserves may be dedicated within these cave and groundwater systems.

The State of Illinois sought a management role of these caves in order to provide better protection for the karst ecosystems. 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 and the Monroe County Soil and Water Conservation District (MCSWCD). Within this report are the delineations of the recharge areas of Stemler Cave, the Krueger System, Fogelpole Cave, and Illinois Caverns. In addition to the delineations, the dye traces and other supporting data are presented along with interpretations.

Some explanation of the terms used in this report is warranted. A cave is defined as a void in earth materials that is humanly enterable for at least twenty feet (Illinois Speleological Survey definition). A cave system 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 cave recharge area is that surface land area that contributes water to a particular cave. A recharge area for a spring is similar in that it is the surface area which contributes water to that spring. We may speak of a cave's groundwater system; this term is basically analogous to the term recharge area except that it refers to the subsurface rather than the surface.

Karst 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 which 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 which 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. We have used these terms at several points within this report when the dye tracing data support their use.

2.1 Purpose of the Study

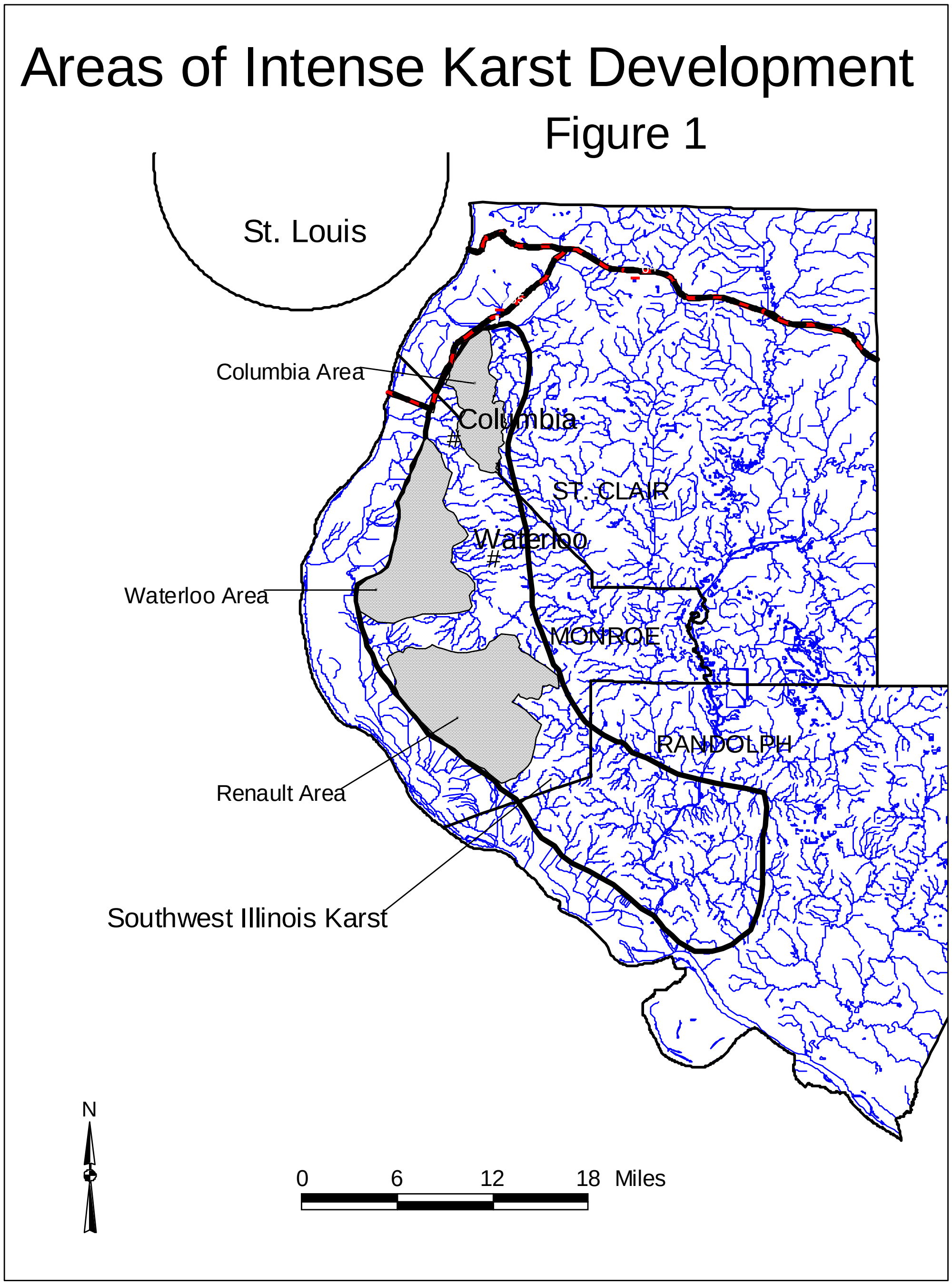
Delineation of the recharge areas of the four biologically significant caves was conducted to enhance the protection that could be afforded the four cave systems and the aquatic ecosystems they support. Each of these caves is habitat for the Illinois Cave Amphipod (Webb et al., 1998). The Krueger Cave System (often simply called the Krueger System), Fogelpole Cave, and Stemler Cave have sections that have been dedicated as Illinois Nature Preserves. Illinois Caverns is an Illinois Natural Area. The State of Illinois has a management role in each of these cave systems, and it is necessary to understand which lands contribute groundwater to these systems in order to best manage the karst resources associated with the caves.

2.2 The Study Areas

The study focused on four cave systems within the Southwest Illinois Karst region. This region can be divided into three major areas that are intensely karstified. Near Columbia is the Columbia Study Area (CSA), west of Waterloo is another intensely karstified area (not investigated during this study), and in the south near Renault is the Renault Study Area (RSA). Figure 1 shows the relationship between the Southwest Illinois karst region and the three major, intensely karstified areas within it. Fogelpole Cave, Illinois Caverns, and the Krueger System are within the RSA, while Stemler Cave is in the CSA.

The RSA includes parts of the Waterloo, Ames, Renault, and Paderborn 7.5-minute quadrangle maps and includes approximately 71 square miles. Map 1 (in pocket at the end of the report) shows the traces, sampling stations, and the recharge area delineations for the RSA.

The CSA study area is located on the Columbia, Millstadt, and Cahokia 7.5-minute quadrangle maps and includes approximately 33 square miles. Map 2 (in pocket at the end of the report) shows the CSA study area and indicates traces, sampling stations, and delineations for Stemler Cave.


Areas of Intense Karst Development
Figure 1
St. Louis
Columbia Area
Columbia
ST. CLAIR
Waterloo
Waterloo Area
MONROE
RANDOLPH
Renault Area
Southwest Illinois Karst
N
0
6
12
18
Miles

The OUL placed greater emphasis on distinguishing lands that recharge the three biologically significant caves in the RSA from the land that does not, rather than concentrating on the boundaries between the adjacent three cave recharge areas. In the CSA there is only one cave system for which a recharge area is delineated.

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 in areas between the sinkholes.

The Southwest Illinois Karst lies between the Ozark Dome and the Illinois Basin. This results in a regional dip to the northeast. 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. The four biologically significant caves appear to be limited to the St. Louis Limestone.

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).

Both the CSA and the RSA are 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.

2.4 Hydrogeologic Setting

The Southwest Illinois 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. The only surface streams are a few hundred to a few thousand feet long and typically lose all of their flow into dissolved out openings in the limestone.

Flow boundaries are drainage divides on the surface or subsurface. They can also be “no flow” boundaries 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.

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.

The following previous dye tracing studies have been conducted in the Southwest Illinois Karst:

1) Fifteen dye traces were conducted by the Ozark Underground Laboratory (OUL) (Aley and Aley, 1998) prior to this study. This work was conducted 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 recovered from multiple springs. Three of the traces conducted for the Karst Committee were in the RSA and are included in the present report. The twelve other traces were conducted in the Waterloo area and are not discussed in the present report.

2) Aley and Moss (1999a, 1999b) reported seven dye traces in the CSA. These dye traces are also discussed in the present report.

3) Moss (1998) reported three dye traces in the Waterloo area.

4) Wightman (1969) reported four dye traces he conducted in the RSA. Two traces were conducted in Illinois Caverns and one trace each in Fogelpole Cave and the Krueger System. He determined that Illinois Caverns discharged at Dye Spring and that water passing through Big Sink discharged at Kelly Spring. He recovered dye introduced in Fogelpole Cave in the headwaters of the South Fork of Horse Creek.

5) Sherrell (1998, personal communication) reported introducing fluorescein dye in Weilbacher Cave in the CSA. He reported that the dye was detected in Columbia Quarry Company's Plant No.1.

6) 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 three 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 these studies was to determine the discharge points for streams in particular caves.

Panno (1996) created unpublished preliminary maps showing his estimation of recharge areas for the four biologically significant caves. Similarly, Natural Area maps were created as part of the Illinois Natural Area Inventory (INAI) that show estimations of recharge areas. Don Coons originally created these maps under contract to IDNR (Coons, personal communication, 2000).

Water quality has been a subject of concern in the Southwest Illinois 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 Southwest Illinois Karst; substantial data were included in this publication on bacteria, nitrates, and pesticides. Panno et al. (1998) discuss the effects of land use in the inferred Fogelpole recharge area. 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 Southwest Illinois Karst. Frasz (1983) sums up exploration in the major known caves in the RSA and provides line plots of Illinois Caverns and the Krueger System. He also presents a map of Fogelpole Cave. Oliver and Graham (1988) report on the natural resources of caves throughout Illinois, including the Southwest Illinois 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. Moss (1999) presents an overlay showing the caves of the RSA.

2.5 Cave Biology

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 Southwest Illinois Karst. Webb (1995) reports that this amphipod is demonstrably present in three of these systems; the Krueger System, Illinois Caverns, and Fogelpole 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, and concluded that this amphipod is demonstrably present in six groundwater systems (three of which are in the Waterloo karst area). These Waterloo karst area populations are additions to the populations that Webb et al. (1998) reported in the RSA. The Lewis et al. (1999) study coincided with fieldwork for our delineation project and cooperation among the investigators led to an improved understanding of population relationships and possible isolation of some populations (Lewis et al., in press).

2.6 Acknowledgments

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 provided locations of potential dye introduction point locations (cave streams) as well as cave maps. These maps increased the efficiency of the study.

A number of other people also assisted in the study through mapping caves, building staff gages, searching for good dye introduction points, and sampling for tracer dyes. We thank them all; they were (in alphabetical order):

Ginny Adams	Randy Holbrook	Matt Nelson	Shirley Tierce
Aaron Addison	Christine Jeep	Neil Nichols	Dr. Rickard Toomey, III
John Archer	Mark Jones	Jean Oettle	Terry Wachter
Dr. Brooks Burr	Dr. Julian Lewis	Tom Panian	Marsha Walker
Lea Claycomb	Dave Mahon	Tony Schmitt	Ed Weilbacher
Robert Collette	Paula Martel	Joe Sikorski	John Weilbacher
Debbie Green	John Matthews	Lara Storm	Rosie Weilbacher
Colleen Haley	Myron Mugele	Dr. Steven Taylor	
Rick Haley	Richard Mueller	Diane Tecic	

During the course of our studies we were able to conduct additional tracing work in the general vicinity of Stemler Cave. This work was funded by the City of Columbia, Illinois and by the Columbia Quarry Company. The resulting data have been very helpful in delineating the western boundary for the Stemler Cave recharge area.

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. 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 during the recharge area delineation work. These were fluorescein, eosine, rhodamine WT, pyranine, and sulforhodamine B. Figure 2 shows the chemical structure of each of these dyes and summarizes some of their more important properties. 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 B provides details on the procedures and criteria used in dye tracing studies conducted by the OUL. These approaches were used throughout this study. Background sampling was conducted prior to any dye introductions. Background data were collected from springs and surface streams. Samplers were replaced periodically until all dye introductions yielded positive dye recoveries at one or more sampling stations. The only exception to that is Trace 99-128, which was introduced in an overflow passage that has not received flow since introduction.

The OUL has considerable experience with the caves that are the focus of this study. Two sets of delineations were available prior to the contract; those of the Illinois Natural Area Inventory and those created by geologists with the Illinois State Geological Survey. Neither of these sets of delineations was based on dye traces. Karst groundwater seldom follows topographic divides. Interconnections between groundwater systems are difficult to impossible to identify without dye tracing. The OUL started with the knowledge of where the caves were based on the cave maps. Springs draining the cave system were then confirmed by dye tracing. Relationships between various in-cave streams were tested for interconnections. As the OUL’s understanding of boundaries within each karst area grew, more traces could be run simultaneously without creating interpretation problems.

Figure 2. Properties of tracer dyes used in the study.

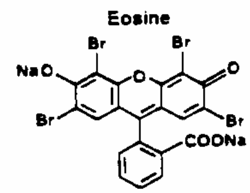
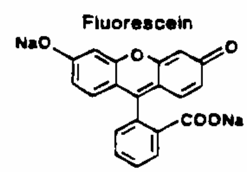
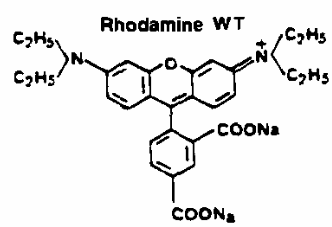
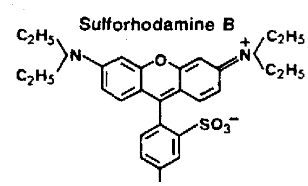
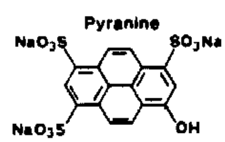
Eosine dye, (Acid Red 87; Color Index Constitution Number 45380) is a greenish to peach-colored dye (the color is a function of concentration). This dye is very successful when used in groundwater tracing in karst and fractured rock aquifers; it has good resistance to adsorption onto soil and rock materials. Eosine is one of the most detectable of the fluorescent dyes. Eosine can be adsorbed onto activated charcoal samplers for cumulative sampling. It can also be analyzed for in water samples.	
Fluorescein dye, (Acid Yellow 73; Color Index Constitution Number 45350) is a brilliant fluorescent yellow-green dye that has been used in groundwater tracing work since near the turn of the century. This dye has a long history of successful use in groundwater tracing in karst and fractured rock aquifers. Fluorescein is the most detectable of the commonly used fluorescent dyes. Fluorescein can be adsorbed onto activated charcoal samplers for cumulative sampling. It can also be analyzed for in water samples.	
Rhodamine WT dye, (Acid Red 388; no assigned Color Index Constitution Number) is a reddish-orange fluorescent dye that, like fluorescein, is commonly used in hydrologic studies. Rhodamine WT is less resistant to adsorption onto soil and rock than eosine or fluorescein. Rhodamine WT is also less detectable with instrument analysis than the other dyes considered. Rhodamine WT can be adsorbed onto activated charcoal samplers for cumulative sampling. It can also be analyzed for in water samples.	

Figure 2 (continued). Properties of tracer dyes used in the study.

Sulforhodamine B dye (Acid Red 52; Color Index Constitution Number 45380) is a red fluorescent dye occasionally used in groundwater tracing work. Sulforhodamine B is less resistant to adsorption onto soil and rock than is rhodamine WT. Under the synchronous scan analytical protocol used by the OUL, the emission peak wavelength range for sulforhodamine B dye is only slightly longer than that for rhodamine WT; some overlap in the acceptable wavelength ranges of the two dyes occurs in activated carbon samplers. Because of the adsorption characteristics and emission peak wavelength ranges, sulforhodamine B is not one of the more commonly used tracer dyes. Sulforhodamine B can be adsorbed onto activated carbon samplers for cumulative sampling. It can also be analyzed for in water samples.	
Pyranine dye, (Solvent Green 7, D&C Green 8; Color Index Constitution Number 59040) is a brilliant fluorescent green dye occasionally used in groundwater tracing work; the color in water is similar to fluorescein. Fluorescein and pyranine are similar in their resistance to adsorption onto soil and rock; they are more resistant to such adsorption than any of the other fluorescent tracer dyes. There can be interference in the fluorescence peaks if fluorescein and pyranine are both present in the sample. The fluorescence of pyranine decreases below a pH of about 9.5; fluorescence peak wavelengths vary as a function of pH. Pyranine can be adsorbed onto activated carbon samplers for cumulative sampling. It can also be analyzed for in water samples.	

When a trace was recovered and determined to be inside or outside of a given recharge area, another trace would be planned to define the recharge area boundary. These plans would be based on the knowledge of flow paths of the caves as mapped, the existing dye traces, and the logistics of dye introduction. This resulted in many of the traces being recovered from systems that are not the focus of this study. In order to define what drains to a particular groundwater system, one has to define what does not drain to it.

In order to introduce dye into perennial groundwater flow, that flow has to be physically accessible to the person introducing the dye. As a result, runoff events are needed for dye introduction at the surface, or water must be hauled to the dye introduction point. While there are many caves in the study areas, many of them are not located in particularly informative places. Runoff events were quite frequent for part of the study, but then virtually stopped. The OUL was able to take advantage of the runoff events because of staff living in the study area. During periods of extended drought, the dye introduction location options were limited to sinkholes accessible to a water truck and further limited by competition from a higher than normal demand for water deliveries.

3.2 Dye Introductions

The results of 58 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 within its study area. For example, Trace 98-105 was initiated in 1998, it is located in the RSA, and is the fifth trace initiated in that study area. Both sampling station numbers and trace numbers use the same scheme to indicate their respective study areas. All the RSA sampling stations are all 100 series numbers. Similarly, the CSA sampling stations are 200 series numbers.

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 1 summarizes data on each of the dye introductions.

3.3 Access to Land

The delineation project depended on the OUL's ability to get onto land in order to introduce dye and to get access for routine sampling. The OUL secured permission to sample at a total of 87 different stations, most of them on private property. The OUL initiated 55 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.

Table 1. Dye Introduction Data.

RSA DYE INTRODUCTIONS

Trace #	Trace Name	Trace Type & Amt. Used	Date Dye Introd.	Where Dye Introduced	Quad	Legal Description	Approx Elev. (ft msl)	Approx Flow (gpm)
96-02	Rolling Hills	Fluorescein 6 lbs	7/30/96	Sinkhole	Renault	SW1/4,SW1/4,Sec 35,T3S,R10W	670	3,200*
96-04	Fogelpole Cave Stream	RWT 2 lbs	8/13/96	NW passage of Fogelpole Cave	Renault	NE1/4,Sec 12,T4S,R10W	595	150
97-05	Fogelpole Cave Ent.	RWT 1 lb	2/20/97	U/S main ent. of cave	Renault	SE1/4,SE1/4,Sec.7,T4S,R9W	600	15
98-101	Illinois Caverns	RWT l lb	6/24/98	IL Cav Str @ Cave Ent.	Renault	NW1/4,NE1/4,Sec.31,T3S,R9W	600	100
98-102	Zebra Passage	Eosine l lb	6/26/98	Zebra Passage Str. in Fogelpole Cave	Renault	SE1/4,NE1/4,Sec.18,T4S,R9W	535	15
98-103	Nobbe	Fluorescein 1 lb	6/29/98	Sinking Str. on Wm. Nobbe's Property	Renault	NE1/4,SE1/4,Sec.25,T3S,R10W	645	1
98-104	Indian Hole	Pyranine 1 oz	9/11/98	Indian Hole	Ames	SE1/4,NW1/4,Sec.16,T4S,R9W	455	None
98-105	Metter Sinking Str.	Fluorescein 1 lb	9/22/98	Metter Sinking Stream	Renault	SE1/4,NE1/4,Sec.34,T3S,R10W	670	10
98-106	Wittenauer	SRB 1 lb	9/25/98	One of sink points along sinking stream channel	Ames	SW1/4,SW1/4,Sec.20,T4S,R9W	590	**
98-107	Jacob's	RWT 1 lb	11/13/98	Cave stream	Renault	NW1/4,NW1/4,Sec.32,T4S,R9W	590	80
98-108	Steingrubey	Eosine 1 lb	12/10/98	Sinkhole below impounded sinking str.	Renault	NW1/4,NW1/4,Sec.10,T4S,R10W	615	4,600*
98-109	Nottmeier	RWT 1 lb	12/12/98	Sinkhole	Renault	NE1/4,NW1/4,Sec.14,T4S,R10W	650	3,200*
98-110	Schuchardt	RWT 1/2 lb	12/20/98	Sinking stream	Waterloo	SW1/4,SE1/4,Sec.19,T3S,R9W	590	4
99-111	LL Road Corner	Eosine 2 lbs	1/12/99	Culvert carrying surface stream under LL Road	Ames	SW1/4,SW1/4,Sec.32,T3S,R9W	610	10
99-112	St. Joe	Fluorescein 1 lb	1/31/99	Sinkhole	Renault	SE1/4,NE1/4,Sec.36,T3S,R10W	690	60
99-113	Fults Road	SRB 1 lb	1/31/99	Sinkhole	Renault	NW1/4,NE1/4,Sec.24,T4S,R10W	600	15
99-114	Rockhouse Creek	Eosine 2 lbs	2/23/99	Rockhouse Creek	Waterloo	NW1/4,SE1/4,Sec.18,T3S,R9W	630	20
99-115	Schultheis Sinking Str.	Eosine 1 lb	2/27/99	Schultheis Sinking Str.	Renault	SW1/4,NE1/4,Sec.1,T4S,R10W	635	75
99-116	Walsh	RWT 1 lb	3/9/99	Sinkhole	Renault	SE1/4,SW1/4,Sec.30,T3S,R9W	650	2
(cont'd)								

Table 1 (cont'd). Dye Introduction Data.

Trace #	Trace Name	Trace Type & Amt. Used	Date Dye Introd.	Where Dye Introduced	Quad	Legal Description	Approx Elev. (ft msl)	Approx Flow (gpm)
99-117	Fountain Creek	Eosine 2 lbs	3/23/99	Rd xing over trib of Fountain Creek	Waterloo	SW1/4,NW1/4,Sec.24,T3S,R10W	650	175
99-118	Church	Eosine 3/4 lb	3/23/99	Sinkhole in ditch along Kaskaskia Rd.	Renault	NW1/4,NW1/4,Sec.31,T4S,R9W	460	1
99-119	Frees	Pyranine 1 lb	4/1/99	Sinking stream	Ames	SW1/4,SE1/4,Sec.4,T4S,R9W	530	8
99-120	MM Road Trace	RWT 1 lb	4/3/99	Sinking stream	Ames	SW1/4,SW1/4,Sec.4,T4S,R9W	595	90
99-121	Polka	Fluorescein 1/2 lb	4/3/99	Sinkhole	Ames	NE1/4,SW1/4,Sec.6,T4S,R9W	630	45
99-122	Barchet	Eosine 1 lb	4/28/99	Sinkhole	Ames	SE1/4,NW1/4,Sec.5,T4S,R9W	610	1
99-123	IL Caverns Natural Area	SRB 1 lb	5/5/99	Sinkhole	Renault	NW1/4,NE1/4,Sec.31,T3S,R9W	670	5
99-124	Henning Road	RWT 1 lb	5/5/99	Sinkhole	Renault	NE1/4,NE1/4,Sec.19,T4S,R9W	560	40
99-125	Gotto	Fluorescein l lb	6/21/99	Sinkhole	Renault	NW1/4,SE1/4,Sec.2,T4S,R10W	665	1
99-126	Garner	RWT 2 lbs	8/15/99	Sinkhole	Renault	SE1/4,NE1/4,Sec.13,T4S,R10W	620	3,200*
99-127	Brinner	Eosine l lb	9/12/99	Sinkhole	Renault	SE1/4,SE1/4,Sec.18,T4S,R9W	570	3,200*
99-128	Zebra Overflow	SRB 1 lb	11/2/99	Side passage off Zebra Passage in Fogelpole Cave	Renault	NE1/4,SE1/4,Sec.18,T4S,R9W	537	None
00-129	Brushy Prairie	RWT 2 lbs	2/18/00	Sinkhole	Renault	NE1/4,NE1/4,Sec.33,T3S,R10W	740	10
00-130	Kruse	Eosine 1 lb	2/18/00	Sinking stream	Renault	NW1/4,SE1/4,Sec.31,T3S,R9W	640	80
00-131	Kaskaskia Road	Fluorescein 1 lb	2/18/00	Sinkhole	Renault	SE1/4,SE1/4,Sec.12,T4S,R10W	640	30
00-132	Tipton	RWT 1 lb	3/27/00	Surface Stream	Ames	SW1/4,NW1/4,Sec.33,T3S,R9W	590	2
00-133	Metter Replicate	RWT 3 lbs	5/7/00	Metter Sinking Stream	Renault	SE1/4,NE1/4,Sec.34,T3S,R10W	670	150
CSA DYE INTRODUCTIONS								
98-201	Cossil Fast	Eosine 1 lb	6/22/98	Deep pool of water in pit	Columbia	SE1/4,NW1/4,Sec.12,T1S,R10W	585	None
98-202	Charles Sink	Fluorescein 2/3 lb	7/14/98	Small, subsurface stream	Columbia	NE1/4,SE1/4,Sec.13,T1S,R9W	635	0.5
98-203	Gilmore Lakes Sink	RWT 2 lbs	7/21/98	Sinkhole fed by lake spillway	Columbia	SW1/4,NE1/4,Sec.25,T1S,R10W	630	6
98-204	Gummerscheimer NE	Fluorescein 1/2 lb	9/24/98	Sinkhole	Columbia	NE1/4,SW1/4,Sec.2,T1S,R10W	645	**

(cont'd)

Table 1 (cont'd). Dye Introduction Data.

Trace #	Trace Name	Trace Type & Amt. Used	Date Dye Introd.	Where Dye Introduced	Quad	Legal Description	Approx Elev. (ft msl)	Approx Flow (gpm)
98-205	Gummerscheimer South	SRB 1 lb	9/24/98	Sinkhole	Columbia	SE1/4,SE1/4,Sec.2,T1S,R10W	635	**
98-206	Cemetery	Fluorescein 1/2 lb	12/12/98	Cemetery Sink	Columbia	NE1/4,SW1/4,Sec.15,T1S,R10W	540	3,200*
98-207	Pioneer Ridge	RWT 1 lb	12/12/98	Sinkhole in Pioneer Ridge Subdivision	Columbia	NW1/4,NE1/4,Sec.15,T1S,R10W	560	3,200*
99-208	Breidecker	Eosine 1 lb	1/6/99	Sinkhole in Pioneer Ridge Subdivision	Columbia	SW1/4,SE1/4,Sec.15,T1S,R10W	530	10
99-209	Gummerscheimer House	RWT 2 lbs	1/12/99	Sinkhole	Columbia	NE1/4,SW1/4,Sec.2,T1S,R10W	640	2
99-210	Gummerscheimer Central	Fluorescein 1 lb	1/13/99	Sinkhole	Columbia	SE1/4,SW1/4,Sec.2,T1S,R10W	660	4
99-211	Rodemich	Pyranine 15 oz	1/22/99	Sinking stream at Rt. 156 road crossing	Columbia	SE1/4,SE1/4,Sec.13,T1S,R10W	635	15
99-212	Spring Valley	Eosine 2 lbs	2/11/99	Headwaters of Spring Valley	Columbia	SW1/4,NW1/4,Sec.18,T1S,R9W	685	25
99-213	Stumpf	RWT 2.5 lbs	2/11/99	Sinkhole	Columbia	NE1/4,NE1/4,Sec.26,T1S,R10W	600	8
99-214	Harvell Hill	RWT 1 lb	2/27/99	Sinkhole	Columbia	SE1/4,NW1/4,Sec.35,T1N,R10W	605	4
99-215	Stemler Road	SRB 1 lb	3/23/99	Sinkhole along Stemler Rd.	Columbia	SE1/4,NE1/4,Sec.11,T1S,R10W	640	0.5
99-216	Jost	Eosine 1 lb	4/3/99	Sinkhole	Columbia	NW1/4,NW1/4,Sec.24,T1S,R10W	635	15
99-217	Wagner Road	RWT 1 lb	5/12/99	Sinkhole	Columbia	SW1/4,SE1/4,Sec.36,T1N,R10W	555	0.5
99-218	Bremser Road	Fluorescein 1 lb	5/12/99	Sinkhole	Columbia	NW1/4,NW1/4,Sec.14,T1S,R10W	645	0.5
99-219	Prairie du Long	Eosine 2 lbs	6/23/99	Prairie du Long Creek	Columbia	SE1/4,NE1/4,Sec.36,T1S,R10W	615	70
99-220	Krause	RWT 1 lb	9/12/99	Sinkhole	Columbia	NW1/4,NE1/4,Sec.14,T1S,R10W	625	3,200*
99-221	Hardin	Fluorescein 1 lb	9/12/99	Sinkhole	Cahokia	NE1/4,SW1/4,Sec.26,T1N,R10W	570	3,200*
00-222	Centreville Road	Eosine 1 lb	2/18/00	Sinkhole	Cahokia	SE1/4,NE1/4,Sec.23,T1S,R10W	660	3

* = Value indicates volume of water hauled to the site and introduced for the trace.
** = Dry set; dye mobilized by storm event.

3.4 Sampling Stations Used

A total of 87 stations were selected for use in this study. Fifty-three sampling stations were established in the RSA and are shown on Map 1. The RSA sampling stations are listed in Table 2. Thirty-four sampling stations were established in the CSA and are shown on Map 2. The CSA sampling stations are listed in Table 3.

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 the OUL's procedures and criteria document which is included as Appendix B.

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 most common duration for leaving activated carbon samplers in place is about a week.

The activated carbon samplers used during this study were manufactured by the OUL. They were packets of fiberglass screening partially filled with approximately 4.25 grams of activated coconut charcoal. The charcoal used by the OUL was Barnebey and Sutcliffe coconut shell carbon, 6 to 12 mesh, catalog type AC. The samplers are about four inches long by two inches wide; the samplers are closed by heat sealing.

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 or not a tracer dye has reached a sampling station. Water samples were analyzed during the study for background samples or at other times that seemed appropriate to the study. Water samples were also analyzed if activated carbon samplers had been lost to flood flows.

Samplers placed at springs and surface streams were placed in flowing water, where applicable, and 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.

Table 2. Index to RSA dye sampling stations.

Sta.	Station Name	Map	Location	El. (ft)
9	Vandeventer Spring	Waterloo	SE 1/4 SE 1/4 Sec 21 T2S R10W	450
101	Collier Spring	Ames	NE 1/4 SW 1/4 Sec 16 T4S R9W	458
102	Tierce Spring	Ames	SE 1/4 NW 1/4 Sec 16 T4S R9W	454.5
103	Indian Hole (pool)	Ames	SE 1/4 NW 1/4 Sec 16 T4S R9W	455
104	Indian Hole (channel)	Ames	SE 1/4 NW 1/4 Sec 16 T4S R9W	456
105	Kelly Spring (N)	Ames	SE 1/4 NE 1/4 Sec 29 T3S R9W	520
106	Kelly Spring (S)	Ames	SE 1/4 NE 1/4 Sec 29 T3S R9W	520
107	Kelly Spring (C)	Ames	SE 1/4 NE 1/4 Sec 29 T3S R9W	520
108	Lantz Spring	Ames	SW 1/4 NE 1/4 Sec 4 T4S R9W	480
109	Illinois Caverns Entrance	Renault	NW 1/4 NE 1/4 Sec 31 T3S R9W	600
110	Junction Room	Renault	SE 1/4 SE 1/4 Sec 7 T4S R9W	500
111	Coon Pit	Renault	NE 1/4 SE 1/4 Sec 18 T4S R9W	510
112	Lemonade Passage	Renault	SW 1/4 SW 1/4 Sec 5 T4S R9W	570
113	NW Passage	Renault	SW 1/4 NE 1/4 Sec 12 T4S R10W	595
114	Dye Spring	Ames	SW 1/4 NW 1/4 Sec 3 T4S R10W	475
115	Walsh Cave	Ames	SW 1/4 NE 1/4 Sec 4 T4S R10W	515
116	Walsh Spring	Ames	SW 1/4 NE 1/4 Sec 4 T4S R10W	515
117	Madonnaville Spring	Waterloo	NE 1/4 SE 1/4 Sec 19 T3S R10W	640
118	Spring #1	Renault	NW 1/4 SW 1/4 Sec 31 T4S R9W	420
119	Juelf's Spring	Renault	$38^0$11'30"N $90^0$10'00"W	535
120	Wanda's Waterfall	Renault	SW 1/4 SE 1/4 Sec 5 T4S R10W	520
121	Fults Cr. @ Fults Rd. Xing 1 mi. E. of Fults	Renault	$38^0$110'15"N $90^0$11'40"W	403
122	Morrison Hollow @ Bluff Rd.	Renault	SE 1/4 SW 1/4 Sec 17 T4S R10W	405
123	Walsh Seep	Ames	SW 1/4 NE 1/4 Sec 4 T4S R10W	510
124	Maeystown Cr. @ Baum Rd	Renault	NW 1/4 NW 1/4 Sec 5 T4S R10W	415
125	Couch's Spring	Renault	NW 1/4 SW 1/4 Sec 31 T4S R9W	440
126	Trapper Falls @ Bluff Rd.	Renault	Section line between Sec 35 & 36 T4S R10W	395
127	Unnamed Cr. @ Kaskaskia Rd. & Bluff Rd.	Renault	NW 1/4 NE 1/4 Sec 1 T5S R10W	395
128	Horse Cr. @ MM Rd Xing Sec. 2	Ames	SW 1/4 SE 1/4 Sec 2 T4S R9W	451
129	South Fk @ Rd Xing in Sec. 8	Ames	NW 1/4 SW 1/4 Sec 8 T4S R9W	580
130	South Fk @ Rd Xing in Sec. 15	Ames	SE 1/4 NE 1/4 Sec 15 T4S R9W	435
131	Trib. of Dry Fork @ Carr Rd. Sec. 28	Ames	NE 1/4 NW 1/4 Sec 28 T4S R9W	545

(cont'd)

Table 2 (cont'd). Index to RSA dye sampling stations.

Sta.	Station Name	Map	Location	El. (ft)
132	Bat Sump	Ames	SE 1/4 NE 1/4 Sec 17 T4S R9W	485
133	Curran Spring	Ames	NE 1/4 NE 1/4 Sec 33 T3S R9W	470
134	Spider Cave	Renault	NW 1/4 SW 1/4 Sec 30 T3S R9W	630
135	Big Sink	Ames	NW 1/4 SE 1/4 Sec 29 T3S R9W	545
136	Cr. U/S of Kelly Spr.	Ames	SE 1/4 NE 1/4 Sec 29 T3S R9W	522
137	Collier D/S	Ames	NE 1/4 SW 1/4 Sec 16 T4S R9W	458
138	Jacob's Sink	Ames	SE 1/4 NW 1/4 Sec 32 T4S R9W	590
139	Little Spring	Renault	NW 1/4 SE 1/4 Sec 31 T4S R9W	560
140	Spring #3	Renault	NE 1/4 SW 1/4 Sec 31 T4S R9W	560
141	Horse Cr. @ Ames Rd. Xing	Ames	NE 1/4 SE 1/4 Sec 14 T4S R9W	410
142	Steam Thresher Spring (U)	Renault	NE 1/4 NW 1/4 Sec 14 T4S R10W	555
143	Steam Thresher Spring (L)	Renault	NW 1/4 NW 1/4 Sec 14 T4S R10W	520
144	Alfred Spring	Renault	NW 1/4 NW 1/4 Sec 14 T4S R10W	515
145	Fruth's Pump Hole	Waterloo	NW 1/4 NE 1/4 Sec 30 T3S R9W	580
146	Fountain Cr. @ Maeystown Rd.	Waterloo	NW 1/4 SE 1/4 Sec 35 T2S R10W	545
147	Rockhouse Cr. @ J Rd.	Paderborn	NE 1/4 SE 1/4 Sec 11 T3S R9W	435
148	Rockhouse Cr. @ Rt. 3	Paderborn	SW 1/4 SW 1/4 Sec 8 T3S R9W	588
149	Unnamed Cr. @ Bluff Rd. in Sec. 36	Renault	SE 1/4 SW 1/4 Sec 36 T4S R10W	390
150	Sm. Cr. @ Bluff Rd in French Sec.	Renault	38^{0}08'51"N 90^{0}11'02"W	385
151	Horse Cr. U/S Curran Spr.	Ames	NE 1/4 NE 1/4 Sec 33 T3S R9W	475
152	Zebra P. U/S of Coon Pit	Renault	NE 1/4 SE 1/4 Sec 18 T4S R9W	510
153	Cascade Canyon	Renault	SE ¼ NE ¼ Sec 31 T4S R9W	590

Table 3. Index to Columbia Study Area dye sampling stations.

Sta.	Station Name	Map	Location	El. (ft)
201	Stemler Cave	Columbia	SW 1/4 NW 1/4 Sec 12 T1S R10W	550
202	Sparrow Spring	Columbia	NW 1/4 NW 1/4 Sec 36 T1N R10W	495
203	Ritter Spring	Columbia	SE 1/4 NW 1/4 Sec 15 T1S R10W	480
204	Cement Hollow D/S of springs	Columbia	SW 1/4 NW 1/4 Sec 34 T1N R10W	520
205	County Line Spring	Columbia	NE 1/4 NE 1/4 Sec 23 T1S R10W	615
206	Spring Valley Spr.	Columbia	NE 1/4 NE 1/4 Sec 36 T1N R10W	530
207	Cement Hollow Cr. @ Rt. 3	Columbia	$38^0$29'06"N $90^0$12'50"W	415
208	Hill Lake Cr. @ Rt. 3	Columbia	$38^0$28'11"N $90^0$13'14"W	415
209	Palmer Cr. @ Ghent Rd.	Columbia	$38^0$27'45"N $90^0$13'18"W	415
210	Wilson Cr. @ Old Rt. 3	Columbia	SE 1/4 NW 1/4 Sec 22 T1S R10W	475
211	Hickman Cr. @ Saeger Rd.	Columbia	SW 1/4 SE 1/4 Sec 31 T1N R9W	507
212	Spring Valley U/S Spr.	Columbia	NE 1/4 NE 1/4 Sec 36 T1N R10W	515
213	Haney Spring	Columbia	NW 1/4 NE 1/4 Sec 23 T1S R10W	590
214	Falling Springs	Cahokia	SE 1/4 SE 1/4 Sec 15 T1N R10W	500
215	Palmer Cr. @ Rueck Rd.	Columbia	NE 1/4 NE 1/4 Sec 9 T1S R10W	445
216	Spring Valley @ Saeger Rd.	Columbia	NE 1/4 NE 1/4 Sec 1 T1S R10W	545
217	Spring Valley @ Kropp Rd.	Columbia	Section line between Sec 6 & 7 T1S R10W	585
218	Quarry Discharge	Columbia	NE 1/4 SE 1/4 Sec 10 T1S R10W	505
219	Quarry Pond	Columbia	NW 1/4 NW 1/4 Sec 11 T1S R10W	456 (bottom of pond)
220	Stemler Cave-2	Columbia	NE 1/4 NE 1/4 Sec 12 T1S R10W	544
221	Stemler Cave-3	Columbia	SW 1/4 NE 1/4 Sec 1 T1S R10W	539
222	Stemler Cave-4	Columbia	SW 1/4 NE 1/4 Sec 1 T1S R10W	540
223	Stemler Cave-5	Columbia	NE 1/4 NE 1/4 Sec 1 T1S R10W	530
224	WH Spring	Columbia	NW 1/4 NW 1/4 Sec 36 T1N R10W	520

(cont’d)

Table 3 (cont'd). Index to Columbia Study Area dye sampling stations.

Sta.	Station Name	Map	Location	El. (ft)
225	Cemetery Sink	Columbia	NE 1/4 SW 1/4 Sec 15 T1S R10W	540
226	Trib. of Wilson Cr. @ Centreville Rd.	Columbia	NE 1/4 NE 1/4 Sec 22 T1S R10W	500
227	Trib. of Palmer Cr. @ Cherry St.	Columbia	SW 1/4 SW 1/4 Sec 15 T1S R10W	485
228	Headquarters Spring	Columbia	NE 1/4 NW 1/4 Sec 23 T1S R10W	565
229	Prairie du Pont Cr. @ Imbs Sta. Rd.	Cahokia	NW 1/4 SW 1/4 Sec 19 T1N R9W	425
230	Fish Lake Cr. @ Frontage Rd.	Cahokia	SE 1/4 NE 1/4 Sec 28 T1N R10W	395
231	W. Fk. Richland Cr. @ Roenicke Rd.	Millstadt	NW 1/4 NW 1/4 Sec 29 T1S R9W	615
232	Prairie du Long Cr. @ Bohleysville Rd.	Millstadt	NE 1/4 SE 1/4 Sec 4 T2S R9W	505
233	Plant #1 Spr.	Columbia	NW 1/4 NW 1/4 Sec 11 T1S R10W	610
234	Quirky Quarry Spr.	Columbia	NW 1/4 NW 1/4 Sec 23 T1S R10W	530

At all stream and spring sampling stations at least two independently anchored samplers were placed to minimize the risk of sampler loss. To the extent reasonable both samplers were placed in similar settings so that they would be likely to produce similar analytical results.

When carbon samplers were collected, new samplers were placed. Collected samplers were placed in sterile plastic bags ("Whirl-Paks"). The bags were labeled on the outside with the station name and the date and time of collection. At stream and spring stations where two samplers were collected both samplers were placed in the same sample bag. Sometimes one of the samplers might be out of the water at the time of collection because of flooding or because of a drop in water level. If this were the case, or if for some other reason one sampler appeared to have been appreciably better positioned to sample the water, the better positioned packet was folded and stapled prior to insertion into the sample bag to identify it. This better positioned sampler was then the sampler selected in the laboratory for analysis.

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

Carbon samplers arriving at the OUL were washed under relatively strong jets of water to remove sediment and organic material. For stations where two samplers were collected for the same sampling period one of the samplers was placed in frozen storage. One sampler from each sampling station was then eluted with 15 ml of a standard eluting solution for a period of one hour. The standard eluting solution was prepared as follows. First, a solution was prepared which consisted of 5% aqua ammonia solution and 95% isopropyl alcohol solution. The aqua ammonia solution contained 29% ammonia and 71% reagent water. The isopropyl alcohol solution was 70% isopropyl alcohol and 30% reagent water. Next, pellets of potassium hydroxide were added to the solution until saturation occurred; this was evidenced by the development of a super-saturated solution in the bottom of the container. The supernatant (i.e., the liquid above the super-saturated layer) was then poured off and was used as the eluting solution.

After the one-hour elution period the eluting liquid was gently poured off the activated carbon from a sampler and the carbon was discarded. All containers used for elution or sample transfer were disposable and were kept covered with disposable covers. Approximately 2.5 ml of the elutant was withdrawn with a disposable pipette and placed in a disposable cuvette. This sample was then subjected to analysis in a Shimadzu RF-5000U Spectrofluorophotometer using a synchronous scan of excitation and emission wavelengths with a 17 nm wavelength separation. Elutant samples were analyzed using a 5 nm excitation slit and a 3 nm emission slit to ensure adequate discrimination between tracer dyes and other fluorescent materials that might be present. A Shimadzu RF-540 Spectrofluorophotometer was available as a back-up instrument, but was not used during this study. All disposable materials are used only once and are then discarded.

Fluorescence peaks in the emission fluorescence profile were picked to the nearest 0.1 nm. The OUL has a large database of results from actual groundwater traces. Using this database, the OUL has calculated an acceptable wavelength range for each of the tracer dyes in each matrix tested (the matrixes are the standard eluting solution and water). Acceptable wavelength ranges are specific to the instrument being used. The acceptable wavelength range is the mean emission fluorescence peak plus and minus two standard deviations. The acceptable wavelength ranges for the five dyes used in this study are identified in the following paragraphs; the detection limit for each of the dyes (based upon the as-sold weight of the dye) is also indicated.

The acceptable wavelength range for fluorescein dye in the standard elutant is from 510.7 to 515.0 nm. The detection limit is 0.010 micrograms per liter (parts per billion).

The acceptable wavelength range for eosine dye in the standard elutant is from 533.0 to 539.6 nm. The detection limit is 0.020 micrograms per liter (parts per billion).

The acceptable wavelength range for rhodamine WT dye in the standard elutant is from 561.7 to 568.9 nm. The detection limit is 0.155 micrograms per liter (parts per billion).

The acceptable wavelength range for sulforhodamine B dye in the standard elutant is from 567.5 to 577.5 nm. The detection limit is 0.080 micrograms per liter (parts per billion).

The acceptable wavelength range for pyranine dye in the standard elutant is from 499.1 to 503.9 nm. The detection limit is 0.125 micrograms per liter (parts per billion).

Criteria for Positive Fluorescein Dye Recoveries in Elutant

There are sometimes some fluorescence background peaks in the range of fluorescein dye present at some of the stations used in groundwater tracing studies. We routinely conduct background sampling prior to the introduction of any tracer dyes to characterize this background fluorescence and to identify the existence of any tracer dyes that may be present in the area. For activated carbon packet elutant samples subjected to analysis on the RF-5000U we routinely identify all fluorescence peaks with wavelengths between 503.9 and 520.9 nm. The fact that a fluorescence peak is identified in our analytical results is not proof that it is fluorescein dye or that it is fluorescein dye from the trace of concern. The following 4 criteria are used to identify wavelength peaks that are deemed to be fluorescein dye recoveries from our tracing work.

Criterion 1. There must be at least one fluorescence peak at the station in question in the range of 510.7 to 515.0 nm for samples analyzed by the RF-5000U.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. For the RF-5000U the fluorescein detection limit in elutant samples is 0.010 ppb, thus this reporting concentration limit equals 0.030 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of fluorescein. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of fluorescein. In addition, there must be no other factors that suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work.

Criteria for Positive Eosine Dye Recoveries in Elutant

There are usually no detectable fluorescence background peaks in the general range of eosine dye encountered in most groundwater tracing studies. The following four criteria are used to identify wavelength peaks that are deemed to be eosine dye.

Criterion 1. There must be at least one fluorescence peak at the station in question in the range of 533.0 to 539.6 nm for samples analyzed by the RF-5000U.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. For the RF-5000U the eosine detection limit in elutant samples is 0.020 ppb, thus this reporting concentration limit equals 0.060 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of eosine. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of eosine. In addition, there must be no other factors that suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work.

Criteria for Positive Rhodamine WT Dye Recoveries in Elutant

There are generally no detectable fluorescence background peaks in the general range of rhodamine WT dye encountered in most groundwater tracing studies. The following four criteria are used to identify wavelength peaks that are deemed to be rhodamine WT.

Criterion 1. For samples analyzed on the RF-5000U, there must be at least one fluorescence peak at the station in question in the range of 561.7 to 568.9 nm.

Criterion 2. The dye concentration associated with the rhodamine WT peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in elutant samples is 0.155 ppb, thus this reporting concentration limit equals 0.465 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of rhodamine WT. In addition, there must be no other factors that suggest that the fluorescence peak may not be dye from the groundwater tracing work under investigation.

Criteria for Positive Sulforhodamine B Dye Recoveries in Elutant

There are generally no detectable fluorescence background peaks in the general range of sulforhodamine B dye encountered in most groundwater tracing studies. The following four criteria are used to identify wavelength peaks that are deemed to be sulforhodamine B.

Criterion 1. For samples analyzed on the RF-5000U, there must be at least one fluorescence peak at the station in question in the range of 567.5 to 577.5 nm.

Criterion 2. The dye concentration associated with the sulforhodamine B peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in elutant samples is 0.080 ppb, thus this reporting concentration limit equals 0.240 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of sulforhodamine B. In addition, there must be no other factors that suggest that the fluorescence peak may not be dye from the groundwater tracing work under investigation.

Criteria for Positive Pyranine Dye Recovery in Elutant

The following four criteria are used to identify emission fluorescence peaks that are pyranine dye in elutant samples. The acceptable wavelength ranges shown are derived from the general OUL dye tracing database.

Criterion 1. There must be at least one emission fluorescence peak at the station in question in the range of 493.5 to 508.5 nm.

Criterion 2. The dye concentration associated with the emission fluorescence peak must be at least three times the detection limit. For the RF-5000U, this detection limit in elutant is 0.125 ppb, thus this reporting concentration limit equals 0.375 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the dye sampling station in question.

Criterion 4. The shape of the emission fluorescence peak must be typical of pyranine. In addition, there must be no other factor or factors that suggest that the emission fluorescence peak may not be dye from the groundwater tracing work under investigation

3.5.2 Water Samples

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 a Shimadzu RF-5000U Spectrofluorophotometer using a synchronous scan of excitation and emission wavelengths with a 17 nm wavelength separation. Water samples were analyzed using a 5 nm excitation slit and a 10 nm emission slit to insure adequate discrimination between tracer dyes and other fluorescent materials that might be present.

Fluorescence peaks in the emission fluorescence profile were picked to the nearest 0.1 nm. The OUL has a large database of results from actual groundwater traces. Using this database, the OUL has calculated an acceptable wavelength range for each of the tracer dyes in each matrix tested (the matrixes are the standard eluting solution and water). Acceptable wavelength ranges are specific to the instrument being used. The acceptable wavelength range is the mean emission fluorescence peak plus and minus two standard deviations. The acceptable wavelength ranges for the five dyes relevant to the water samples collected (fluorescein, eosine, rhodamine WT, sulforhodamine B, and pyranine) are identified in the following paragraphs; the detection limit for each of the dyes (based upon the as-sold weight of the dye) is also indicated.

The acceptable wavelength range for fluorescein dye in water is from 505.6 to 510.5 nm. The detection limit is 0.0005 micrograms per liter (parts per billion).

The acceptable wavelength range for eosine dye in water is from 529.6 to 538.4 nm. The detection limit is 0.001 micrograms per liter (parts per billion).

The acceptable wavelength range for rhodamine WT dye in water is from 569.4 to 574.8 nm. The detection limit is 0.007 micrograms per liter (parts per billion).

The acceptable wavelength range for sulforhodamine B dye in water is from 576.2 to 579.7 nm. The detection limit is 0.020 micrograms per liter (parts per billion).

Pyranine dye is pH adjusted with eluent. Thus, there are no criteria for positive pyranine dye recovery in water, the elutant standard is used in all cases.

Criteria for Positive Fluorescein Dye Recoveries in Water

The following three criteria are used to identify emission fluorescence peaks that are fluorescein dye in water samples.

Criterion 1. The associated activated carbon sampler for the station should also contain fluorescein dye in accordance with the criteria listed earlier. This criterion may be waived if no activated carbon sampler exists.

Criterion 2. There must be no fact or factors that suggest that the fluorescence peak may not be fluorescein dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 505.6 to 510.5 nm.

Criterion 3. The dye concentration associated with the fluorescein peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in water samples is 0.0005 ppb, thus this reporting concentration limit equals 0.0015 ppb.

Criteria for Positive Eosine Dye Recoveries in Water

The following three criteria are used to identify emission fluorescence peaks that are eosine dye in water samples.

Criterion 1. The associated activated carbon sampler for the station should also contain eosine dye in accordance with the criteria listed earlier. This criterion may be waived if no activated carbon sampler exists.

Criterion 2. There must be no fact or factors that suggest that the fluorescence peak may not be eosine dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 529.6 to 538.4 nm.

Criterion 3. The dye concentration associated with the eosine peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in water samples is 0.001 ppb, thus this reporting concentration limit equals 0.003 ppb.

Criteria for Positive Rhodamine WT Dye Recoveries in Water

The following three criteria are used to identify emission fluorescence peaks that are rhodamine WT dye in water samples.

Criterion 1. The associated activated carbon sampler for the station should also contain rhodamine WT dye in accordance with the criteria listed earlier. This criterion may be waived if no activated carbon sampler exists.

Criterion 2. There must be no fact or factors that suggest that the fluorescence peak may not be rhodamine WT dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 569.4 574.8 nm.

Criterion 3. The dye concentration associated with the rhodamine WT peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in water samples is 0.007 ppb, thus this reporting concentration limit equals 0.021 ppb.

Criteria for Positive Sulforhodamine B Dye Recoveries in Water

The following three criteria are used to identify emission fluorescence peaks that are sulforhodamine B dye in water samples.

Criterion 1. The associated activated carbon sampler for the station should also contain sulforhodamine B dye in accordance with the criteria listed earlier. This criterion may be waived if no activated carbon sampler exists.

Criterion 2. There must be no fact or factors that suggest that the fluorescence peak may not be sulforhodamine B dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 576.2 to 579.7 nm.

Criterion 3. The dye concentration associated with the sulforhodamine B peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in water samples is 0.020 ppb, thus this reporting concentration limit equals 0.060 ppb.

Criteria for Positive Pyranine Dye Recovery in Water.

The following three criteria are used to identify emission fluorescence peaks that are pyranine dye in water samples. The acceptable wavelength ranges shown are derived from the general OUL dye tracing database.

Criterion 1. The associated charcoal samplers for the station should also contain pyranine dye in accordance with the criteria listed above. This criterion may be waived if no charcoal sampler exists.

Criterion 2. There must be no factor or factors that suggest that the emission fluorescence peak may not be pyranine dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 499.1 to 503.9 nm.

Criterion 3. The dye concentration associated with the emission fluorescence peak must be at least three times the detection limit. Pyranine dye is pH adjusted with eluent. Thus, there are no criteria for positive pyranine dye recovery in water, the elutant standard is used in all cases. For the RF-5000U, this detection limit in elutant is 0.125 ppb, thus this reporting concentration limit equals 0.375 ppb.

4.0 RESULTS

4.1 Introduction

The contracts required a combined total of 30 to 36 dye traces using about 35 sampling stations. The OUL made 49 dye introductions specifically for this study and is including the results of 58 dye introductions in this report. Dye was recovered for 57 of the 58 dye introductions. Trace 99-128, the Zebra Overflow Trace, was placed as a dry set and has not been mobilized by a large enough storm event. Eighty-seven sampling stations were established in the course of the study. Maps 1 and 2 (to be introduced later) show the introduction points and the sampling stations used. These maps also show the diagrammatic path from the introduction point to the recovery point for each trace. The traces will be discussed by study area. Three dye traces were conducted by the 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). Three additional traces were conducted for the City of Columbia and fall into the CSA (Aley and Moss, 1999b) and four more traces were conducted for the Columbia Quarry Company (Aley and Moss, 1999a), also in the CSA. A discussion of these traces in this report (Section 4.2) is included to insure completeness.

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) water 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 recovered,
7) estimated groundwater flow path velocities,
8) elevation change between introduction and recovery points,
9) groundwater flow path gradient,
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.

The figures are 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 maps to understand the geography of each trace. These figures include all the sampling stations that are in the current ArcView file. Some of the sampling stations were not established at the time of the early traces. The lines representing the dye traces are straight lines between the introduction points and each recovery point. In some cases the lines pass over or near sampling stations where dye was not recovered. These instances are addressed in the discussion of the individual results. For some traces the actual flow paths may be quite different from the straight lines presented in this report.

Dye concentrations for each sampling station where dye was recovered are tabulated in the discussion of the relevant trace. The concentrations are reported in parts per billion (ppb). The data are from charcoal samplers unless otherwise noted. Within the tables, 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.

A brief discussion of terminology used throughout the rest of this report will be useful. The 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 all lands which contribute water to known cave passages plus other lands which contribute water to the spring or springs through which water from the cave discharges.

There are various Illinois State Nature Preserves and Natural Areas which overlie caves studied in this investigation. To assist in the management of these areas we have routinely delineated the portions of the cave recharge areas which contribute water to individual Nature Preserves or Natural Areas.

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. Shared recharge areas are also discussed in the tracing results and delineated in this report.

4.2 Dye Tracing Results by Individual Traces, Renault Study Area

Each of the dye traces in the RSA is discussed in the following section of this report. For each trace, the most relevant portions of the analytical results for the dye detection stations are shown. All data from the traces is found in Appendix A.

Some of the same sampling stations used in the previous study (Aley and Aley, 1998) were used in the current study. The numbering scheme has changed in the current project. The current station numbering is shown in parentheses in the relevant results tables.

Groundwater trace distances, elevation losses, gradients, and travel times for RSA traces are summarized in Table 4, which is located at the end of Section 4.2. Actual mean groundwater velocity values shown in the table are based upon straight-line distances from the point of dye introduction to the point of detection. The actual flow route is obviously longer, so the true mean velocity is somewhat greater than reported. However, the velocities reported are useful for predicting time of travel for any traced flow path under similar hydrologic conditions. Mean groundwater gradient values are also somewhat greater than reported since these calculations also assume straight-line distance.

Three of the studied cave systems are located in the RSA and are proximate to each other. The caves identified in this contract are Illinois Caverns, the Krueger System, and Fogelpole Cave. The main entrance to Illinois Caverns is within the IDNR-owned Illinois Caverns Natural Area. One hundred and five (105) acres of privately owned land have been dedicated as the Armin Krueger Speleological Nature Preserve and contains four entrances to the Krueger system. Three of the entrances are to the Krueger end of Krueger – Dry Run Cave. The farthest downstream of these, Big Sink, was sampled for dye. The fourth entrance to the system is Dual Pit, an entrance to Kelly Spring Cave. Kelly Spring Cave is a cave that comprises the downstream section of the Krueger System, and includes the discharge point for the system, Kelly Spring. Kelly Spring is not part of the Nature Preserve. The main entrance to Fogelpole Cave is on the IDNR-owned Fogelpole Cave Nature Preserve.

4.2.1 Trace 96-02: Rolling Hills Trace.

This trace predates the current study. Six pounds of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced in the SW ¼ SW ¼ Section 35, T3S, R10W. The elevation of the dye introduction point is approximately 670 feet msl. The dye was introduced into a sinkhole using potable water that was hauled to the sinkhole by truck. 3,200 gallons of water were introduced into the groundwater system on the morning of July 30, 1996. The discharge rate to the sinkhole during discharge from the tank truck averaged about 160 gallons per minute (gpm); this did not result in any ponding of water in the sinkhole. The trace is shown on Figure 3.

Mr. Charles Harrison proposed a subdivision to be called Rolling Hills Estate. The subdivision includes all, or essentially all, of the land in SW ¼ SW ¼ of Section 35, T3S, R10W. This area is shown on the Renault 7.5-minute quadrangle map. The Illinois Department of Natural Resources (IDNR) became involved through the consultation process and was concerned that the proposed subdivision might contribute water to the Fogelpole Cave System. It was the concern of IDNR that the proposed subdivision might contaminate the water and adversely affect the ecosystem of the Fogelpole Cave Nature Preserve.

The concern of IDNR is understandable. The IDNR presumed that the area of the proposed subdivision contributed water to the Fogelpole Cave System because a high density of sinkholes that is relatively continuous from over known parts of Fogelpole Cave to this site. Fogelpole Cave is incompletely mapped and it was not known whether or not there are passages connecting to Fogelpole Cave that underlie the proposed subdivision. Assessment of this potential contribution required a groundwater tracer study and the Mississippi Karst Resources Planning Committee directed some of their resources towards providing that assessment.

The stations sampled for this trace were (using the current numbering scheme): 101, 108, 109, 110, 113, 114, 117, 119, 121, 128, 130, 131.

Data on dye recovery locations for Trace 96-02 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 1. Collier Spring (Station 101)

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
6/24 to 7/23/96	ND	ND
7/23 to 8/14/96	513.4	2,910
7/23 to 8/14/96 (dup.)	513.5	2,630
8/14 to 9/2/96	513.7	7,990
8/14 to 9/2/96 (dup.)	513.8	9,100
9/2 to 10/5/96	513.0	59.3

Station 33. South Fork at Road Crossing in Section 15 (Station 130)

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
6/27 to 7/23/96	ND	ND
7/23 to 8/13/96	511.8	1.17
8/13 to 9/2/96	513.4	1,510
8/13 to 9/2/96 (dup.)	513.8	1,830

Fluorescein dye was recovered from the Rolling Hills Trace at Collier Spring (also known as Big Spring). Collier Spring is located in the NE ¼ SW ¼ of Section 16, T4S, R9W. It is shown on the Ames 7.5-minute quadrangle map and is shown on Figure 3 as Station 101. The straight-line groundwater travel distance is approximately 26,000 feet. The elevation loss from the dye introduction point to Collier Spring is about 210 feet. The mean gradient of this flow path is approximately 43 feet per mile. Water discharging from Collier Spring on August 14, 1996 at 1930 hours was visibly green with fluorescein dye. Dye continued to be discharged from Collier Spring for at least a month.

No fluorescein was detected in activated carbon samplers located in any of the four in-cave sampling stations within Fogelpole Cave; Stations 13 and 48 at the upstream end of the Northwest Passage (replaced by Station 113), Station 14 at the Main Entrance (Station 110), or at Station 50 in Zebra Passage (replaced by Station 111). Figure 3 shows the diagrammatic line of the dye trace as passing very close to Stations 110 and 132. No dye was recovered at those stations. The line that is defined only by the dye input point and the dye recovery point happens to fall near those sampling stations. It does not mean that the actual flow path is close to those sampling stations. It is more likely that the actual flow path curves around the Fogelpole Cave recharge area.

Collier Spring discharges to the South Fork of Horse Creek. Station 33 (130) is located about two stream miles downstream from Collier Spring. This section of Horse Creek has very slow velocity under low flow conditions. Based upon these conditions and the dye concentrations, we estimate that dye from Trace 96-02 first began to discharge from Collier Spring on about August 11; this was approximately 12 days after dye introduction. From this estimate and assuming a straight-line flow path, the groundwater traveled at an average rate of 2,170 feet per day under these conditions.

The Rolling Hills Trace demonstrates that groundwater in the RSA can travel great distances. Dye can be considered a surrogate for contaminants in groundwater. The high concentration of dye at the spring suggests that in spite of significant dilution and the natural attenuation of dye flowing through streams, whether above or below ground, that there was little natural cleansing of the groundwater.

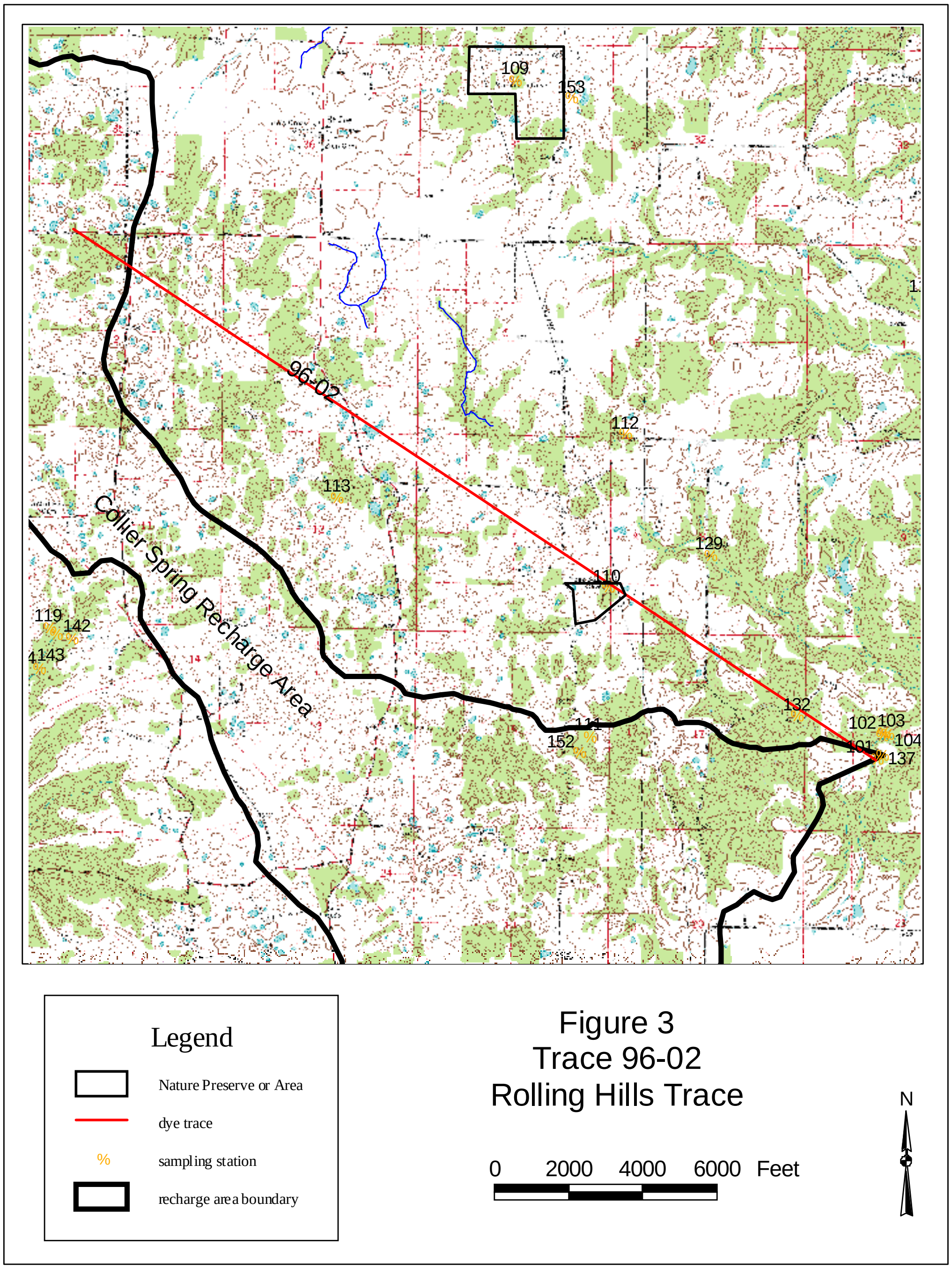


Figure 3
Trace 96-02
Rolling Hills Trace

4.2.2 Trace 96-04: Fogelpole Cave Stream Trace.

This trace is part of the data predating this study. Two pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced in the NE ¼ of Section 12, T4S, R10W. The elevation of the dye introduction point is estimated to be 595 feet msl and is in the Northwest Passage of Fogelpole Cave. The cave stream flow was not estimated at the time of introduction, but base flow at that point is about 150 gpm. The dye introduction was made on August 13, 1996 at 1730 hours. The dye introduction site is shown on the Renault 7.5-minute quadrangle map. The trace is shown on Figure 4.

The stations sampled for this trace were (using the current numbering scheme): 101, 110, and 130.

Data on dye recovery locations for Trace 96-04 are listed below All data are for charcoal samplers unless otherwise noted.

Station 14. Main Entrance Fogelpole Cave (Station 110)

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
7/20 to 8/19/96	563.4	1,080
8/19 to 8/30/96	564.0	40.8

Station 33. South Fork at Road Crossing in Section 15 (Station 130)

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
6/27 to 7/23/96	ND	ND
7/23 to 8/13/96	ND	ND
8/13 to 9/2/96	563.8	231
8/13 to 9/2/96 (dup.)	563.7	215

Rhodamine WT dye was recovered from Fogelpole Cave at the sampling station in the Junction Room, which is located near the entrance shown on the Renault 7.5-minute quadrangle map. Rhodamine WT dye was also recovered from the South Fork of Horse Creek demonstrating that the spring discharging the water from Fogelpole is upstream from that sampling station. This trace was partially replicated by Trace 97-05 after the OUL had placed samplers in Tierce Spring and Indian Hole. The results of Trace 97-05 indicate that dye from Trace 96-04 was discharged from Tierce Spring. No fluorescein dye from Trace 96-02 was detected in the Junction Room in Fogelpole Cave. This demonstrates that the groundwater flow paths followed by Traces 96-02 and 96-04 were different.

Taking into account the results of Trace 97-05 (to be discussed next), the groundwater flow path from the dye introduction point to Tierce Spring was approximately 15,500 feet, and the elevation loss was approximately 140 feet. From the point of dye introduction to the Junction Room (which is near the main entrance to Fogelpole Cave) the straight line distance is approximately 7,700 feet. The time of first arrival of the dye and the peak dye concentration occurred within six days of dye introduction. If we assume that the first dye arrival at the Junction Room actually occurred 5 days after dye introduction, then the mean groundwater travel rate for this trace from the dye introduction point to the Junction Room was about 1,540 feet per day. The elevation loss between the dye introduction point and the Junction Room is about 95 feet, which represents a mean gradient of 65 feet per mile.

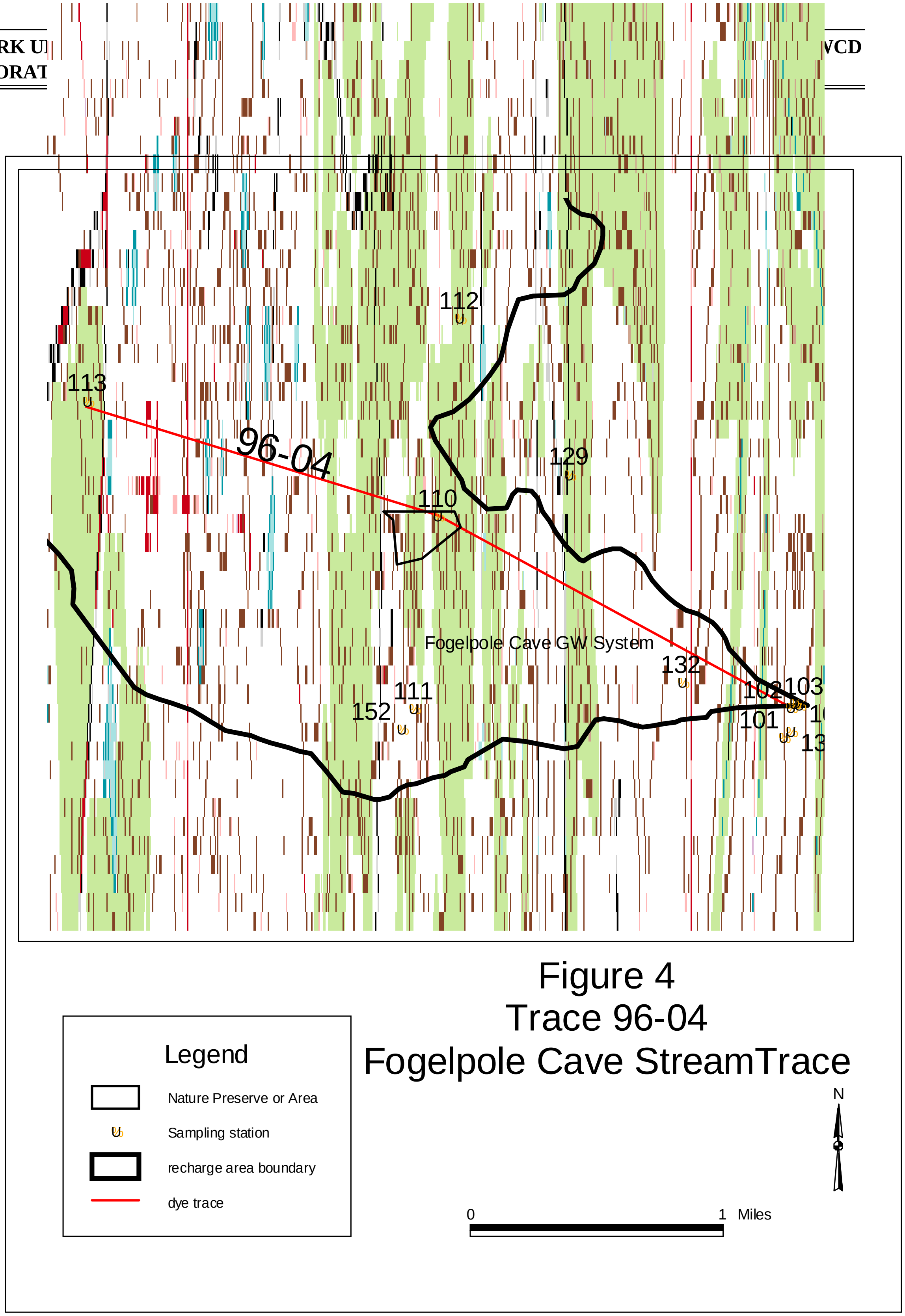


Figure 4
Trace 96-04
Fogelpole Cave StreamTrace

4.2.3 Trace 97-05: Fogelpole Cave Entrance Trace.

This is the last of the previously conducted traces. One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced in the SE ¼ SE ¼ of Section 7, T4S, R9W. The elevation of the dye introduction point is approximately 600 feet msl. The dye introduction was made on February 20, 1997 at 1710 hours, just upstream of the main entrance to the cave. At the time of dye introduction water was sinking into the groundwater system at this location at a rate of 15 gpm as a result of storm runoff. This flow is wet weather flow only, and the water sank into the streambed before reaching the cave entrance. The dye introduction point is shown on the Renault 7.5-minute quadrangle map. The trace is shown on Figure 5.

The stations sampled for this trace were (using the current numbering scheme): 101, 102, 103, and 130. Data on dye recovery locations for Trace 97-05 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 33. South Fork at Road Crossing in Section 15 (Station 130)

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
2/5 to 2/15/97	ND	ND
2/15 to 2/23/97	562.5	8.31
2/23 to 3/15/97	ND	ND

Station 63. Tierce Spring (Station 102)

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
2/5 to 2/15/97	ND	ND
2/15 to 2/23/97	563.5	43.2
2/23 to 3/15/97	ND	ND

Dye from Trace 97-05 was recovered from Station 33 (Station 130), South Fork at Road Crossing in Section 15. Station 33 is downstream of Collier Spring, Indian Hole (an overflow spring associated with Tierce Spring), and Tierce Spring. Rhodamine WT dye was recovered from Tierce Spring demonstrating that it is a discharge point for Fogelpole Cave. Based on this trace, it is our conclusion that dye from Trace 96-04 also discharged from Tierce Spring. No rhodamine WT dye was recovered from Collier Spring.

These results, when combined with the data from Traces 96-02 and 96-04, indicate that the groundwater systems feeding Collier and Tierce Springs are separate under these conditions. This appears to be in conflict with the findings of Wightman (1969). A close reading of Wightman (1969) indicates that these results are not in conflict with Wightman's results since he sampled downstream of the confluence of Collier and Tierce Springs. He apparently inferred that the dye he detected had discharged from Collier Spring.

The straight-line groundwater travel distance for this trace to Tierce Spring is approximately 8,400 feet. The elevation loss from the dye introduction point to Tierce Spring is approximately 146 feet. The cave drops 95 feet from the entrance to the Junction Room (Hauck and Addison, 2000). The mean groundwater flow path gradient from the Junction Room to Tierce Spring is approximately 32 feet per mile. Dye was first recovered in less than 67 hours after introduction at dye recovery stations. If we assume that the first dye arrival at Tierce Spring occurred 2 days after dye introduction, the mean groundwater flow velocity along this flow path was about 4,200 feet per day. All detectable dye was discharged from Tierce Spring within three days after dye introduction.

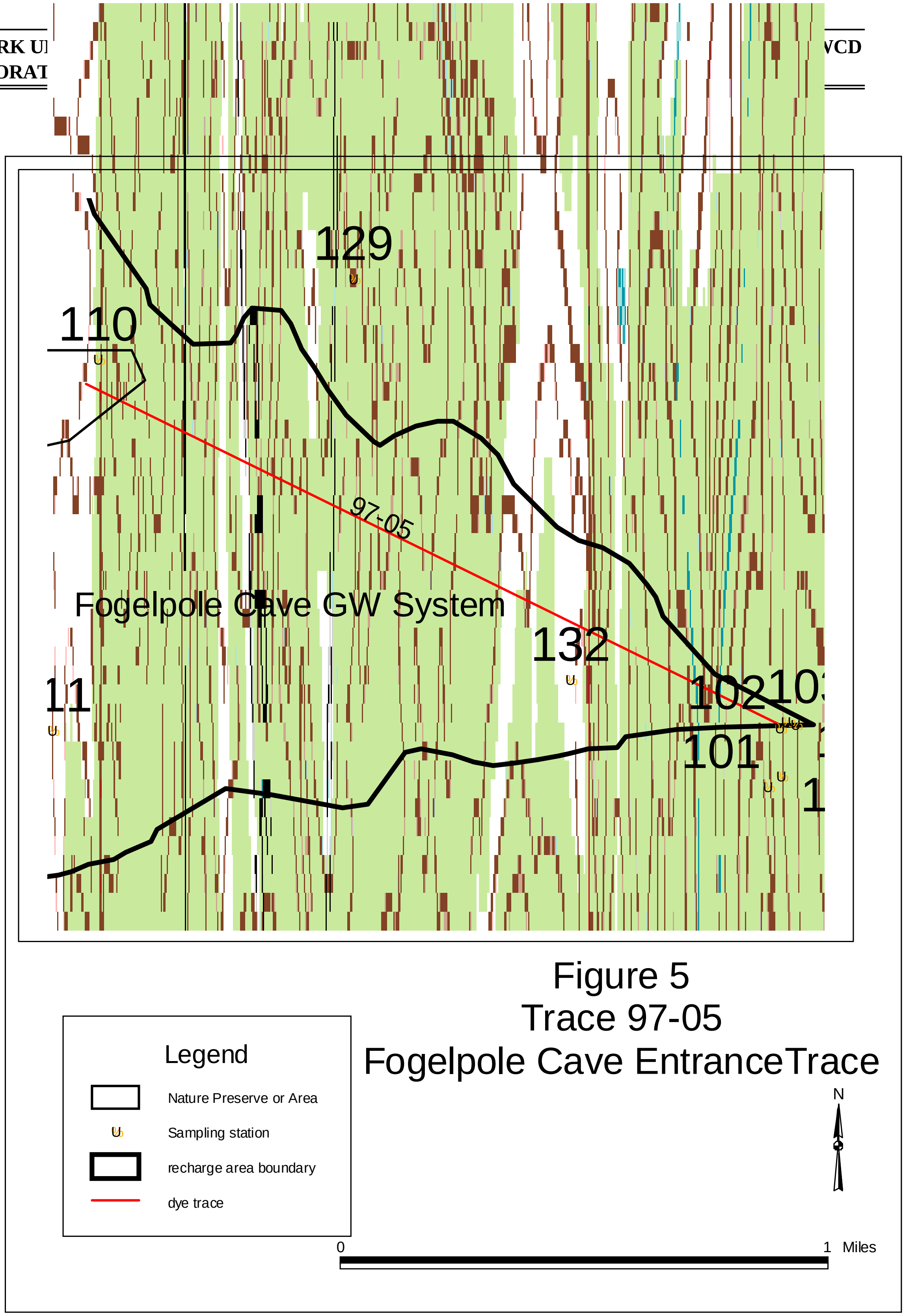


Figure 5
Trace 97-05
Fogelpole Cave EntranceTrace

4.2.4 Trace 98-101: Illinois Caverns Trace.

This is the first of the traces done as part of the current study. One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into the Illinois Caverns stream at the entrance of the cave at 1924 hours on June 24, 1998. There was approximately 100 gpm flowing in the cave stream at the time of dye introduction. The introduction elevation is approximately 600 feet msl and is located in the NW ¼ NE ¼ of Section 31, T3S, R9W. The location is shown on the Renault 7.5-minute quadrangle map. This trace was designed to identify all of the springs which drain the Illinois Caverns groundwater system. The trace is shown on Figure 6.

The stations sampled for this trace were: 101 through 108, 114, 115, 116, 123, 128, 133, and 135.

Data on the dye recovery locations for Trace 98-101 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 114. Dye Spring.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
6/9 to 6/19/98	ND	ND
6/19 to 7/2/98	564.5	1,040
7/2 to 7/14/98	563.6	20.6
7/2 to 7/14/98 (dup.)	562.4	13.0
7/14 to 7/28/98	565.0	SH
7/28 to 9/10/98	ND	ND

Station 115. Walsh Cave.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
6/9 to 6/19/98	ND	ND
6/19 to 7/2/98	564.0	81.1
7/2 to 7/13/98	564.1	494
7/13 to 7/28/98	ND	ND

Station 116. Walsh Spring.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
6/19 to 7/2/98	ND	ND
7/2 to 7/13/98	563.0	21.7
7/13 to 7/28/98	ND	ND

Station 128. Horse Creek at MM Road Crossing in Section 2.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
6/10 to 6/19/98	ND	ND
6/19 to 7/2/98	564.0	60.3
7/2 to 7/14/98	565.0	SH
7/14 to 7/28/99	ND	ND

Rhodamine WT dye from the Illinois Caverns Trace was recovered three springs and from Horse Creek downstream from these springs. Walsh Cave and Walsh Spring are approximately 250 feet apart, while Dye Spring is approximately 3000 feet downstream of these two features. All three springs have perennial discharge. The dye was recovered under moderate flow conditions, as this part of the summer was unseasonably wet. P. Moss recorded a two-inch rain on July 4, 1998 in Waterloo.

The first dye arrival and the peak dye concentration at Dye Spring was within eight days of dye introduction; we estimate that the first dye arrival was about six days after dye introduction. The straight-line groundwater flow path distance was approximately 15,350 feet. This trace confirms earlier work by Wightman (1969) who recovered fluorescein dye at Dye Spring after introducing it in Illinois Caverns. The elevation loss is approximately 125 feet. Rhodamine WT continued to be discharged from Dye Spring for about 20 days after dye introduction. Assuming that the first arrival of dye at Dye Spring occurred six days after dye introduction, the mean groundwater flow velocity along this flow path from the Illinois Caverns entrance to Dye Spring was about 2,560 per day.

Dye first arrived at Walsh Cave within eight days of dye introduction. The peak dye discharge was between 8 and 19 days following dye introduction. All detectable quantities of dye discharged from the spring within 19 days of dye introduction. The straight-line groundwater flow path distance was approximately 12,300 feet. Based upon the first arrival of dye occurring about 8 days after dye introduction, the mean groundwater flow velocity along this flow path was about 1,540 feet per day. The elevation loss is approximately 85 feet. The mean groundwater flow path gradient is approximately 36 feet per mile.

The travel time to Walsh Spring was slower than the travel time to Walsh Cave. The dye passed through Walsh Spring between 8 and 19 days following dye introduction; we estimate the first arrival of the dye occurred about 10 days after dye introduction. All detectable quantities of dye discharged from this spring within 19 days of dye introduction. The straight-line groundwater flow path distance was approximately 12,400 feet. Based upon the estimated first arrival of dye, the mean groundwater flow velocity along this flow path was about 1,240 feet per day. The elevation loss is approximately 85 feet. The mean groundwater flow path gradient is approximately 36 feet per mile.

This trace demonstrates the complexity of the Illinois Caverns groundwater system. Dye was recovered at three different springs at significantly different elevations. Two of these springs had only speculatively been connected to the system. The springs had different responses in terms of dye concentrations and travel times. The ratio of dye concentrations at the springs varies with hydrologic conditions (see Section 4.2.15). This may be related to the presence of separate streams in the cave. The map of the cave (Galandak, undated) shows the cave stream leaving the main passage shortly past the Sand Crawl, which is about halfway through the cave. Investigation by P. Moss, D. Tecic, T. Schmitt, and M. Mugele on July 25, 1999 confirmed the map information. Two small tributaries enter from the southeast downstream of the Sand Crawl and flow to the terminal sump. It is likely that this small flow discharges at Walsh Cave and Walsh Spring. We have no data to suggest whether it also discharges from Dye Spring.

Station 153 (Figure 6) was not established at the time of this trace. Dye would not have been detected at this sampling station since it was in a side passage, Cascade Canyon, which is off the main stream where the dye was flowing.

Dye Spring appears to be an underflow spring for Illinois Caverns. Flow measurements and staff gage data indicate that Dye Spring receives most of the discharge of the Illinois Caverns groundwater system at low flows. At high flows, Walsh Cave receives most of the discharge from the Illinois Caverns groundwater system. The hydrologic and physical characteristics of these springs suggest that Dye Spring is of hydrologically recent origin and is in the process of capturing the discharge of the Illinois Caverns groundwater system.

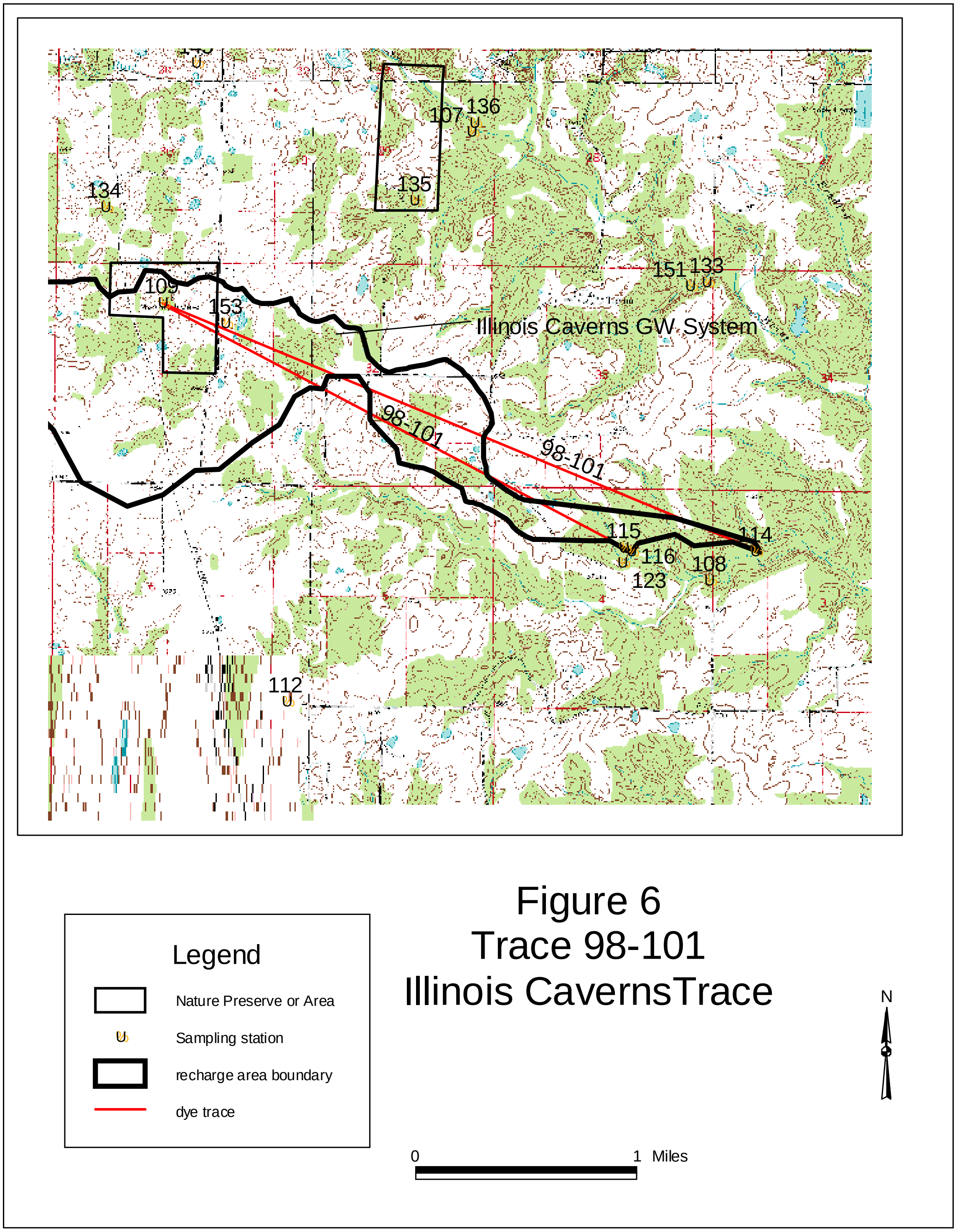


Figure 6
Trace 98-101
Illinois CavernsTrace

4.2.5 Trace 98-102: Zebra Passage Trace.

Approximately one pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into the Zebra Passage stream in Fogelpole Cave at 1653 hours on June 26, 1998. The flow of the cave stream was approximately 15 gpm at the time of dye introduction. The elevation of the dye introduction point is approximately 535 feet msl, and is in the SE ¼ NE ¼ of Section 18, T4S, R9W. The location is shown on the Renault 7.5-minute quadrangle map. The trace is shown on Figure 7.

This purpose of this trace was to identify the discharge point for the stream in Zebra Passage. The stream passage has been mapped to a sump (no airspace) that lies between Tierce and Collier Springs. The OUL wanted to determine whether this stream was a tributary to the main stream in Fogelpole Cave or whether it discharged at Collier Spring, or both. This passage was considered to be a possible hydrologic link between the Fogelpole Cave and Collier Spring groundwater systems.

The stations sampled for this trace were: 101, 102, 103, 104, 130, and 132. Data on the dye recovery locations for Trace 98-102 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 102. Tierce Spring.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
6/19 to 7/2/98	ND	ND
7/2 to 7/13/98	538.9	60.9
7/13 to 7/28/98	535.6	1.23
7/28 to 9/10/98	ND	ND

Station 103. Indian Hole (pool)

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
6/19 to 7/2/98	ND	ND
7/2 to 7/13/98	538.7	56.9
7/13 to 7/28/98	ND	ND

Station 104. Indian Hole (channel)

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
6/19 to 7/2/98	ND	ND
7/2 to 7/13/98	538.9	87.7
7/13 to 7/28/98	ND	ND

Station 130. South Fork at Road Crossing in Section 15

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
6/19 to 7/2/98	ND	ND
7/2 to 7/13/98	538.6	19.4
7/13 to 7/28/98	536.0	SH
7/28 to 9/10/98	ND	ND

Station 132. Bat Sump

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
7/15 to 7/28/98	538.8	28.2
7/28 to 9/10/98	536.6	4.18
9/10 to 9/22/98	533.2	SH
9/10 to 9/22/98 (dup.)	536.0	SH
9/22 to 10/20/98	533.2	1.15
10/20 to 12/16/98	536.0	SH

The Zebra Passage Trace demonstrates great complexity in the Fogelpole Cave groundwater system. Station 104, Indian Hole (channel), receives flow during high flow conditions. The channel is the discharge route for Indian Hole, which has no flow (see section 4.2.7 for relevant data) under base flow conditions. This trace demonstrated that Indian Hole is an overflow spring for the Fogelpole groundwater system, while Tierce Spring is the underflow spring (perennial discharge) for the system. Station 130 is located downstream of the three spring sampling stations. Station 132, Bat Sump, is located in a small cave that was not previously known to be part of the Fogelpole Cave System. It was assumed to be a tributary to either Collier Spring or Indian Hole, but it was not thought to be downstream of Zebra Passage. Samplers were not in place in Bat Sump at the time of dye introduction in Zebra Passage. The relationship between Bat Sump and the springs is not completely understood at this time. Bat Sump continued to have eosine dye present after no dye was detectable at the springs.

The straight-line distance from the introduction point for Trace 98-102 to Tierce Spring is approximately 7,575 feet. The travel time for the first arrival of dye was between 6 and 17 days. The difference in response between Indian Hole and Tierce Spring is probably because of stagnation in Indian Hole during periods of low flow (see Trace 98-104). There was a relatively high flow period for the system as indicated by Indian Hole overflowing down its discharge channel, mostly likely associated with a storm event on July 4, 1998. The relatively high dye concentration at Station 104 suggests that the first arrival of dye (and perhaps peak dye discharge) probably occurred during the July 4 storm event, as the water levels in the Fogelpole Cave system rise and fall quickly. The elevation loss for this trace was approximately 80 feet. The mean groundwater gradient is approximately 56 feet per mile. The mean groundwater velocity for the first arrival of dye at Tierce Spring (assuming this occurred on July 4) was about 945 feet per day.

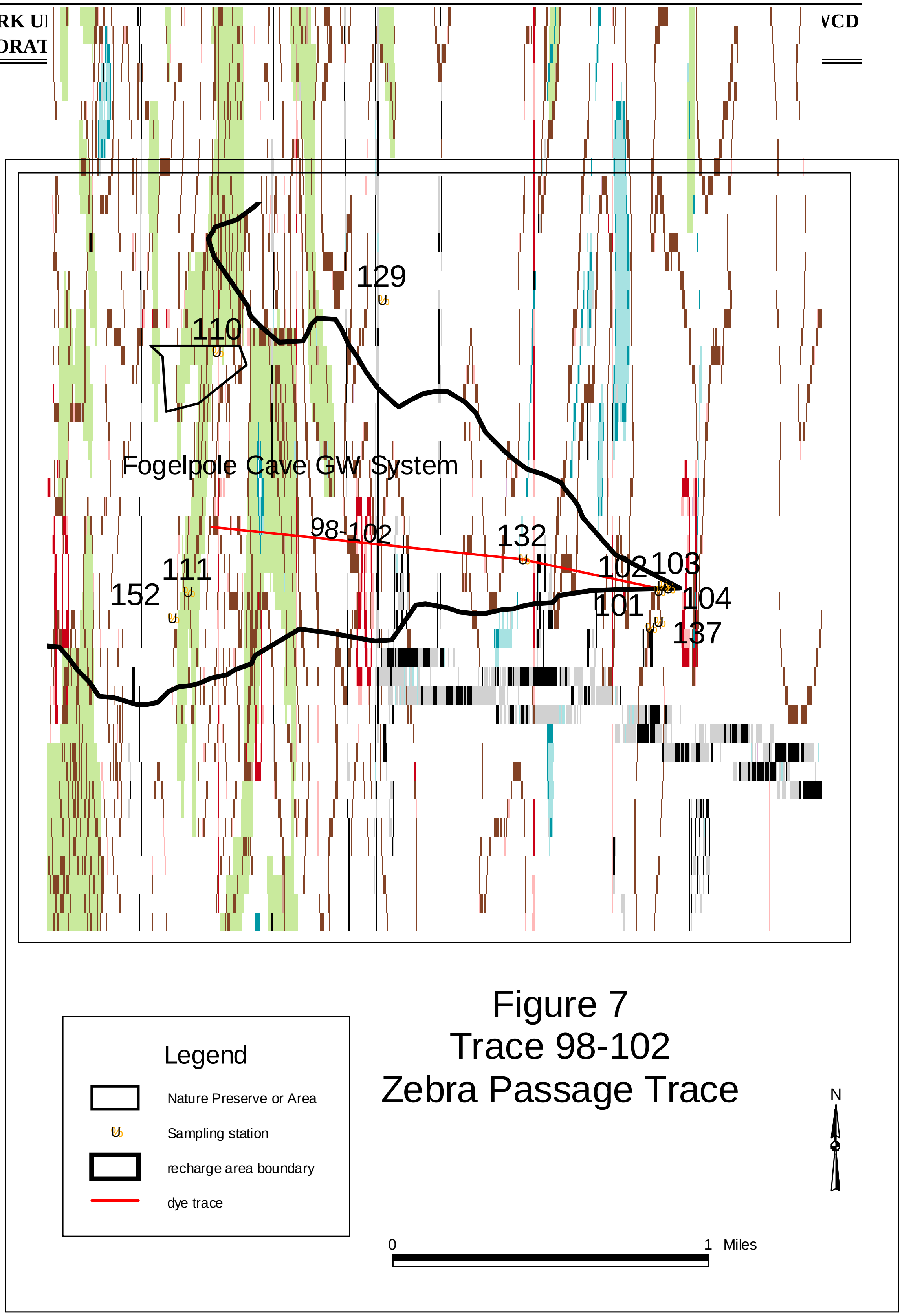


Figure 7
Trace 98-102
Zebra Passage Trace

4.2.6 Trace 98-103: Nobbe Trace.

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinking stream on William Nobbe's property at 1230 hours on June 29, 1998. There was approximately one gpm flow at the time of dye introduction. The dye introduction elevation is approximately 645 feet msl and the dye introduction point is in the NE ¼ SE ¼ Section 25, T3S, R10W. The location is shown on the Renault 7.5-minute quadrangle map. The purpose of this trace was to determine which groundwater systems receive water from this sinking stream. The trace is shown on Figure 8.

The stations sampled for this trace were: 105, 106, 107, 109, 115, 116, 123, 128, 133, 134, 135, 136, and 145.

Data on the dye recovery locations for Trace 98-103 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 105. Kelly Spring (North outlet)

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
6/9 to 6/19/98	ND	ND
6/19 to 7/2/98	513.5	538
7/2 to 7/13/98	512.7	67.4

Station 106. Kelly Spring (South outlet)

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
6/9 to 6/19/98	ND	ND
6/19 to 7/2/98	513.1	771
7/2 to 7/13/98	513.4	152

Station 107. Kelly Spring (combined)

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
6/9 to 6/19/98	ND	ND
6/19 to 7/2/98	513.6	712
6/19 to 7/2/98 (dup.)	514.1	665
7/2 to 7/13/98	513.4	94.4
7/13 to 7/28/98	513.0	16.4
7/28 to 9/8/98	511.0	0.983
9/8 to 10/1/98	ND	ND

Station 128. Horse Creek at MM Road Crossing in Section 2

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
6/19 to 7/2/98	ND	ND
7/2 to 7/14/98	512.8	11.7
7/14 to 7/28/98	511.6	2.30
7/28 to 9/10/98	ND	ND

Station 134. Spider Cave

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
6/10 to 6/19/98	ND	ND
6/19 to 7/2/98	513.1	127
7/2 to 7/14/98	513.8	1,540
7/14 to 7/28/98	513.4	260
7/28 to 9/6/98	512.9	6.85
9/6 to 9/22/98	511.0	1.36
9/22 to 10/1/98	510.8	0.452
10/1 to 10/19/98	512.5	2.66
10/19 to 11/1/98	511.8	3.85
11/1 to 11/9/98	511.2 s	1.58
11/9 to 11/15/98	511.0 s	1.18
11/15 to 12/7/98	512.7	8.81
12/7 to 12/20/98	512.6	20.1
12/20 to 12/31/98	512.3	7.27
12/31/98 to 1/20/99 *	512.1	8.77

* Fluorescein dye continued to be present at Spider Cave through the sampling period ending June 23, 1999. See Appendix A for details.

Station 135. Big Sink

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
6/9 to 6/19/98	ND	ND
6/19 to 7/2/98	514.2	387
6/19 to 7/2/98 (dup.)	513.7	551
7/2 to 7/13/98	513.2	87.5
7/2 to 7/13/98 (dup.)	513.0	67.1
7/13 to 7/28/98	513.0	21.8
7/28 to 9/10/98	511.0	0.801
9/10 to 10/1/98	ND	ND

Station 145. Fruth's Pump Hole

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
12/20 to 12/24/98	510.3 a,s	1.32
12/20 to 12/24/98 (dup.)	510.7 s	1.24
12/24 to 2/3/99	ND	ND

Trace 98-103 had dye recovered at six sampling stations. The multiple Kelly Spring sampling stations were used to determine if both spring orifices had similar water discharging from them. The OUL has concluded that they do have similar water and only continued to sample the combined station (107). Big Sink (Station 135) is especially significant because it is located within the Armin Krueger Speleological Nature Preserve. Station 145, established on December 20, 1998 recovered residual dye from Trace 98-103, indicating that the flow path of the Nobbe Trace passed through Fruth's Pump Hole.

The flow path of the Nobbe Trace from the dye introduction point to Kelly Spring is approximately 14,525 feet long. The elevation loss to Fruth's pump hole is approximately 65 feet; to Big Sink is approximately 100 feet, and 120 feet total elevation loss to Kelly Spring. The first arrival of dye at Kelly Spring which occurred within 3 days of dye introduction; for purposes of flow rate calculations we will assume that the first arrival occurred 2 days after dye introduction. Therefore, the mean groundwater flow velocity along this flow path was about 7,250 feet per day. Flow conditions were moderate during the period of dye recovery at most of the sampling locations due to the wet period in the early part of the summer. Some of the time that Spider Cave had fluorescein dye present was a period of drought; the drought lasted from August 20 until January 2, 1999.

The straight-line groundwater flow path from the sinking stream to Spider Cave is approximately 2,275 feet and the elevation loss is approximately 15 feet. The average groundwater flow path gradient to Spider Cave is approximately 35 feet per mile. The straight-line groundwater flow path distance from Spider Cave to Fruth's pump hole is approximately 4,000 feet. The elevation loss between Spider Cave and Fruth's pump hole is approximately 50 feet. The mean gradient from Spider Cave to Fruth's pump hole is approximately 66 feet per mile.

The straight-line groundwater flow path distance from Fruth's pump hole to Big Sink is approximately 6,150 feet. The elevation loss is approximately 35 feet and the average gradient is approximately 30 feet per mile. The travel time to Big Sink and Kelly Spring was less than three days and that period included arrival of the peak concentration of dye.

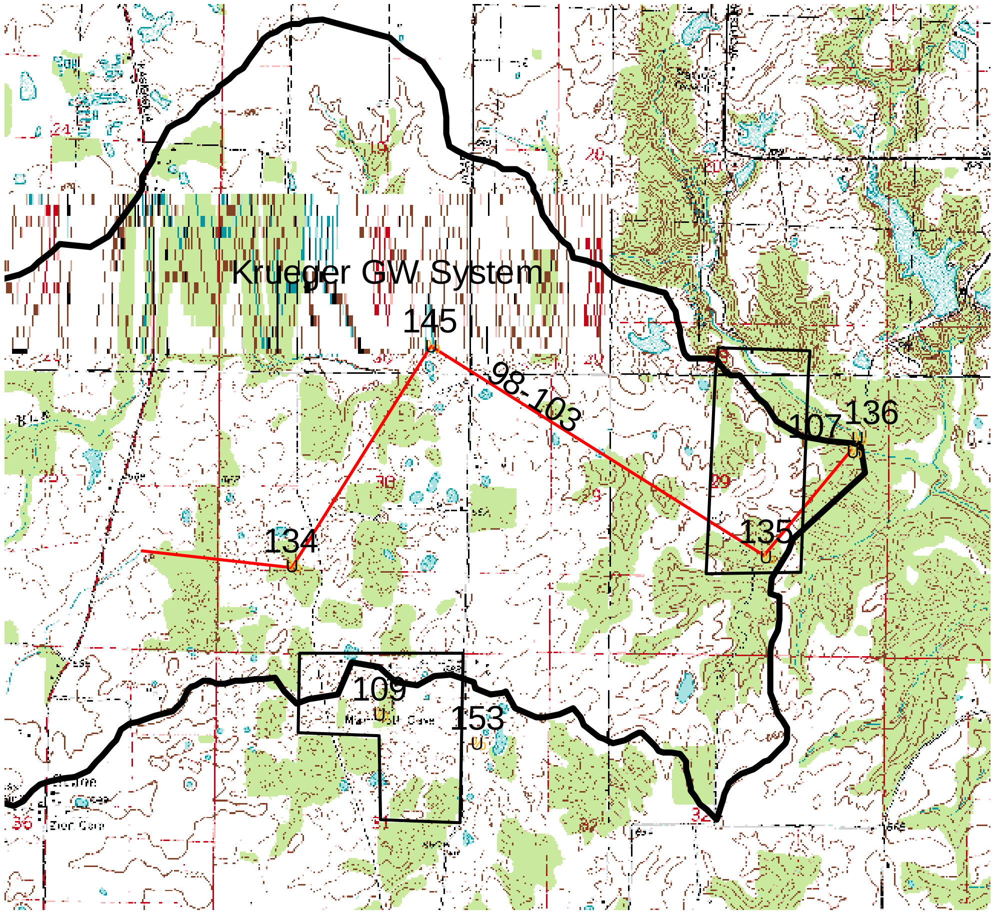
The straight-line groundwater flow path distance from Big Sink to Kelly Spring is approximately 2,100 feet and the elevation loss is approximately 25 feet. The mean groundwater flow path gradient from Big Sink to Kelly Spring is approximately 63 feet per mile. The northeast flowing segments of the flow path (Figure 8) have almost twice the gradient of the southeast flowing segments in the Krueger System. The difference in these gradients may be a result of the attitude of the rock. The regional dip is to the northeast

(Weller and Weller, 1939). The steeper gradients are aligned with the regional dip and the more gentle gradients are along strike (perpendicular to dip).

It should be noted that fluorescein dye at Spider Cave, a known *Gammarus acherondytes* location (Lewis et al., 1999), was still detectable approximately one year after dye introduction. The Nobbe sinking stream drains along and across Kaskaskia Road and some smaller county roads. If there were a spill in the Nobbe sinking stream watershed, it could result in long-term exposure of the aquatic community to the contaminants. This sinking stream watershed also contributes road runoff to the Armin Krueger Speleological Nature Preserve.

The Nobbe Trace extends the Krueger System recharge area into a surface watershed that sinks into the groundwater system. This trace also demonstrates that Spider Cave is a tributary to the Krueger System. The trace also indicates that Kelly Spring is the sole discharge point for the Krueger System.

These data were used by The Nature Conservancy of Illinois to make Spider Cave a high priority for biological research. The biological research resulted in Spider Cave being identified as a new location for *G. acherondytes* with a relatively high proportion of *G. acherondytes* collected (Lewis et al., 1999) compared to an earlier study in the Armin Krueger Speleological Nature Preserve (Webb, 1995). Subsequent to the Draft Final Report, Dr. Julian Lewis (personal communication, 2000) reported that the Illinois Cave Amphipod was absent in Spider Cave and that there was a strong, septic odor.



Legend

- Nature Preserve or Area
- Sampling station
- recharge area boundary
- dye trace

Figure 8
Trace 98-103
NobbeTrace

N

0 1 Miles

4.2.7 Trace 98-104: Indian Hole Trace.

Approximately one ounce of pyranine dye mixture containing approximately 77% dye and 23% diluent was introduced into Indian Hole at 1354 hours on September 11, 1998. Flow through the rise pool was not apparent and no water was discharging from the channel. The dye introduction elevation is approximately 455 feet msl and is located in the SE ¼ NW ¼ of Section 16, T4S, R9W. The location is on the Ames 7.5-minute quadrangle map. The purpose of this trace was to determine if there was flow through the spring pool when the rise pool is not discharging to the surface. This introduction point is shown on Figure 9.

The sampling stations for this trace were: 101, 102, 103, 104, and 128. Data on the dye recovery locations for Trace 98-104 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 103. Indian Hole (pool)

Sampling Period	Peak Emission Wavelength (nm)	Pyranine Dye Concentration (ppb)
7/28 to 9/10/98	ND	ND
9/10 to 9/20/98	502.6	227
9/20 to 10/1/98	502.4	709
water sample 10/1/98	501.0	0.702
10/1 to 10/12/98	502.6	611
10/12 to 10/20/98	502.4	374
10/20 to 10/28/98	502.6	554
10/28 to 11/4/98	502.3	285
11/4 to 11/16/98	ND	ND

Station 104. Indian Hole (channel)

Sampling Period	Peak Emission Wavelength (nm)	Pyranine Dye Concentration (ppb)
7/28 to 9/10/98	ND	ND
9/10 to 11/4/98	502.1	45.7
11/4 to 11/10/98	502.8	29.7
11/10 to 11/16/98	ND	ND

Dye from Trace 98-104 was recovered at two sampling stations. One sampling station, Indian Hole (pool) was the location of the dye introduction. The other station, Indian Hole (channel) is located in the discharge channel and is exposed to water only when Indian Hole flows. The Indian Hole Trace shows that, at low flow conditions, there is no flow to Tierce Spring and therefore no flow through the pool. The only outlet for Indian Hole is the surface discharge channel. This should not be construed to mean that they are not connected; they are, as demonstrated by the results of Trace 98-102. Trace 98-102 had dye recoveries at

Tierce Spring and both Indian Hole stations. At low flow levels, Indian Hole is stagnant. Indian Hole is an overflow spring for the Fogelpole Cave System, while Tierce Spring is an underflow spring for the system.

In order to not replace samplers in the Indian Hole channel (Station 104) when there had been no flow since the last visit, a simple flow detection system was used. A nail was driven into the streambed and a piece of flagging was tied to the nail. The flagging was bunched when the packet was replaced. When there was flow, the flagging was stretched along the streambed, indicating that the sampler has been exposed to water discharging from the spring.

The OUL's data indicate that the overflow channel was active twice during this sampling for Trace 98-104. The first flow episode occurred on November 2, 1998 after a storm event that day. P. Moss recorded 1.6 inches of rain in Waterloo on that date. The second storm event leading to discharge down the channel was on November 10, 1998. P. Moss recorded 0.70 inch of rain the night of November 9, 1998 in Waterloo. On November 10, 1998 at 1042 hours, the staff gage installed in the Indian Hole channel indicated 0.45 feet of water running through the channel. Under no flow conditions, the staff gage is not in contact with water.

Figure 9 shows the vicinity of the trace. There is no line representing the trace on the figure since the dye did not enter the groundwater system. The dye was not detected at a significant distance downstream from the dye introduction point.

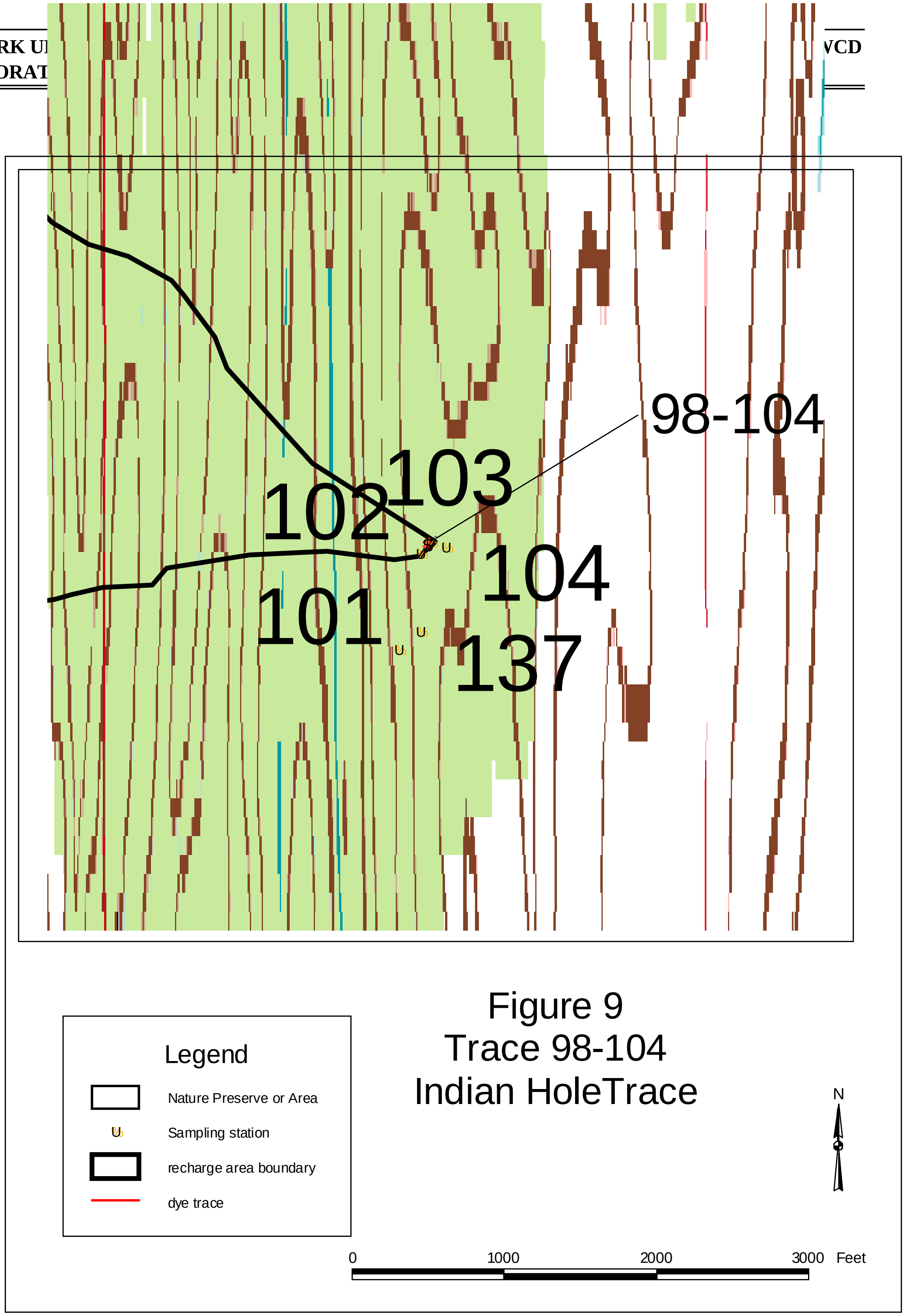


Figure 9
Trace 98-104
Indian HoleTrace

4.2.8 Trace 98-105: Metter Sinking Stream Trace.

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into Metter sinking stream at 1820 hours on September 22, 1998. There was a flow of approximately 10 gpm entering the groundwater system at the time of dye introduction. The introduction elevation is approximately 670 feet msl and is in the SE ¼ NE ¼ of Section 34, T3S, R10W. The location is shown of the Renault 7.5-minute quadrangle map. This sinking stream is located near a suspected drainage divide separating the three biologically significant cave systems in the RSA from other groundwater systems. Trace 98-105 was designed to test this potential divide. The trace is shown on Figure 10.

The sampling stations for this trace were: 101, 102, 103, 104, 107, 108, 109, 110, 111, 113, 114, 115, 117, 118, 119, 120, 121, 122, 124, 125, 126, 127, 128, 130, 134, 135, 136, and 137.

Data on the dye recovery locations for Trace 98-105 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 101. Collier Spring

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
10/1 to 10/4/98	ND	ND
10/4 to 10/12/98	514.2	3700
water sample 10/12/98	ND	ND
water sample 10/12/98 (rep.)	ND	ND
10/12 to 10/20/98	514.2	562
10/20 to 10/28/98	512.6	27.6
10/28 to 11/4/98	512.9	9.42
10/28 to 11/4/98 (dup.)	512.7	15.5
11/4 to 11/16/98	512.3	5.11
11/4 to 11/16/98 (dup.)	512.6	8.74
11/16 to 12/9/98	511.9	5.18
12/9 to 12/16/98	511.1	2.85 s
12/16 to 12/24/98	511.4	2.14 s
12/24 to 12/31/98	510.9	1.27 s
12/31/98 to 1/18/99	510.8	1.67 s
1/18 to 1/30/99	ND	ND

Station 130. South Fork at Road Crossing in Section 15

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
9/20 to 10/1/98	ND	ND
10/1 to 10/12/98	514.1	166
10/12 to 10/20/98	514.1	221
10/20 to 11/4/98	512.5	11.4
11/4 to 11/16/98	511.0 s	2.01
11/16 to 12/7/98	510.8 s	1.64
12/7 to 12/17/98	ND	ND

Station 137. Collier Downstream

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
10/20/98 (water)	507.5	0.100
10/20 to 10/28/98	512.4	14.2
10/28 to 11/4/98	512.9	20.8
10/28 to 11/4/98 (dup.)	512.8	17.1
11/4 to 11/10/98	512.7	10.4
11/10 to 11/16/98	511.4	2.35
11/10 to 11/16/98 (dup.)	511.3	2.77
11/16 to 12/9/98	512.1	5.00
12/9 to 12/16/98	511.2 s	2.35
12/9 to 12/16/98 (dup.)	511.2 s	2.65
12/16 to 12/24/98	511.4 s	1.86
12/24/98 to 12/31/98	ND	ND
12/31/98 to 1/18/99	510.9 s	2.02
1/18 to 1/30/99	ND	ND

Fluorescein dye from the Metter Sinking Stream Trace was recovered at three sampling stations. Collier Downstream (Station 137) is a sampling station approximately 150 feet downstream from the main rise of Collier Spring. Our flow measurements indicate that there is an increase in discharge between Collier Spring and this sampling of approximately 10%. Station 137 was added to the sampling routine to help determine if this additional discharge has a distinct dye signature. Station 130 is located downstream of both Collier Spring and Collier Downstream. Spider Cave, Station 134, had an anomalous rise in the concentration of fluorescein detected between November 15 and December 7, 1998 (see Appendix A). The increase in fluorescein dye detected did not meet the OUL criteria for a positive trace. However, a replicate trace was initiated as Trace 00-133 (Section 4.2.36) to determine if, in fact, the Metter sinking stream does contribute to both the Collier and Krueger groundwater systems.

The straight-line groundwater flow path to Collier Spring is approximately 29,700 feet.

The elevation loss is approximately 210 feet. The first arrival of dye and the peak dye discharge were both during the sampling period between 8 and 20 days following dye introduction. Much of this period did not have runoff from storm events. There were storms on October 5 and 6, 1998 which produced approximately 1.3 and 0.3 inches of rain, respectively. The OUL estimates that the fluorescein dye arrived at Collier Spring on or about the time of the storm event of October 5, 1998; this was 13 days after dye introduction. The estimated mean groundwater velocity for first dye arrival under these conditions was approximately 2,280 feet per day. Dye continued to be discharged for about three months after dye introduction in spite of the area receiving appreciable precipitation during this period.

The Metter sinking stream trace helped define the northwest boundary of the Fogelpole Cave groundwater system. The recharge areas of interest; Illinois Caverns, the Krueger system, and Fogelpole Cave, are all proximate to one another at their headwaters. Metter sinking stream lies to the west or northwest the recharge areas for these cave systems.

The flow path shown in Figure 10 appears to pass through Fogelpole Cave. However, the flow path representation is diagrammatic. It is likely that the actual flow path curves around the Fogelpole Cave recharge area and does not actually pass near Stations 110 and 132.

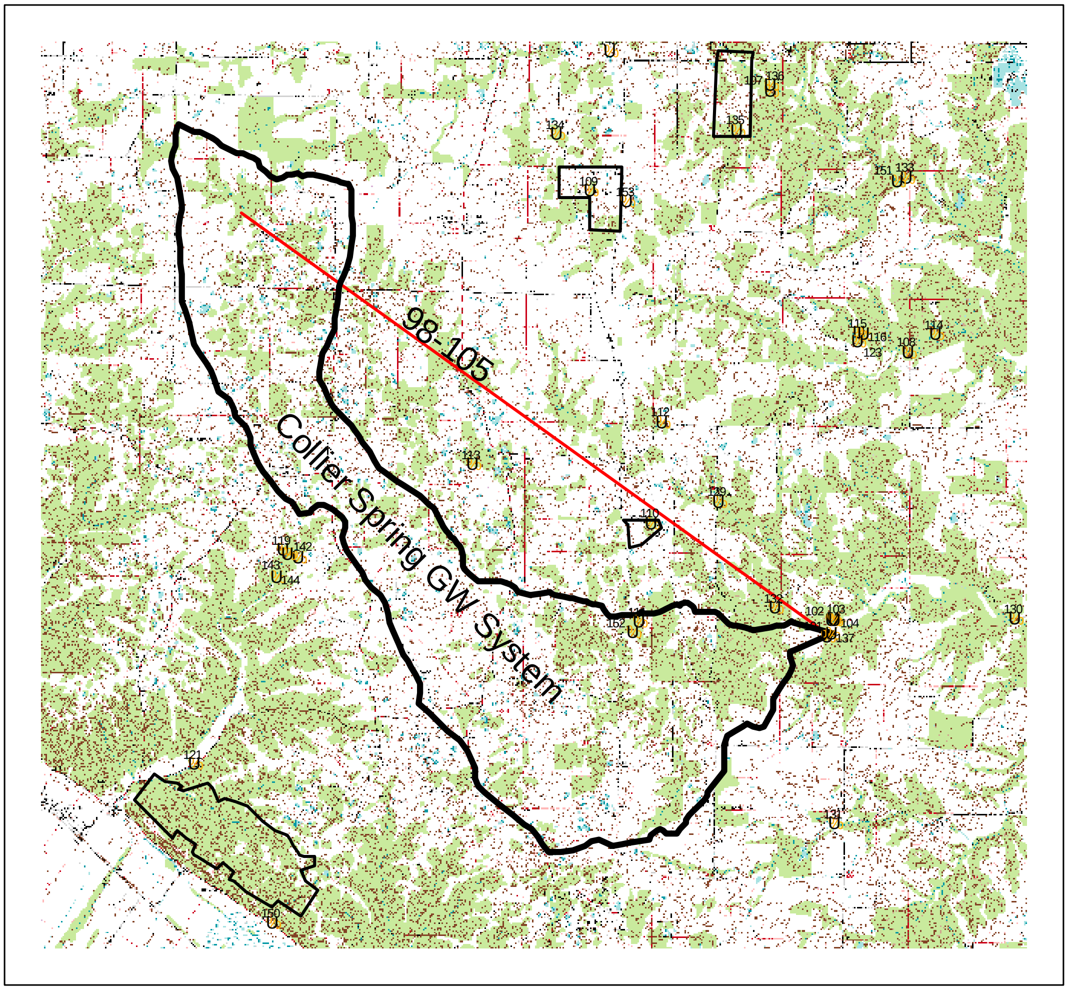
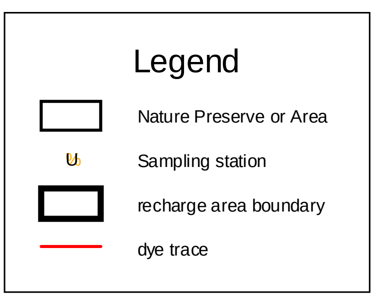
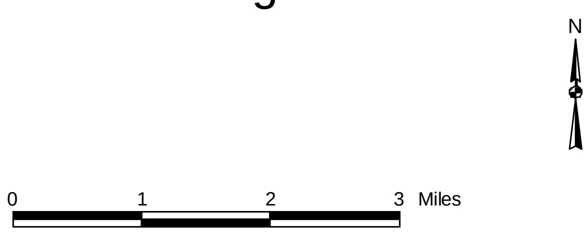


Figure 10
Trace 98-105
Metter Sinking StreamTrace





4.2.9 Trace 98-106: Wittenauer Trace.

One pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was placed as a dry set at 1045 hours on September 25, 1998. A dry set consists of dye being placed at or near the introduction point in such a manner as to provide for its introduction into the groundwater system when there is runoff. The introduction point is one of the sinks along a dry valley. At the time of dye placement there was no flow in the channel. The introduction elevation is 590 feet msl, and is in the SW ¼ SW ¼ of Section 20, T4S, R9W. The location is shown on the Ames 7.5-minute quadrangle map. The trace is shown on Figure 11.

The sampling stations for this trace were: 101, 102, 103, 104, 118, 125, 126, 130, 131, 132, 137, and 141.

Data on the dye recovery locations for Trace 98-106 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 101. Collier Spring

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B dye Concentration (ppb)
10/28 to 11/4/98	ND	ND
10/28 to 11/4/98 (dup.)	ND	ND
11/4 to 11/16/98	575.2	32.0
11/4 to 11/16/98 (dup.)	575.0	19.0
11/16 to 12/9/98	575.1	39.5
12/9 to 12/16/98	573.9	15.0
12/16 to 12/24/98	ND	ND
12/24 to 12/31/98	572.8	3.19
12/31/98 to 1/18/99	ND	ND
1/18 to 1/30/99	ND	ND
1/30 to 2/4/99	574.6	6.10
2/4/ to 2/14/99	ND	ND

Station 130. South Fork at Road Crossing in Section 15

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
10/20 to 11/4/98	ND	ND
11/4 to 11/16/98	574.1	7.59
11/16 to 12/7/98	575.0	42.4
12/7 to 12/17/98	570.6	1.80
12/17 to 12/24/98	ND	ND

Station 137. Collier Downstream

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
11/4 to 11/10/98	ND	ND
11/10 to 11/16/98	575.0	48.3
11/10 to 11/16/98 (dup.)	575.4	35.1
11/16 to 12/9/98	575.0	38.5
12/9 to 12/16/98	574.0	11.6
12/9 to 12/16/98 (dup.)	573.6	12.3
12/16 to 12/24/98	ND	ND
12/24 to 12/31/98	572.8	4.00
12/31/98 to 1/18/99	ND	ND

Station 141. Horse Creek at Ames Road Crossing

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
11/17 to 12/7/98	574.4	13.6
12/7 to 12/17/98	ND	ND

The Wittenauer Trace had sulforhodamine B dye recovery at four sampling stations. These were: Collier Spring (Station 101), Colliers Downstream (Station 137), Station 130 (South Fork at Road Crossing in Section 15), and Station 141 (Horse Creek at Ames Road Crossing). All dye was discharged from the groundwater system through Collier Spring.

The dry valley into which dye for Trace 98-106 was introduced lies south of the recharge area of the Fogelpole Cave System. This trace was run during a relatively dry period.

The straight-line groundwater flow path distance from the dye introduction point to Collier Spring is approximately 8,900 feet and the elevation loss is approximately 130 feet. The mean groundwater flow path gradient is approximately 77 feet per mile.

The OUL believes that the dye did not get introduced into the groundwater system until the storm event of November 2, 1998, when P. Moss recorded 1.6 inches of rain in Waterloo. An earlier storm event on October 5 and 6, 1998 probably did not produce sufficient runoff to mobilize the dry set. Using this assumption, the time of first dye arrival is estimated to have occurred 12 days after the dye entered the groundwater system. Based upon this estimate, the mean groundwater velocity for the first arrival of dye was approximately 740 feet per day.

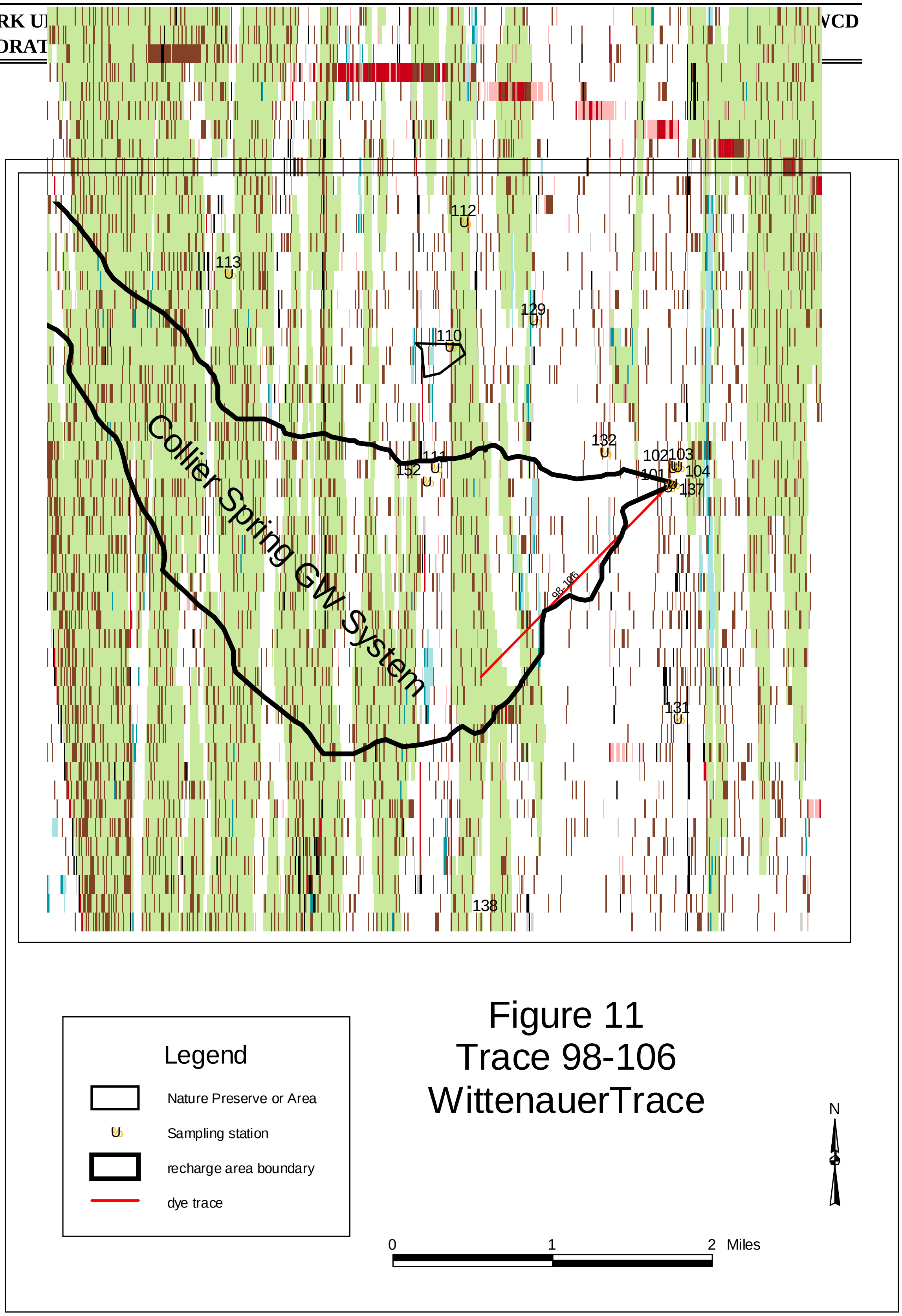


Figure 11
Trace 98-106
WittenauerTrace

4.2.10 Trace 98-107: Jacob's Trace.

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a cave stream at 1325 hours on November 13, 1998. The stream had a discharge of approximately 80 gpm at the time of introduction. The introduction elevation is approximately 590 feet msl and is in the NW ¼ NW ¼ of Section 32, T4S, R9W. The location is shown on the Renault 7.5-minute quadrangle map. The trace is shown on Figure 12. The purpose of this trace was to assess the hydrologic relationship between Jacob's Sink (part of the Renault Cave System, which is an Illinois Natural Areas Inventory site) and the Fogelpole Cave ground-water system.

The sampling stations for this trace were: 101, 118, 125, 126, 131, 132, 137, 139, 140, and 141. Data on the dye recovery locations for Trace 98-107 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 118. Spring #1

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
10/27 to 11/13/98	ND	ND
11/13 to 11/15/98	564.6	1,650
water sample 11/15/98	570.7	12.7
water sample 11/16/98	570.7	540
11/15 to 12/8/98	562.6	10,700
12/8 to 12/14/98	561.6 a	5.91
12/14 to 12/24/98	562.8	6.51
12/24 to 12/31/98	560.0	1.94
12/31/98 to 1/19/99	561.6 a,s	1.13
water sample 1/19/99	ND	ND
1/19 to 2/23/99	ND	ND

Station 127. Unnamed Creek at Kaskaskia Road and Bluff Road

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
10/20 to 11/5/98	ND	ND
11/5 to 11/15/98	563.8	115
11/15 to 12/9/98	562.6	10,400
12/9 to 12/14/98	562.1 a	8.35
12/14 to 12/24/98	562.0	6.74
12/24 to 12/31/98	562.0	4.34
12/31/98 to 1/19/99	562.0	1.20
1/19 to 2/5/99	ND	ND

Rhodamine WT dye from Trace 98-107 was recovered from two sampling stations; Spring #1 and an unnamed creek at Kaskaskia Road and Bluff Road. The latter station is downstream from Spring #1 and the dye recovered is derived from Spring #1. Martha Church called P. Moss to notify him that the creek by her house had turned red. The call was made at 1010 hours on November 15, 1998. Moss inspected the area and found that the stream was colored by rhodamine WT dye. The Spring #1 sampling station is located approximately 1800 feet downstream of the actual spring location. This sampling location was established for time efficiency. Having seen the creek discolored with rhodamine WT dye, Moss collected water from the spring orifice and placed samplers in two small, nearby springs; Little Spring (Station 139) and Spring #3 (Station 140). No dye was detected from those samplers.

The straight-line groundwater flow path distance to Spring # 1 is 4,000 feet and the elevation loss is approximately 130 feet to the spring. The mean groundwater flow path gradient is approximately 172 feet per mile. The time of first dye arrival is estimated to be approximately 35 hours after dye introduction, which would represent a mean groundwater flow rate for the first recovery of dye of 2,740 feet per day. The peak dye discharge occurred approximately 3 days after dye introduction. Dye continued to be discharged from the groundwater system for about 2 months.

The Jacob's Trace lies to the south of the Fogelpole Cave System. The OUL concludes that Jacob's Cave discharges from a single spring: Spring #1. The trace was conducted under low flow conditions. Some of the residual dye persisted through the snowmelt floods that began on January 14, 1999.

The Renault Cave System, as defined by the Illinois Natural Areas Inventory, includes two springs; Spring #1 and Couch's Spring (Spring #2). This trace along with Trace 99-118 (Church Trace) indicates that the Renault Cave System is actually two cave systems.

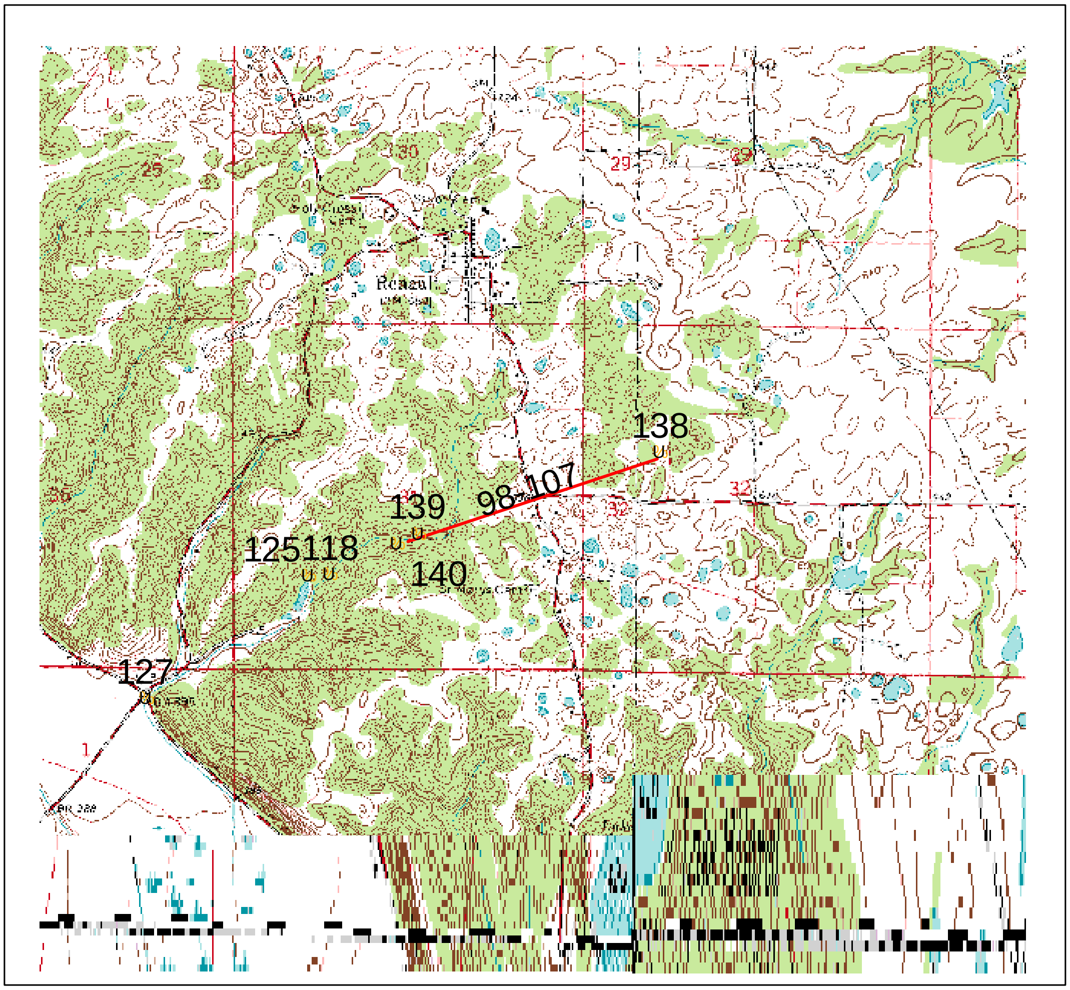


Figure 12
Trace 98-107
Jacob's Trace

Legend

- Nature Preserve or Area
- Sampling station
- recharge area boundary
- dye trace

0 1 Miles

N

4.2.11 Trace 98-108: Steingrubey Trace.

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a small pool of water in a sinkhole below an impounded sinking stream at 1622 hours on December 10, 1998. No flow was observed at the time of dye introduction. From 1140 hours on December 15, 1998 until 1107 hours on December 16, 1998, a siphon hose was run from the pond into the sinkhole. Approximately 4,600 gallons of water was siphoned to mobilize the dye. The dye introduction elevation is approximately 615 feet msl and is in the NW ¼ NW ¼ of Section 10, T4S, R10W. The location is shown on the Renault 7.5-minute quadrangle map. The trace is shown on Figure 13. The purpose of this trace was to help define the western boundary of the recharge areas of interest.

The sampling stations for this trace were: 101, 102, 104, 119, 120, 121, 122, and 124.

The dye recovery data for Trace 98-108 are shown below.

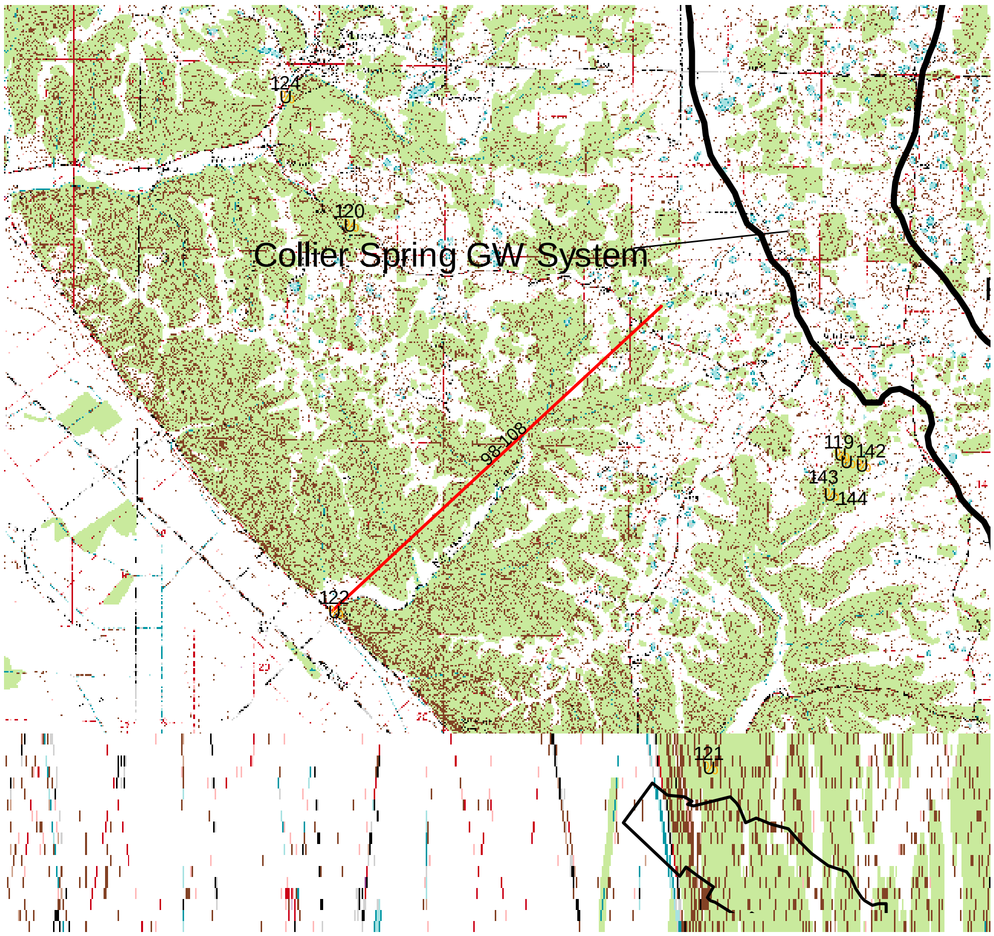
Station 122. Morrison Hollow at Bluff Road

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
12/9 to 12/14/98	ND	ND
12/14 to 12/24/98	538.5	162
12/24 to 12/31/98	538.5	53.4
water sample 1/19/99	ND	ND
1/19 to 1/30/99	536.9	5.20
1/30 to 2/5/99	534.2	1.28
2/5 to 2/14/99	534.8	0.837
2/14 to 3/2/99	534.0	0.426
3/2 to 3/19/99	ND	ND

Eosine dye from Trace 98-108 was recovered from Station 122 (Morrison Hollow at Bluff Road). The OUL has not investigated Morrison Hollow for the presence of springs. A snowmelt-induced flood occurred on January 14, 1999. Prior to this, the groundwater system was under low flow conditions.

Since the OUL is not aware of the particular location of the spring or springs that discharged dye into Morrison Hollow, the minimum distance to the headwaters of Morrison Hollow is used as the groundwater flow path distance. That distance is approximately 2,200 feet. The elevation loss to Station 122 is approximately 210 feet. The head of the valley is approximately 35 feet below the dye introduction elevation.

The first arrival of dye and the peak dye concentration from the Steingrubey Trace at Station 122 were both less than nine days after dye introduction. This trace demonstrates that groundwater in the vicinity of the dye introduction location is flowing southwest, which is away from the three biologically significant cave systems in the RSA.



Legend

- Nature Preserve or Area
- Sampling station
- recharge area boundary
- dye trace

Figure 13
Trace 98-108
Steingrubey Trace

N

0 1 2 Miles

4.2.12 Trace 98-109: Nottmeier Trace.

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole using potable water trucked to the sink. The dye introduction was made at 1617 hours on December 12, 1998. Approximately 200 gallons of water was introduced into the sink prior to dye introduction. A total of 1,600 gallons of water was introduced between 1615 and 1620 hours. From 1706 to 1716 a second load of 1,600 gallons was used to help flush the dye into the groundwater system. There was no ponding of water in the sinkhole.

The sinkhole is at 650 feet msl and is in the NE ¼ NW ¼ of Section 14, T4S, R10W. The location is shown on the Renault 7.5-minute quadrangle map. The trace is shown on Figure 14. The purpose of this trace was to help define the western boundary of the recharge areas of the three biologically significant RSA cave systems.

The sampling stations for this trace were: 101, 102, 104, 119, 121, 122, 125, 126, 142, 143, and 144.

Data on the dye recovery locations for Trace 98-109 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 121. Fults Creek at Fults Road Crossing one mile east of Fults

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
12/9 to 12/14/98	ND	ND
12/14 to 12/31/98	563.9	704
12/31/98 to 1/19/99	562.0	5.51
water sample 1/19/99	ND	ND
1/19 to 1/30/99	ND	ND

Station 142. Steam Thresher Spring (upper)

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
water sample 12/14/98	570.6	1060

Station 143. Steam Thresher Spring (lower)

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
water sample 12/14/98	570.8	317

Rhodamine WT dye was recovered from Trace 98-109 at three sampling stations. Two of the stations are springs, an overflow and underflow pair. The surface stream station is located downstream of the springs. Dye was visible at both of the springs at the time of water collection on December 14, 1998. The Nottmeier Trace demonstrates that water in the area of the dye introduction flows away from the cave systems that are the focus of this study.

The straight-line groundwater flow path from the dye introduction point to Lower Steam Thresher Spring is approximately 1,775 feet. The elevation loss is approximately 130 feet to the lower spring. The mean groundwater flow path gradient to the Lower Steam Thresher Spring is 387 feet per mile.

If we assume that the dye entered the groundwater system on December 12 and was first recovered on December 14, then the mean groundwater velocity under these flow conditions was approximately 900 feet per day. The peak discharge was probably close to the time of water collection on December 14. Flow conditions varied during this trace, starting under low flow and during the final detection period, there were high flow events.

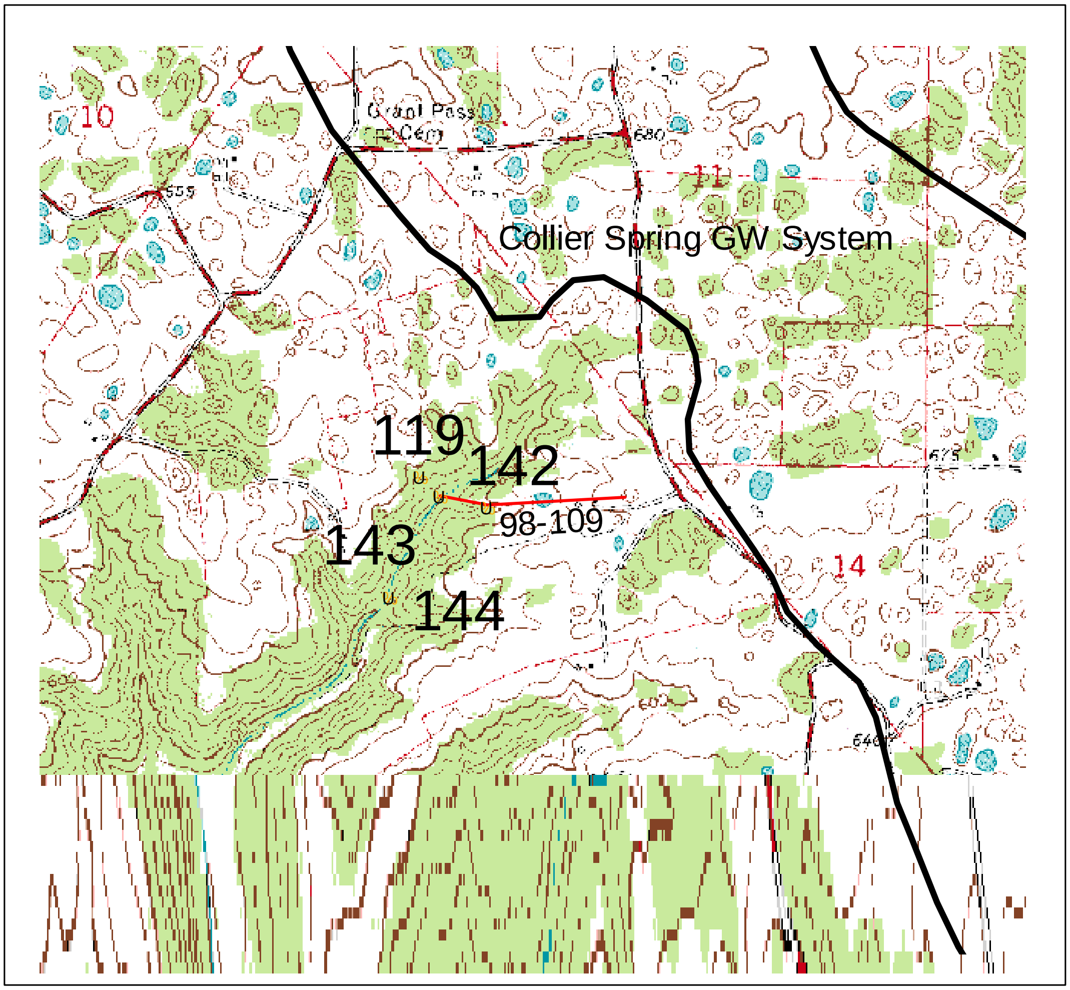


Figure 14
Trace 98-109
Nottmeier Trace

4.2.13 Trace 98-110: Schuchardt Trace.

One-half pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinking stream at 1428 hours on December 20, 1998. The stream had an estimated 4 gpm flow at the time of dye introduction. The elevation of the introduction point is 590 feet msl and is in the SW ¼ SE ¼ of Section 19, T3S, R9W. The area is shown on the Waterloo 7.5-minute quadrangle map. The trace is shown on Figure 15. The purpose of this trace was to help define the northern boundary for the Krueger System.

The sampling stations for this trace were: 107, 128, 135, 136, 141, and 145.

Data on the dye recovery locations for Trace 98-110 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 107. Kelly Spring (combined)

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
12/7 to 12/20/98	ND	ND
12/20 to 12/24/98	563.8	196
12/24 to 12/31/99	564.1	299
12/31/98 to 1/16/99	563.9	136
12/31/98 to 1/16/99 (dup.)	564.3	78.6
water sample 1/16/99	ND	ND
1/16 to 1/29/99	ND	ND

Station 128. Horse Creek at MM Road Crossing

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
12/17 to 12/24/98	ND	ND
12/24 to 12/31/98	563.5	140
12/31/98 to 1/16/99	563.3	46.7
1/16 to 1/29/99	ND	ND

Station 135. Big Sink

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
12/7 to 12/20/98	ND	ND
12/20 to 12/24/98	563.8	181
12/24 to 12/31/98	564.7	646
12/31/98 to 1/20/99	563.9	94.9
water sample 1/20/99	ND	ND
1/20 to 1/29/99	ND	ND

Station 141. Horse Creek at Ames Road Crossing

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
12/17 to 12/24/98	ND	ND
12/24 to 12/31/98	563.4	23.0
12/31/98 to 2/3/99	NS	NS
2/3 to 2/14/99	ND	ND

Rhodamine WT dye from the Schuchardt Trace was recovered from four sampling stations. Big Sink is in the Armin Krueger Speleological Nature Preserve and Kelly Spring is the discharge point for this groundwater system. Station 128 is located on Horse Creek downstream from Kelly Spring and derives its dye from the spring discharge. Station 141 is farther downstream on Horse Creek from Station 128.

The straight-line groundwater flow path distance from the dye introduction point to Kelly Spring is 8,600 feet. The straight-line distance to Big Sink is approximately 6,500 feet. The elevation loss is approximately 45 feet to Big Sink and approximately 70 feet to Kelly Spring. The mean groundwater flow path gradient from the dye introduction point to Big Sink is approximately 37 feet per mile. The mean groundwater flow path gradient from Big Sink to Kelly Spring is approximately 63 feet per mile.

First arrival of dye at Big Sink occurred approximately 2.5 days after dye introduction. Based upon the first arrival of dye, the mean groundwater flow velocity along this flow path was about 2,600 feet per day. Periods of very high discharge from Kelly Spring occurred between January 14 and January 20, 1999. By January 20, discharge had dropped to approximately 5,000 gpm. Base flow is a few hundreds of gallons per minute.

We estimate that the travel time for this trace from Big Sink to Kelly Spring was 0.5 days which yields an estimated mean groundwater velocity for this portion of the flow route of 4,200 feet per day.

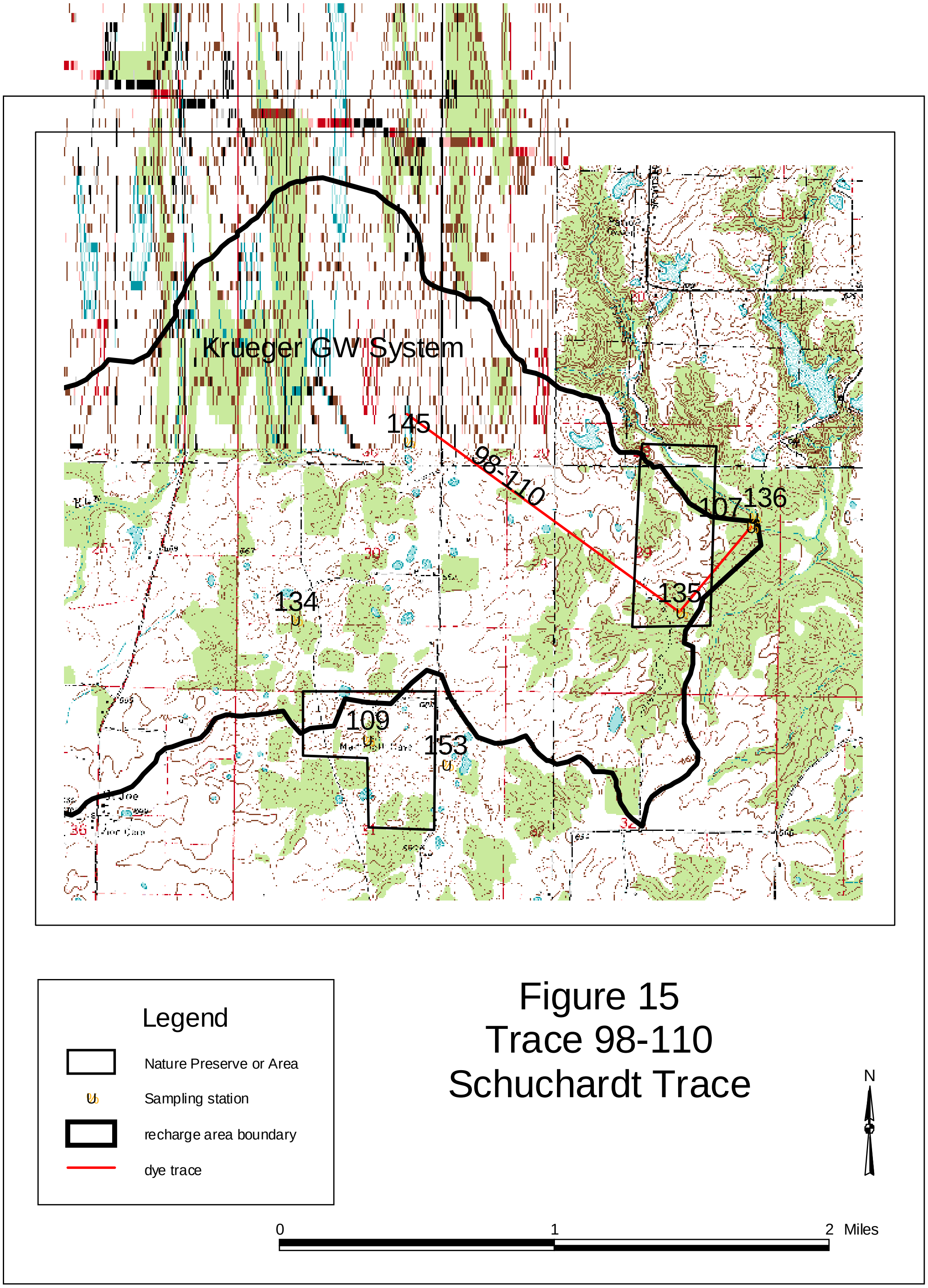


Figure 15
Trace 98-110
Schuchardt Trace

4.2.14 Trace 99-111: LL Road Corner Trace.

Two pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a culvert carrying a surface stream under LL Road at 1738 hours on January 12, 1999. The stream had an estimated flow of 10 gpm from snowmelt. This was followed by 0.3 inches of rain overnight on an accumulation of snow. The elevation of the introduction point is approximately 610 feet msl and is in the SW ¼ SW ¼ of Section 32, T3S, R9W. The location is shown on the Ames 7.5-minute quadrangle map. The trace is shown on Figure 16. The purpose of this trace was to determine if this stream leaks into either the Illinois Caverns or Fogelpole Cave groundwater systems.

The sampling stations for this trace were: 102, 104, 108, 114, 115, 128, and 141.

Data on the dye recovery locations for Trace 99-111 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 108. Lantz Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
11/4 to 12/24/98	ND	ND
12/24/98 to 1/19/99	538.0	15.7
1/19 to 1/29/99	538.3	12.0
1/29/99 (water)	530.8 a	0.136
1/29 to 2/5/99	538.2	8.40
2/5 to 2/14/99	537.1	2.51
2/14 to 2/23/99	536.8	2.80
2/23 to 3/2/99	536.8	2.44
3/2 to 3/11/99	533.2	0.872
3/11 to 3/19/99	535.8	1.20
3/19 to 3/31/99	537.2	2.37
3/31 to 4/6/99	536.0	SH
4/6/99 (water)	ND	ND
4/6 to 4/14/99	536.0	0.718
4/14 to 4/22/99	536.0	1.09
4/22/99 (water)	ND	ND

Station 128. Horse Creek at MM Road Crossing

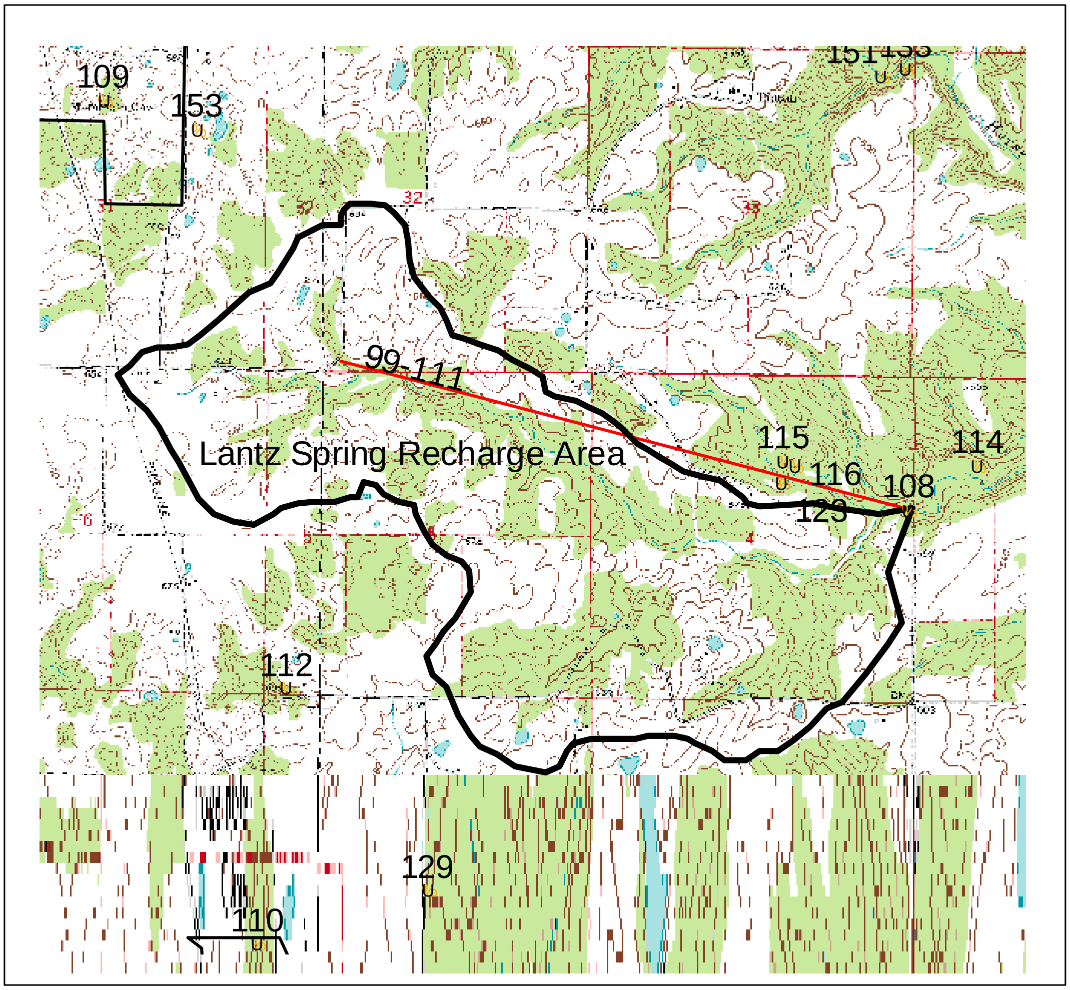
Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
12/24 to 12/31/98	ND	ND
12/31/98 to 1/16/99	537.9	3.93
1/16 to 1/29/99	534.8	1.30
1/29 to 2/5/99	ND	ND

Dye was recovered from Trace 99-111 at two locations; Lantz Spring and Horse Creek at MM Road crossing (Station 128). The latter sampling station is downstream of the tributary of Horse Creek in which the eosine dye was introduced and is also downstream of Lantz Spring. The OUL has determined that at low flow conditions the entire stream flow sinks into the groundwater system. Reconnaissance of the area in preparation for the later Traces 99-119 and 99-120 revealed a sink point in the tributary bed. All water in the channel was sinking at that time. Water would have to rise over four feet in order to overflow down the stream channel. At high flows only a portion of the flow enters the groundwater system. The OUL does not have data regarding whether all the flow was sinking into the groundwater system at the time of dye introduction for Trace 99-111.

The groundwater flow path distance is approximately 1,100 feet from the subsequently discovered sink point to Lantz Spring. The difference in elevation for this flow segment is 20 feet, which represents a mean gradient of 95 feet per mile. The travel time for the first arrival of dye at Lantz Spring is estimated to be approximately three days. This represents a mean groundwater travel velocity of 365 feet per day. This trace was conducted under moderate flow conditions.

The OUL's conclusion from this trace is that this tributary of Horse Creek is a boundary between the Illinois Caverns groundwater system and the Fogelpole Cave groundwater system. This boundary has some width since there is a watershed for the tributary and there is a section of the sinkhole plain that contributes water to this spring as well.

The LL Road Corner Trace has demonstrated that surface channels shown on United States Geologic Survey (USGS) maps may be sinking streams and contribute all or part of their flows to groundwater systems in the Southwest Illinois Karst.



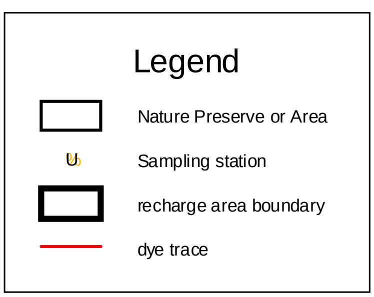
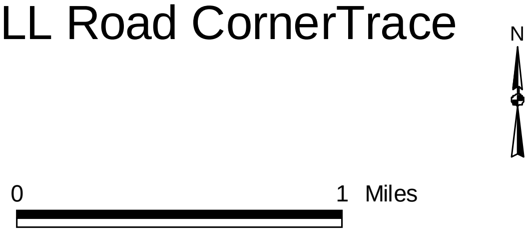


Figure 16
Trace 99-111
LL Road CornerTrace



4.2.15 Trace 99-112: St. Joe Trace.

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 0824 hours on January 31, 1999. There was approximately 60 gpm entering the groundwater system at the time of dye introduction. The flow was a result of a storm event. The OUL believes that there is not perennial flow entering the groundwater system at this dye introduction point.

The elevation of the introduction point is 690 feet msl and in the SE ¼ NE ¼ of Section 36, T3S, R10W. The location is shown on the Renault 7.5-minute quadrangle map. The trace is shown on Figure 17. The purpose of this trace was to help define the relationship of the recharge areas of the Krueger groundwater system, the Illinois Caverns groundwater system, and the Fogelpole Cave groundwater system near their western boundaries.

The sampling stations for this trace were: 102, 104, 108, 109, 110, 113, 114, 115, 128, 130, and 141.

Data on the dye recovery locations for Trace 99-112 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 102. Tierce Spring

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
2/4 to 2/14/99	ND	ND
2/14 to 2/23/99	511.6	4.05
2/23 to 3/2/99	ND	ND

Station 109. Illinois Caverns Entrance

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
12/16/98 to 1/30/99	ND	ND
1/30 to 2/3/99	513.9	736
2/3 to 2/14/99	512.7	30.7
2/14/99 (water)	ND	ND
2/14 to 2/24/99	511.1	2.50
2/24/99 (water)	ND	ND
2/24 to 3/2/99	ND	ND

Station 110. Junction Room

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
11/17/98 to 1/30/99	ND	ND
1/30 to 2/24/99	510.9 s	1.44
2/24/99 (water)	ND	ND
2/24 to 3/2/99	ND	ND

Station 113. Northwest Passage

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
12/16/98 to 2/3/99	ND	ND
2/3 to 3/4/99	513.4	4.50
2/3 to 3/4/99 (dup.)	513.1	3.18
3/4 to 3/12/99	ND	ND
3/12 to 4/5/99	514.2	6.69
4/5 to 5/12/99	ND	ND

Station 114. Dye Spring

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
1/19 to 1/29/99	ND	ND
1/29 to 2/5/99	513.9	246
2/5 to 2/14/99	512.2	10.2
2/14/99 (water)	ND	ND
2/14 to 2/23/99	510.7 s	0.970
2/23/99 (water)	ND	ND
2/23 to 3/2/99	ND	ND

Station 115. Walsh Cave

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
1/18 to 1/29/99	ND	ND
1/29 to 2/4/99	513.9	543
2/4 to 2/14/99	512.4	14.4
2/14/99 (water)	ND	ND
2/14 to 2/23/99	ND	ND

Station 128. Horse Creek at MM Road Crossing in Section 2.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
1/16 to 1/29/99	ND	ND
1/29 to 2/5/99	512.8	25.5
2/5 to 2/14/99	511.2	0.785
2/5 to 2/14/99 (dup.)	ND	ND
2/14 to 2/23/99	ND	ND

Fluorescein dye from the St. Joe Trace was recovered at six sampling stations in two cave systems that were previously considered distinct; Illinois Caverns and Fogelpole Cave. The Lantz Spring recharge area separates the Illinois Caverns and the Fogelpole Cave groundwater systems in the eastern portion of the RSA. The St. Joe Trace demonstrates that there is shared recharge in the western sections of the two groundwater systems. Based on concentrations of dye detected in each cave and the normal relationship of discharge in each cave, the OUL estimates that 10% or less of the dyed water went into the Fogelpole Cave groundwater system while the remaining 90% or more flowed through the Illinois Caverns groundwater system. The small percentage of dye that traveled to the Fogelpole groundwater system may represent an overflow path since the introduction of dye was made during very high flow conditions.

The OUL discontinued routine sampling of Station 116, Walsh Spring, since Trace 98-101 demonstrated that Walsh Spring is a discharge point for the Illinois Caverns groundwater system. Figure 17 shows that Walsh Spring is approximately 250 feet from Walsh Cave and is between it and Dye Spring. It is a reasonable assumption that dye is discharged from Walsh Spring when that same dye is being discharged from Walsh Cave and Dye Spring.

The groundwater flow path distance to the sampling station in the Illinois Caverns Natural Area (Station 109) is approximately 3,700 feet. The elevation loss is approximately 90 feet. The mean groundwater flow path gradient is approximately 129 feet per mile. First arrival of dye at Station 109 occurred less than three days (and probably less than one day) after dye introduction due to the high flow conditions that existed at the time. Assuming a one-day travel time, the mean groundwater velocity for the first arrival of dye at Station 109 was 3,700 feet per day.

The groundwater flow path distance from the St. Joe sink to Walsh Cave is approximately 15,800 feet. The time of first arrival of dye at this station from this trace was less than four days; we estimate that the first arrival actually occurred in three days which would represent a mean groundwater velocity for first dye arrival via this flow route of 5,270 feet per day.

The groundwater flow path distance to Dye Spring from the dye introduction point is approximately 15,900 feet. The elevation loss from the introduction point to Dye Spring is approximately 215 feet, which represents a mean gradient of 71 feet per mile. The travel time to Dye Spring under these conditions was less than five days, and for purposes of calculation we estimate that the first arrival of dye at Dye Spring was 3 days after dye introduction. Based upon this, the mean groundwater velocity for the first dye arrival from the dye introduction point to Dye Spring was 5,300 feet per day.

The length of the groundwater flow path from the St. Joe sink to Tierce Spring via the Northwest Passage and the Junction Room of Fogelpole Cave is approximately 26,000 feet. The groundwater flow path from the St. Joe introduction point to the Northwest Passage sampling station is approximately 10,500 feet; the elevation loss for this segment is approximately 95 feet, and the mean groundwater flow path gradient for this segment is approximately 48 feet per mile. This correlates well with gradients in other parts of the Fogelpole Cave groundwater system.

The first arrival of dye from this trace at Tierce Spring was 14 to 23 days after dye introduction. If we use the mid-point of this period (18.5 days) as the first arrival time, this yields an estimated mean velocity for this flow route of 1,400 feet per day.

The St. Joe Trace was the first trace that demonstrates a particular area contributing water to the Illinois Caverns Natural Area. More importantly, this trace demonstrates the existence of a pathway for aquatic cave fauna to move between the Fogelpole Cave and Illinois Caverns groundwater systems.

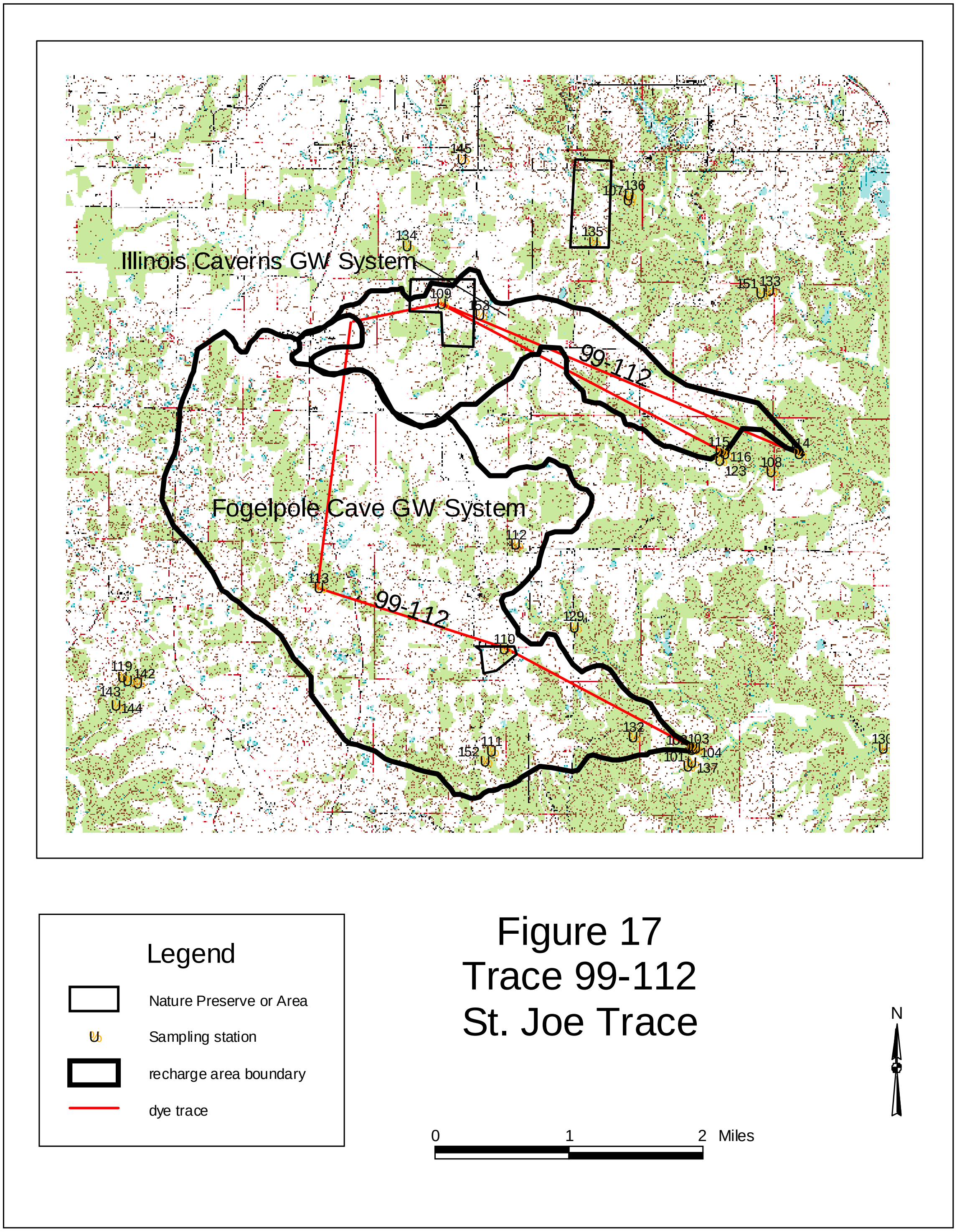


Figure 17
Trace 99-112
St. Joe Trace

4.2.16 Trace 99-113: Fults Road Trace.

One pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 0847 hours on January 31, 1999. The sinkhole had approximately 15 gpm of storm runoff entering the groundwater system through it at the time of dye introduction. The elevation of the introduction point is approximately 600 feet msl and is in the NW ¼ NE ¼ of Section 24, T4S, R10W. The location is shown on the Renault 7.5-minute quadrangle map. The trace is shown on Figure 18. The purpose of this trace was to help define the western boundary of the Fogelpole Cave recharge area.

The sampling stations for this trace were: 101, 102, 104, 110, 111, 118, 119, 120, 121, 122, 124, 125, 126, 130, 131, 137, 141, 149, and 150.

Data on the dye recovery locations for Trace 99-113 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 101. Collier Spring

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B dye Concentration (ppb)
12/31/98 to 1/18/99	ND	ND
1/18 to 1/30/99	ND	ND
1/30 to 2/4/99	574.6	6.10
2/4 to 2/14/99	ND	ND

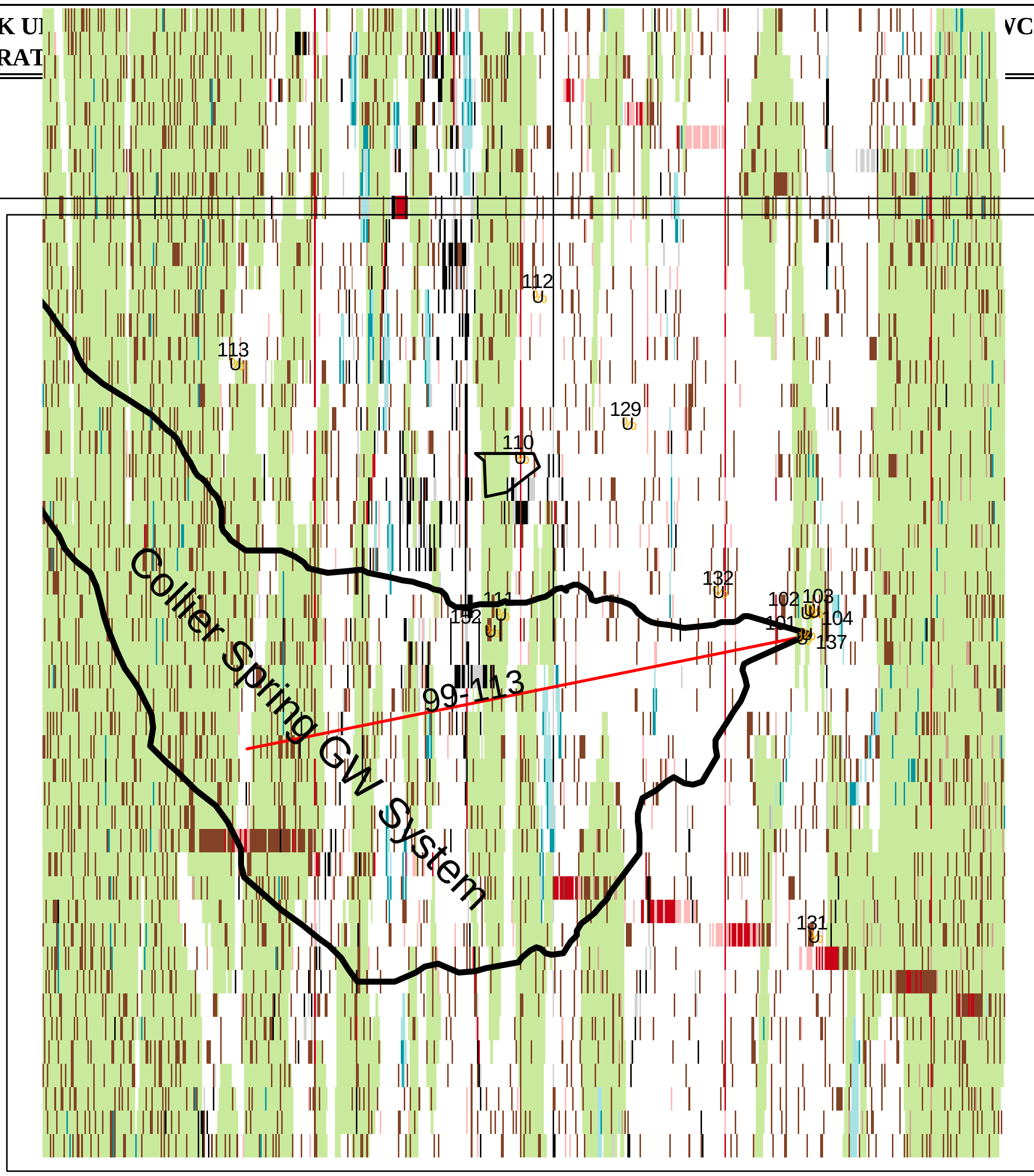
Station 137. Collier Downstream

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B dye Concentration (ppb)
12/31/98 to 1/18/99	ND	ND
1/18 to 1/30/99	ND	ND
1/18 to 1/30/99 (dup.)	ND	ND
1/30 to 2/4/99	574.5	5.59
2/4 to 2/14/99	ND	ND

Trace 99-113 had dye recovered at two sampling stations, both of which sample the same spring, Collier Spring. The Fults Road Trace demonstrates that its introduction point is outside the Fogelpole Cave groundwater system, but that it does contribute water to Collier Spring.

The groundwater flow path from the dye introduction point to Collier Spring is approximately 14,600 feet. The elevation loss is approximately 142 feet. The mean groundwater gradient is approximately 51 feet per mile. The dye first arrived and was flushed out of the system within four days following dye introduction. We estimate that the first dye arrived at Collier Spring 3 days after dye introduction. This represents a mean groundwater velocity of approximately 4,870 feet per day under these flow conditions.

This trace was characterized by considerable loss or dilution of the dye. The recovered dye concentrations are unusually small for the amount of dye introduced. Detection was only possible for a short time before the dye was flushed out of the system. The trace was conducted under moderate flow conditions.



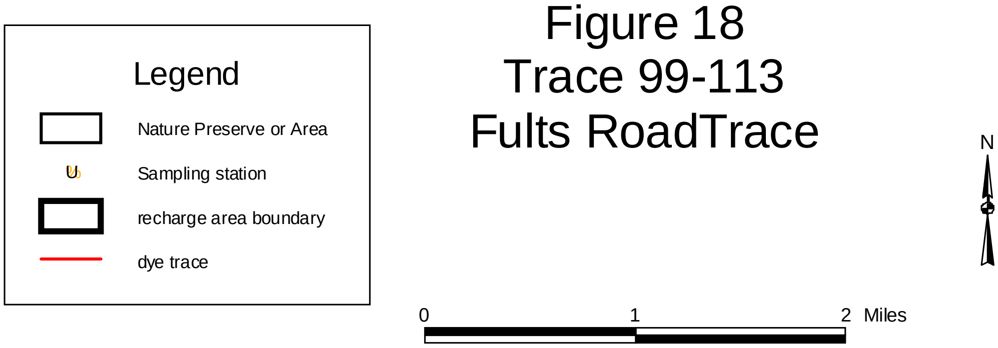


Figure 18
Trace 99-113
Fults RoadTrace

4.2.17 Trace 99-114: Rockhouse Creek Trace

Two pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into Rockhouse Creek at 1747 hours on February 23, 1999. The creek had about 20 gpm flow at the time of dye introduction. The elevation of the dye introduction point is approximately 630 feet msl and is in the NW ¼ SE ¼ of Section 18, T3S, R9W. The location is shown on the Waterloo 7.5-minute quadrangle map. The purpose of this trace was to determine if Rockhouse Creek contributes water to the Krueger groundwater system. The trace is shown on Figure 19.

The sampling stations for this trace were: 107, 128, 135, 136, 145, 147, and 148.

Data on the dye recovery location for Trace 99-114 is listed below. All data are for charcoal samplers unless otherwise noted.

Station 148. Rockhouse Creek at Route. 3

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
2/14 to 2/23/99	ND	ND
2/23 to 3/2/99	539.1	2,210
3/2/99 (water)	531.2	0.078
3/2 to 3/12/99	537.8	6.47
3/12 to 4/14/99	537.0	3.92

Eosine dye was recovered at only one sampling station from Trace 99-114. The station is in the surface channel downstream of the dye introduction point. Eosine dye degrades relatively quickly in surface waters. It is this degradation that accounts for the lack of a strong detection at Station 147. The samples from Station 147 only have an eosine shoulder (Appendix A).

The Rockhouse Creek Trace demonstrates that Rockhouse Creek does not contribute water to any of the RSA groundwater systems.

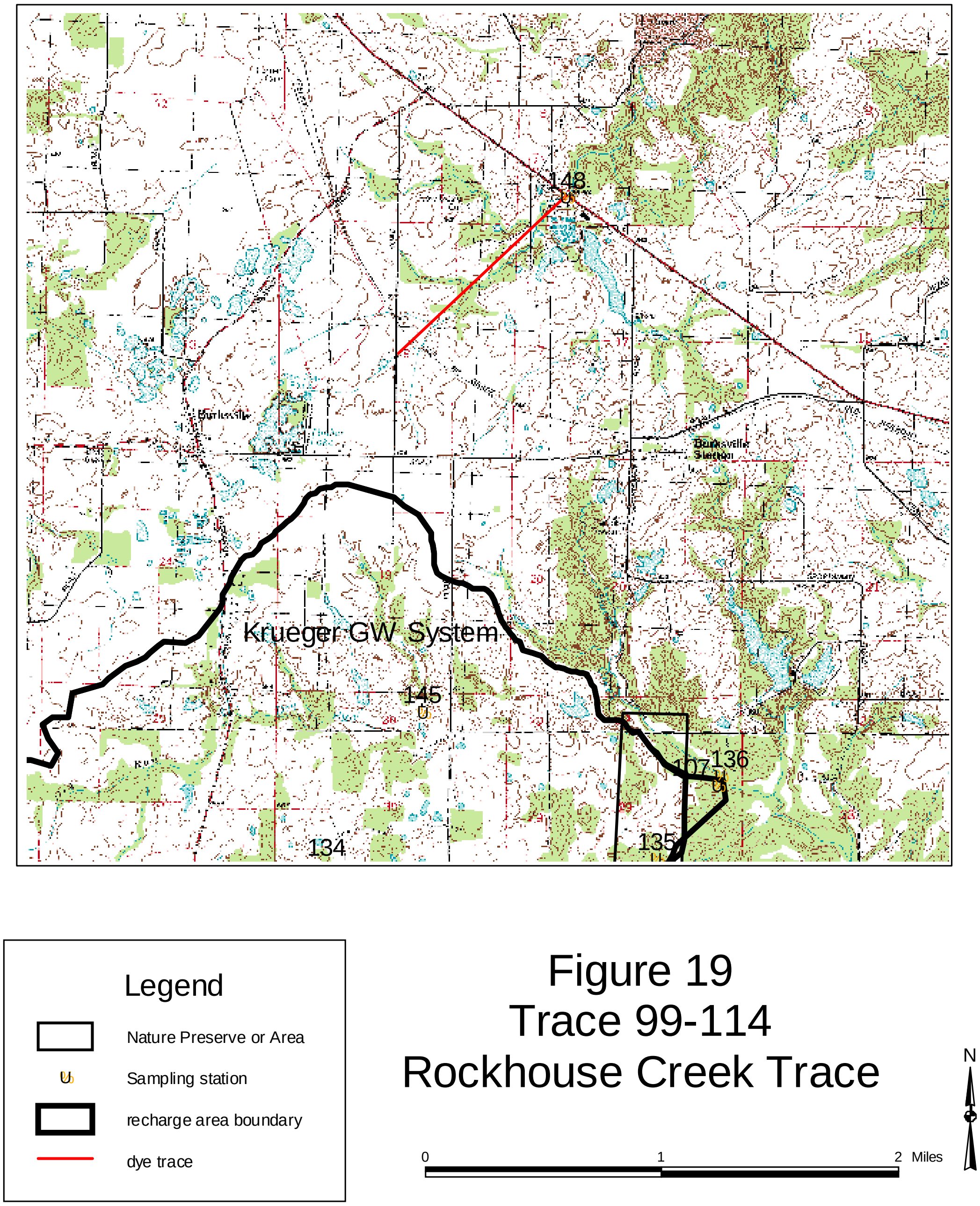


Figure 19
Trace 99-114
Rockhouse Creek Trace

4.2.18 Trace 99-115: Schultheis Sinking Stream Trace.

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into the Schultheis sinking stream at 1500 hours on February 27, 1999. There was approximately 75 gpm of storm runoff entering the groundwater system at the time of the dye introduction. The elevation of the dye introduction point is approximately 635 feet msl and is in the SW ¼ NE ¼ of Section 1, T4S, R10W. The location is shown on the Renault 7.5-minute quadrangle map. The purpose of this trace was to help define the northern border of Fogelpole Cave recharge area. The trace was conducted under moderately high flow conditions. The trace is shown on Figure 20.

The sampling stations for this trace were: 101, 102, 104, 108, 109, 110, 112, 113, 114, 115, and 130.

Data on the dye recovery locations for Trace 99-115 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 102. Tierce Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
2/14 to 2/23/99	ND	ND
2/23 to 3/2/99	538.3	38.5
3/2 to 3/11/99	538.6	254
3/11/99 (water)	ND	ND
3/11 to 3/19/99	536.4	0.543
3/19/99 (water)	ND	ND
3/19 to 3/25/99	535.6	0.426
3/25/99 (water)	ND	ND
3/25 to 3/31/99	ND	ND

Station 104. Indian Hole Channel

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
2/14 to 3/2/99	ND	ND
3/2 to 3/11/99	536.3	1.25
3/22 to 4/6/99	ND	ND

Station 110. Junction Room

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
1/30 to 2/24/99	ND	ND
2/24/99 (water)	ND	ND
2/24 to 3/2/99	538.6	142
3/2/99 (water)	532.0	0.252
3/2 to 3/12/99	537.8	8.99
3/12/99 (water)	ND	ND
3/12 to 4/5/99	538.8	1.00
4/5/99 (water)	ND	ND
4/5 to 4/21/99	ND	ND

Station 113. Northwest Passage

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
12/16/98 to 2/3/99	ND	ND
2/3 to 3/4/99	538.4	57.9
2/3 to 3/4/99 (dup.)	538.3	39.1
3/4 to 3/12/99	536.7	2.93
3/12/99 (water)	ND	ND
3/12 to 4/5/99	ND	ND

Station 130. South Fork at Road Crossing in Section 15

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
2/14 to 2/23/99	ND	ND
2/23 to 3/2/99	538.3	21.9
3/2 to 3/11/99	538.6	77.4
3/11 to 3/19/99	ND	ND

Station 141. Horse Creek at Ames Road Crossing

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
2/14 to 2/23/99	ND	ND
2/23 to 3/2/99	535.2	514
3/2 to 3/19/99	538.3	25.7
3/19 to 3/31/99	ND	ND

Eosine dye was recovered at six sampling stations from Trace 99-115. Four stations (Northwest Passage, Junction Room, Tierce Spring, and Indian Hole Channel) are part of the Fogelpole Cave groundwater system, while Stations 130 and 141 are downstream of the Fogelpole Cave groundwater system.

The straight-line groundwater flow path to the Northwest Passage sampling station is approximately 4,600 feet. The elevation loss is approximately 40 feet and the mean gradient is approximately 46 feet per mile. The dye first arrived at the Northwest Passage station within 5 days of the time of dye introduction.

The distance from the introduction point to the Junction Room, located in the Fogelpole Cave Nature Preserve, is approximately 11,900 feet. The majority of the dye reached and passed through the Junction Room within three days after dye introduction.

Dye from the Schultheis Sinking Stream first reached Tierce Spring within three days following dye introduction. If we use 3 days as the arrival time of the first dye and 20,300 feet as the travel distance, this represents a mean travel rate for first dye arrival of 6,770 feet per day. Most of the dye was discharged from the spring between 3 and 12 days following dye introduction. The data suggest that the peak dye discharge occurred about 4 days after dye introduction.

Dye from the Schultheis Sinking Stream first discharged down the Indian Hole channel between 3 and 12 days after dye introduction. The first dye arrival at this station was probably about 4 days after dye introduction.

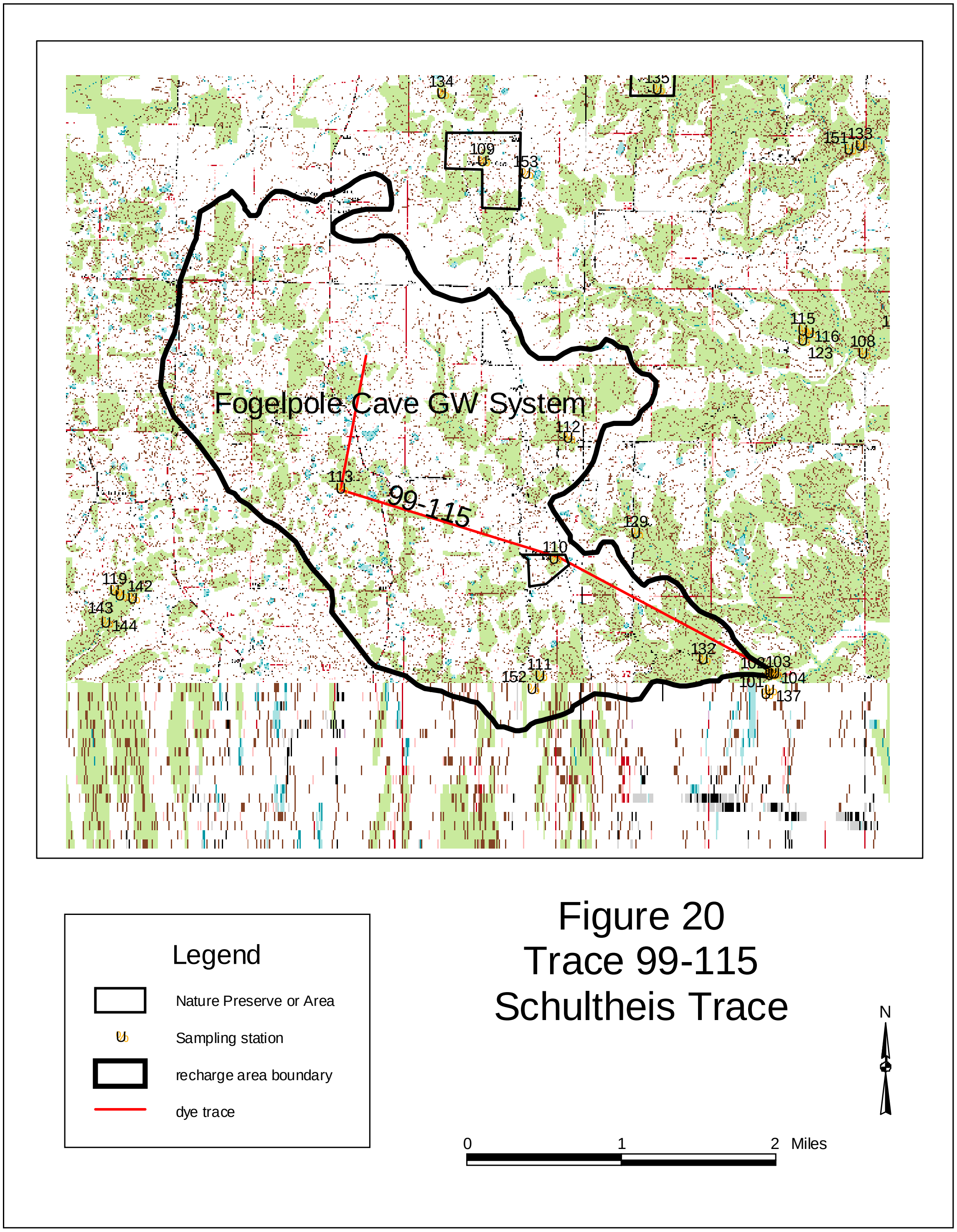


Figure 20
Trace 99-115
Schultheis Trace

4.2.19 Trace 99-116: Walsh Trace.

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole at 1402 hours on March 9, 1999. Approximately 2 gpm of water was entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 650 feet msl and is in the SE ¼ SW ¼ of Section 30, T3S, R9W. The location is shown on the Renault 7.5-minute quadrangle map. The purpose of this trace was to help define the recharge area boundary between the Illinois Caverns and Krueger groundwater systems. The trace is shown on Figure 21.

The sampling stations for this trace were: 107, 109, 114, 115, 128, 133, 134, 135, and 145.

Data on the dye recovery locations for Trace 99-116 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 107. Kelly Spring (combined)

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
2/14 to 3/2/99	ND	ND
3/2/99 (water)	ND	ND
3/2 to 3/11/99	563.3	23.0
3/11/99 (water)	570.5	14.2
3/11 to 3/19/99	564.3	329
3/19/99 (water)	568.8	0.235
3/19 to 3/25/99	563.3	20.3
3/25/99 (water)	ND	ND
3/25 to 3/31/99	563.6	2.36
3/31 to 4/14/99	562.8	1.80
4/14 to 4/21/99	ND	ND

Station 128. Horse Creek at MM Road Crossing

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
3/2 to 3/11/99	ND	ND
3/11 to 3/19/99	563.7	113
3/19 to 3/25/99	562.2	6.94
3/25 to 3/31/99	ND	ND

Station 135. Big Sink

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
2/4 to 3/2/99	ND	ND
3/2/99 (water)	ND	ND
3/2 to 3/11/99	563.8	35.5
3/11/99 (water)	570.2	6.93
3/11 to 3/19/99	564.5	308
3/19/99 (water)	571.2	0.239
3/19 to 3/25/99	563.4	26.5
3/19 to 3/25/99 (dup.)	563.2	24.2
3/25/99 (water)	ND	ND
3/25 to 3/31/99	561.8	4.51
3/31 to 4/14/99	561.6 a	3.41
4/14 to 4/21/99	ND	ND

Station 145. Fruth's Pump Hole

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
12/24/98 to 2/3/99	ND	ND
12/24/98 to 2/3/99 (dup.)	ND	ND
2/3 to 3/22/99	563.4	51.3
2/3 to 3/22/99 (dup.)	562.1	16.8
3/22 to 4/14/99	562.6	11.5
4/14 to 5/12/99	ND	ND

Rhodamine WT dye from the Walsh Trace was recovered from four sampling stations. Big Sink is in the Armin Krueger Speleological Nature Preserve and Kelly Spring is the discharge point for the Krueger groundwater system. Station 128 is located on Horse Creek downstream from Kelly Spring and derived its dye from the spring discharge. Fruth's pump hole is located in the main Dry Run underground stream channel, which is the upstream portion of the Krueger-Dry Run Cave.

Rhodamine WT dye from Trace 99-116 arrived in slightly less than two days following dye introduction at all three groundwater sampling stations. The straight-line groundwater flow path distance to Big Sink via Fruth's pump hole is approximately 11,200 feet. The elevation loss is approximately 105 feet. The mean gradient is approximately 50 feet per mile.

Dye arrived at Kelly Spring about one-half hour prior to sampling on March 11, 1999. It arrived on the same day as the dye reached Big Sink. We estimate that dye first reached Big Sink on the same date (March 11, 1999).

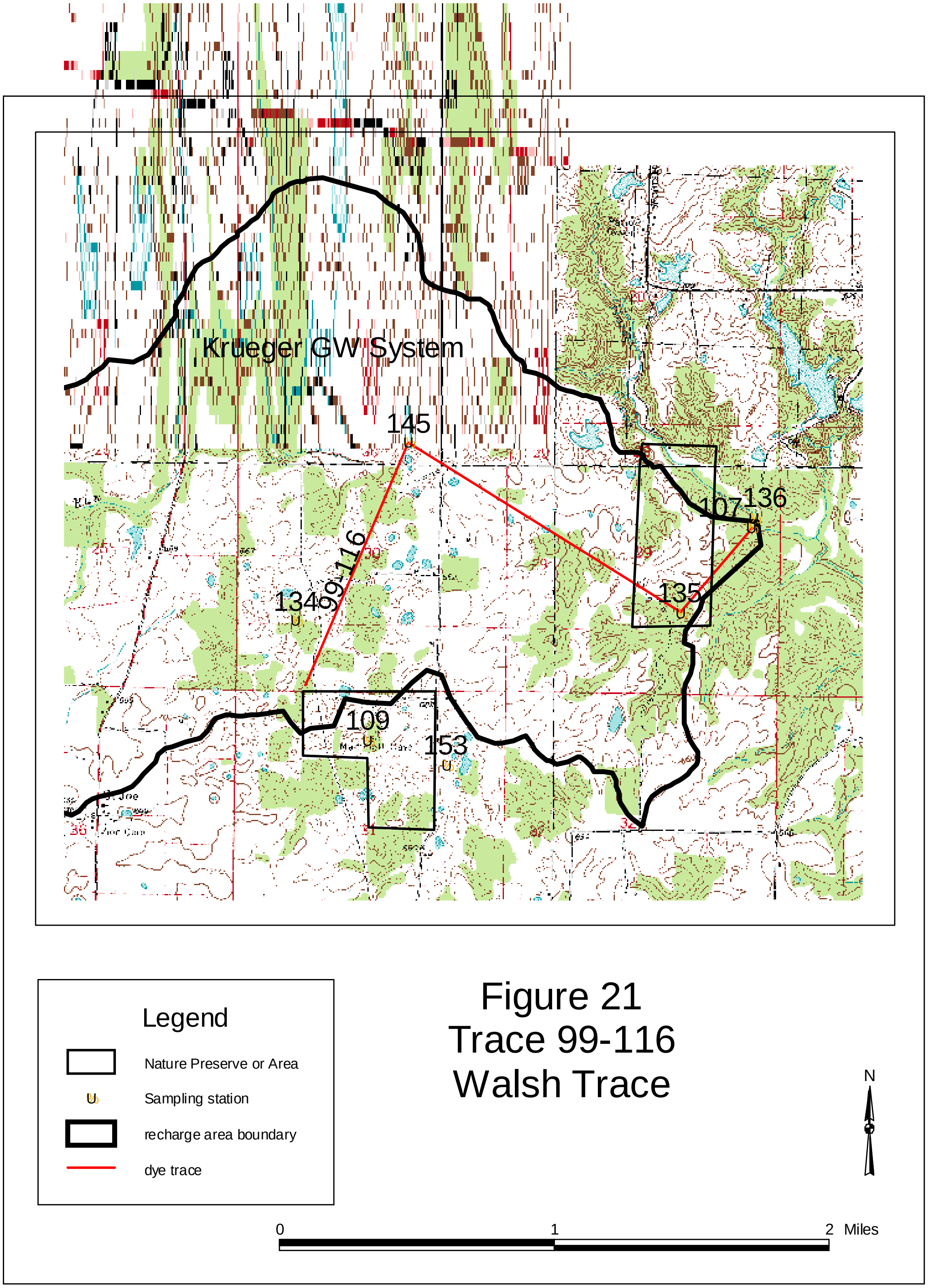


Figure 21
Trace 99-116
Walsh Trace

4.2.20 Trace 99-117: Fountain Creek Trace.

Two pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced at the Brushy Prairie Road crossing over a tributary of Fountain Creek at 0633 hours on March 23, 1999. The flow in the tributary was estimated to be 175 gpm. The elevation of the dye introduction point is approximately 650 feet msl and is in the SW ¼ NW ¼ of Section 24, T3S, R10W. The location is shown on the Waterloo 7.5-minute quadrangle map. The purpose of this trace was to determine if there is any leakage into the Krueger groundwater system from Fountain Creek. Trace 99-117 is shown on Figure 22.

The sampling stations for this trace were: 107, 134, 135, 145, and 146.

Data on the dye recovery location for Trace 99-117 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 146. Fountain Creek at Maeystown Road

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
2/1 to 2/14/99	ND	ND
2/14 to 3/25/99	537.5	3.69
3/25/99 (water)	ND	ND
3/25 to 3/31/99	536.1	1.48
3/25 to 3/31/99 (dup.)	535.4	1.09
3/31/99 (water)	ND	ND
3/31 to 4/6/99	537.2	SH
4/6 to 4/14/99	ND	ND

Eosine dye was recovered from the Fountain Creek Trace at one sampling station, Fountain Creek at Maeystown Road. No dye was detected at any of the sampled springs. This trace demonstrates that Fountain Creek is not contributing detectable amounts of water to the Krueger System or to any of the other RSA groundwater systems. The results of this trace, taken with the results of Trace 99-114, indicate that the topographic and groundwater high around Burksville forms part of the Krueger Cave system recharge area boundary.

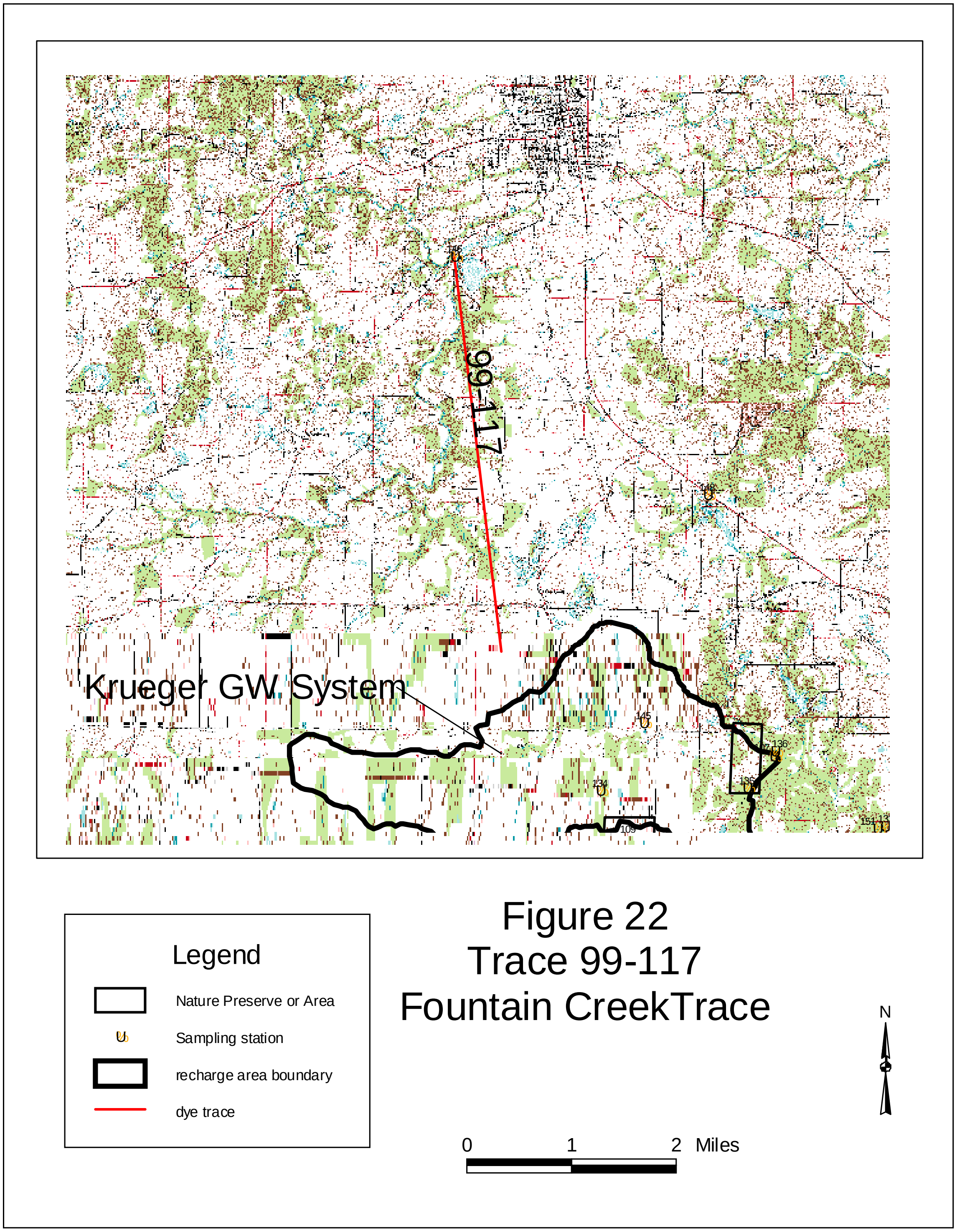


Figure 22
Trace 99-117
Fountain CreekTrace

4.2.21 Trace 99-118: Church Trace.

Three quarters of a pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole in a ditch along Kaskaskia Road at 0716 on March 23, 1999. There was approximately one gpm entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 560 feet msl and is in the NW ¼ NW ¼, Section 31, T4S, R9W. The purpose of this trace was to add to our understanding of groundwater flow in the Renault area. The location of this trace is shown on the Renault 7.5 minute quadrangle map. This trace is shown on Figure 23.

The sampling stations for this trace were: 118, 125, 126, 127, and 149.

Data on the dye recovery locations for Trace 99-118 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 125. Couch's Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
3/11 to 3/25/99	ND	ND
3/25 to 3/31/99	539.0	767
3/31/99 (water)	533.0	90.8
3/31 to 4/6/99	539.0	1,410
4/6/99 (water)	532.8	1.27
4/6 to 4/14/99	538.5	127
4/14 to 5/27/99	538.7	233
5/27 to 8/13/99	537.8	30.8
8/13 to 1/5/00	530.4 a,s	4.09
1/5 to 1/20/00	ND	ND

Station 127. Unnamed Creek at Kaskaskia Road and Bluff Road

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
3/19 to 3/25/99	ND	ND
3/25 to 3/31/99	538.6	89.4
3/31/99 (water)	533.0	7.23
3/31 to 4/14/99	538.8	393
4/14 to 5/27/99	537.9	10.0
5/27 to 8/13/99	535.8	1.66
8/13 to 1/5/00	532.8	1.23

Eosine dye from Trace 99-118 was recovered from two sampling stations; Couch's Spring and Station 127 which is located on the surface stream downstream from Couch's Spring. The straight-line distance from the dye introduction point to the spring is approximately 3,000 feet. The elevation loss from the introduction sink to Couch's Spring is approximately 120 feet and the mean gradient is approximately 211 feet per mile. The dye was first detected within eight days after dye introduction. If we assume that the first dye arrival occurred at this spring eight days after dye introduction the mean groundwater velocity under these flow conditions would be approximately 375 feet per day. Water at the spring was slightly colored with eosine dye at the time of sampling on March 31, 1999. This was eight days after dye introduction, and probably represents the peak concentration discharge from the Church Trace.

The Church Trace demonstrates that underground piracy of surface streams is occurring in the RSA. The introduction point is a sinkhole in a stream valley that is topographically distinct from the valley into which Couch's Spring discharges. The Couch's Spring valley has captured flow from the headwaters of its neighboring valley to the northwest via the Couch's Spring groundwater system.

The Renault Cave System, as defined by the Illinois Natural Areas Inventory, includes two springs; Spring #1 and Couch’s Spring (Spring #2). This trace along with Trace 98-107 (Jacob’s Trace) indicates that the Renault Cave System is actually two cave systems.

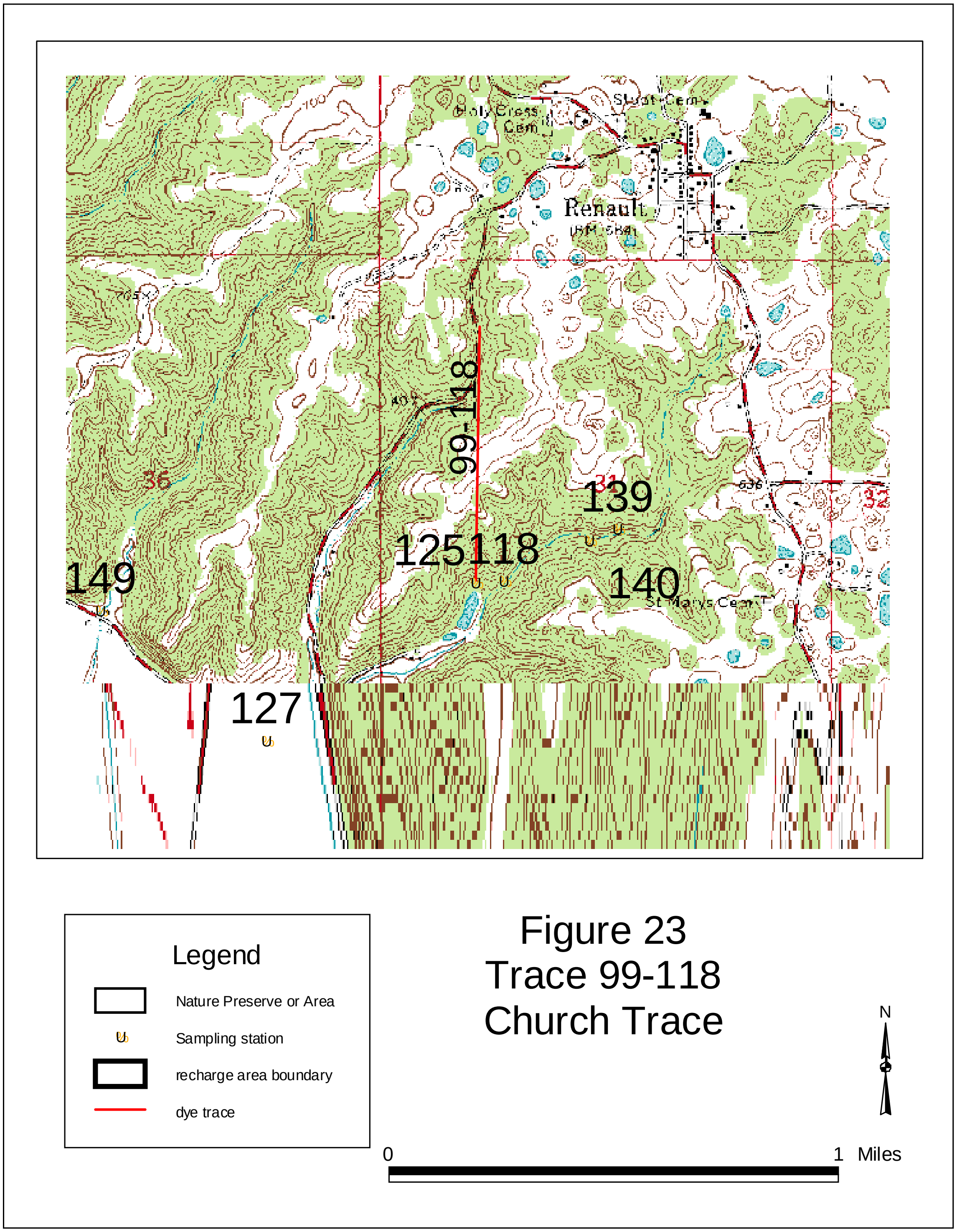


Figure 23
Trace 99-118
Church Trace

4.2.22 Trace 99-119: Frees Trace.

One pound of pyranine dye mixture containing approximately 77% dye and 23% diluent was introduced into a sinking stream at 0710 hours on April 1, 1999. The flow rate of water entering the groundwater system at the time of dye introduction was about 8 gpm. The elevation of the dye introduction point is approximately 530 feet msl in the SW ¼ SE ¼ of Section 4, T4S, R9W. The location is shown on the Ames 7.5-minute quadrangle map. The purpose of this trace was to help define the recharge area boundary between the Fogelpole and Lantz Spring groundwater systems. The trace is shown on Figure 24.

The sampling stations for this trace were: 102, 104, 108, 110, 112, 128, 130, and 141.

Data on the dye recovery location for Trace 99-119 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 108. Lantz Spring

Sampling Period	Peak Emission Wavelength (nm)	Pyranine Dye Concentration (ppb)
3/19 to 3/31/99	ND	ND
3/31 to 4/6/99	501.6	63.3
4/6/99 (water)	ND	ND
4/6 to 4/14/99	ND	ND

Pyranine dye was recovered from the Frees Trace at one location, Lantz Spring. The straight-line distance for this groundwater flow path is 2,370 feet. The elevation loss is approximately 50 feet and the mean groundwater gradient is approximately 111 feet per mile. Dye was recovered at Lantz Spring within five days of dye introduction. The trace was conducted under moderate flow conditions. The mean groundwater velocity under these flow conditions is probably greater than 500 feet per day.

The Frees Trace demonstrates that the dye introduction point lies outside of the Fogelpole Cave groundwater system. This trace helps define both the Fogelpole Cave and the Lantz Spring recharge areas. The Lantz Spring groundwater system lies between the eastern sections of the Fogelpole Cave and the Illinois Caverns recharge areas.

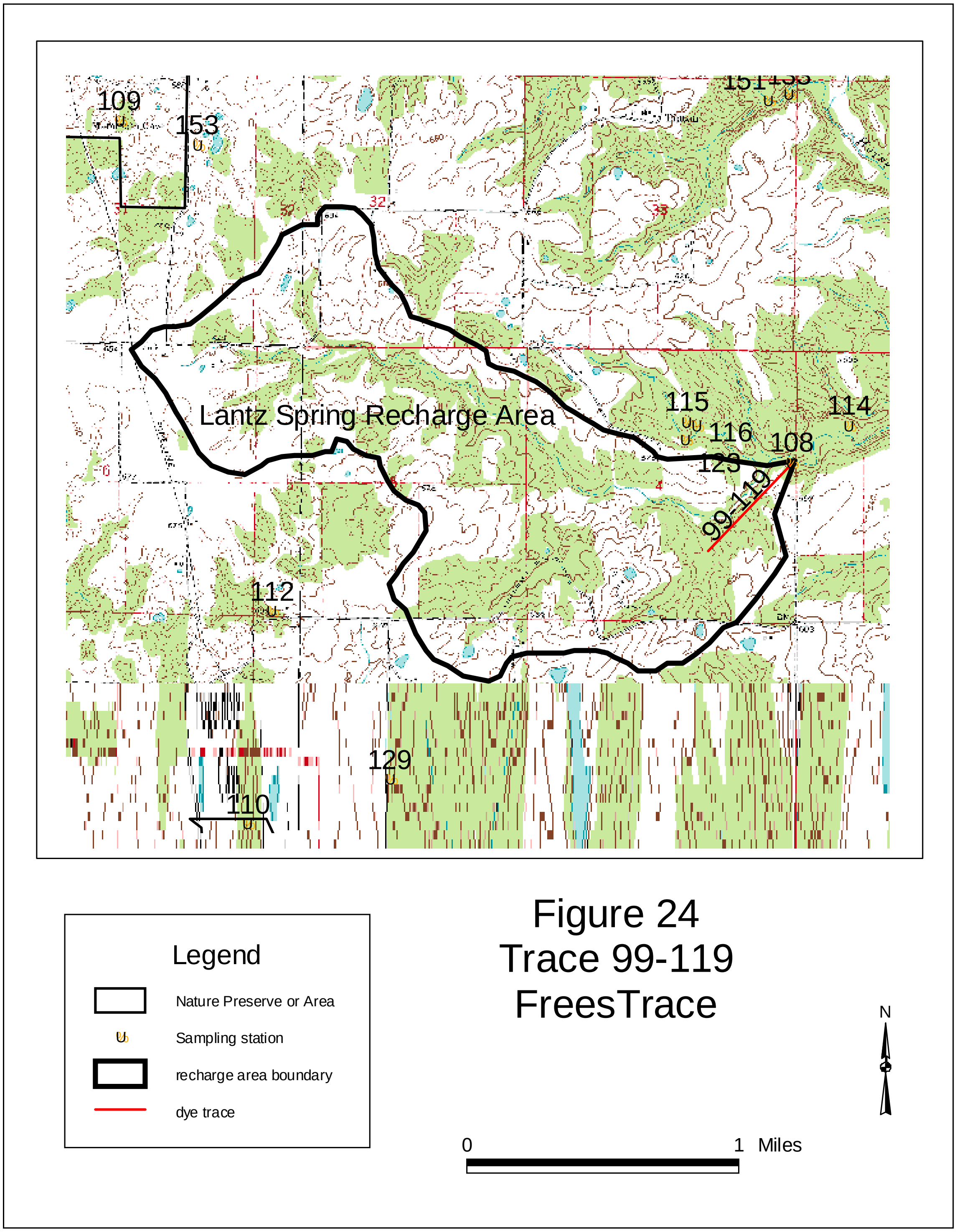


Figure 24
Trace 99-119
FreesTrace

4.2.23 Trace 99-120: MM Road Trace.

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinking stream at 1215 hours on April 3, 1999. There was approximately 90 gpm of storm runoff entering the groundwater system at the time of dye introduction. This sinking stream flows only in wet weather. There was no ponding of water at the time of dye introduction. The elevation of the dye introduction point is approximately 595 feet msl and is in the SW ¼ SW ¼ of Section 4, T4S, R9W. The location is shown on the Ames 7.5-minute quadrangle map. The purpose of this trace was to help define the recharge area boundary between the Fogelpole and Lantz Spring groundwater systems. The trace was conducted under high flow conditions. The trace is shown on Figure 25.

The sampling stations for this trace were: 102, 104, 108, 110, 112, 128, 130, 141, and 151.

Data on the dye recovery locations for Trace 99-120 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 108. Lantz Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
3/19 to 3/31/99	ND	ND
3/31 to 4/6/99	563.4	20.0
4/6/99 (water)	ND	ND
4/6 to 4/14/99	ND	ND

Station 151. Horse Creek upstream of Curran Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
3/22 to 4/22/99	562.0	3.10
4/22 to 5/27/99	ND	ND

Rhodamine WT dye from the MM Road Trace was recovered at Lantz Spring. Dye derived from this spring was also recovered from Station 151 downstream of Lantz Spring. The straight-line distance through the groundwater system for this trace is approximately 5,075 feet. The elevation loss is approximately 115 feet and the mean gradient of the flow path is approximately 120 feet per mile. The OUL estimates that the mean groundwater velocity under the high flow conditions which existed during this trace was approximately 5,000 feet per day. This is partly based on the fact that the dye passed completely out of the system in less than three days. The trace followed a path that is quite open. There was little attenuation of the dye.

Trace 99-120 demonstrates that the wet-weather sinking stream in which this trace was initiated resurges at Lantz Spring. The Lantz Spring recharge area lies between the Fogelpole Cave recharge area and the Illinois Caverns recharge area.

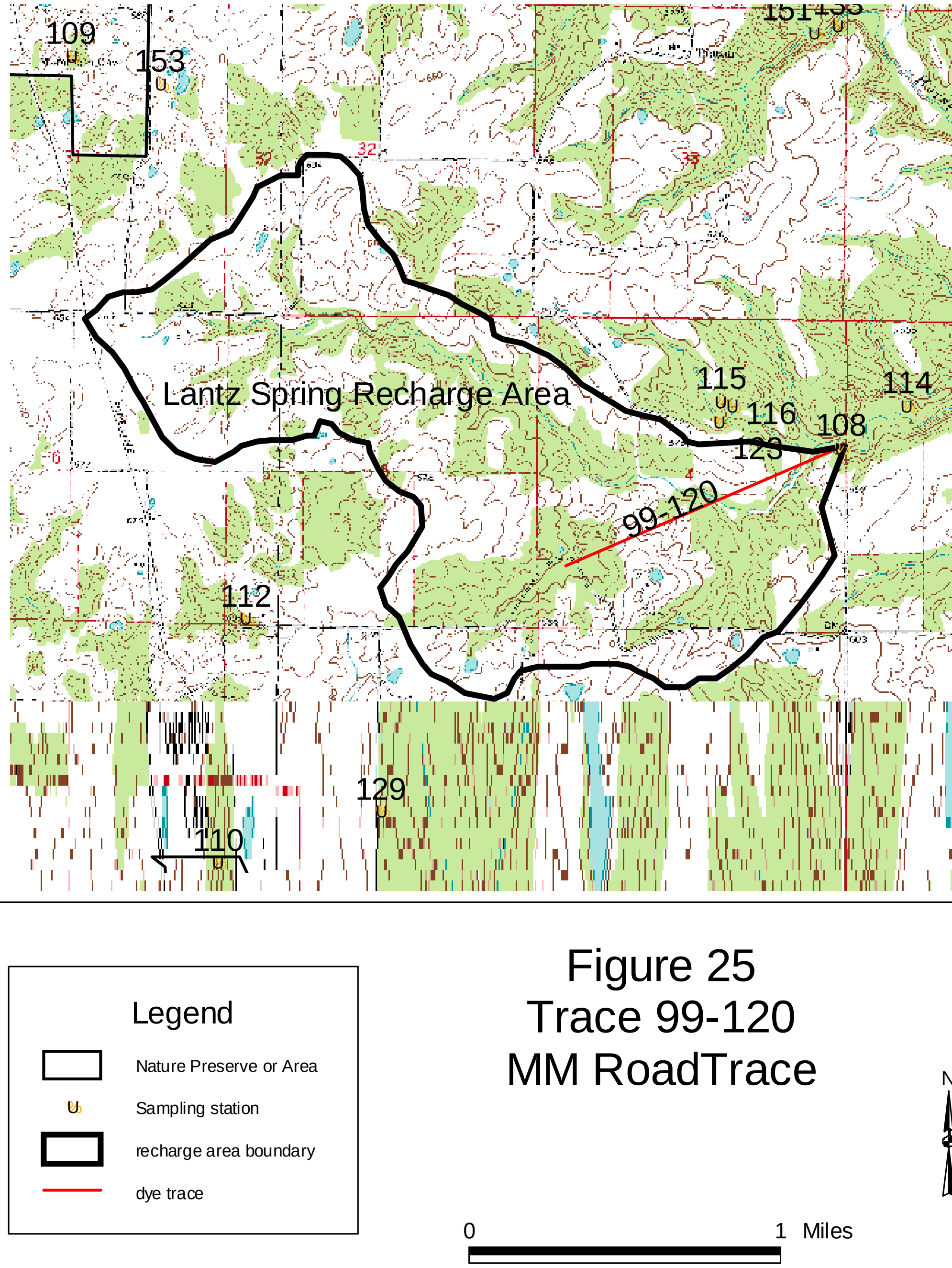


Figure 25
Trace 99-120
MM RoadTrace

4.2.24 Trace 99-121: Polka Trace.

Approximately one-half pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1316 hours on April 3, 1999. There was approximately 45 gpm of storm runoff entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 630 feet msl and is in the NE ¼ SW ¼ of Section 6, T4S, R9W. The location is shown on the Ames 7.5-minute quadrangle map. The purpose of this trace was to help define the recharge area boundary between the Fogelpole and Lantz Spring groundwater systems. The trace is shown on Figure 26.

The sampling stations for this trace were: 102, 104, 108, 110, 112, 128, 130, and 141.

Data on the dye recovery locations for Trace 99-121 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 102. Tierce Spring

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/25 to 3/31/99	ND	ND
3/31 to 4/6/99	512.2	9.97
4/6/99 (water)	ND	ND
4/6 to 4/16/99	ND	ND

Station 104. Indian Hole (channel)

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/2 to 3/11/99	ND	ND
3/11 to 4/6/99	512.3	9.22
4/6 to 5/12/99	ND	ND

Station 110. Junction Room

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/2 to 3/12/99	ND	ND
3/12 to 4/5/99	512.0	5.44
4/5/99 (water)	ND	ND
4/5 to 4/21/99	ND	ND

Station 112. Lemonade Passage

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
2/3 to 3/2/99	ND	ND
3/2 to 4/5/99	513.7	675
4/5/99 (water)	507.3	0.470
4/5 to 4/21/99	512.6	81.2
4/21/99 (water)	507.2	0.036
4/21 to 5/4/99	512.5	10.9
5/4/99 (water)	504.4 a	0.006
5/4 to 5/12/99	ND	ND

Station 130. South Fork at Road Crossing in Section 15

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/25 to 3/31/99	ND	ND
3/31 to 4/14/99	510.9 s	2.35
4/14 to 5/4/99	ND	ND

Fluorescein dye was recovered at five sampling stations: Lemonade Passage and the Junction Room downstream from Lemonade Passage in Fogelpole Cave, Tierce Spring, which is the underflow spring for Fogelpole Cave, Indian Hole, which is the overflow spring for the system, and the downstream surface stream sampling location, Station 130. Trace 99-121 demonstrates that the Polka sink is within the Fogelpole Cave recharge area. In particular, the Polka Sink provides recharge to the Fogelpole Cave Nature Preserve.

The groundwater flow path from the Polka Sink to Tierce Spring is approximately 15,475 feet straight line distance and has a mean gradient of 60 feet per mile. The first arrival of dye at Tierce Spring was within 3 days of dye introduction. We estimate that the first arrival of the dye at Tierce Spring occurred 2.5 days after dye introduction. This represents a mean groundwater flow velocity for the first arrival of the dye at 6,190 feet per day. Significant portions of this flow path are flowing up dip relative to the regional dip of the bedrock.

The elevation loss is approximately 50 feet from the introduction sink to Lemonade Passage. The straight-line distance for this flow path segment is approximately 2,900 feet and has a mean gradient of approximately 91 feet per mile. There is another 70 feet of elevation loss from Lemonade Passage to the Junction Room. The straight-line distance from Lemonade Passage to the Junction Room is approximately 4,400 feet and the mean gradient is approximately 89 feet per mile. From the Junction Room to Tierce Spring there is approximately 46 feet of elevation loss. The mean velocity of the groundwater from the Polka sink to the Junction Room in the Fogelpole Cave Nature Preserve is approximately 3,700 feet per day under the high flow conditions which existed during this trace.

The Polka Trace moved very quickly through the Fogelpole Cave groundwater system. In addition, there was little persistence of the dye within the cave system. Dye was not detectable at the Junction Room or at Tierce Spring three days after dye introduction. There was some persistence in the Lemonade Passage, the most proximate sampling station to the dye introduction point. The persistence of dye near the introduction point is similar to what was observed in the Nobbe Trace (Section 4.2.6) and the Charles Sink Trace (4.3.2).

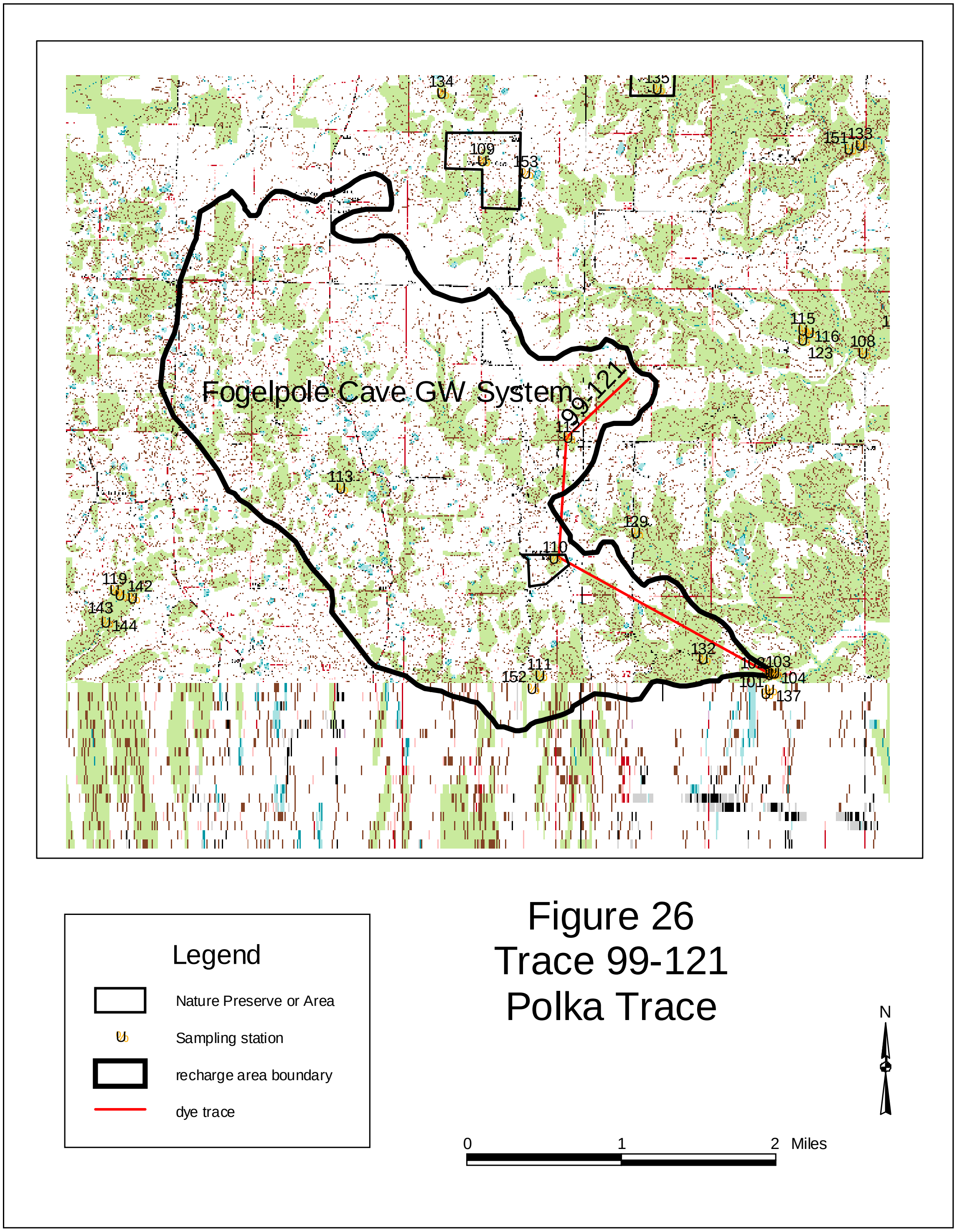


Figure 26
Trace 99-121
Polka Trace

4.2.25 Trace 99-122: Barchet Trace

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1624 hours on April 28, 1999. Approximately one gpm of storm runoff was entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 610 feet msl and is in the SE ¼ NW ¼ of Section 5, T4S, R9W. The location is shown on the Ames 7.5-minute quadrangle map. The purpose of this trace was to help define the recharge area boundary between the Fogelpole and Lantz Spring groundwater systems. The trace is shown on Figure 27.

The sampling stations for this trace were: 102, 104, 108, 110, 112, 128, 130, and 141.

Data on the dye recovery locations for Trace 99-122 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 108. Lantz Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
4/14 to 4/22/99	536.0	1.09
4/22/99 (water)	ND	ND
4/22 to 5/6/99	538.5	67.2
5/6/99 (water)	ND	ND
5/6 to 5/12/99	538.6	21.0
5/12/99 (water)	531.9	0.520
5/12 to 5/27/99	538.2	14.3
5/27/99 (water)	530.4	0.111

Station 128. Horse Creek at MM Road Crossing in Section 2

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
4/14 to 5/4/99	ND	ND
5/4 to 5/12/99	537.3	3.11
5/12 to 5/21/99	ND	ND

Dye was recovered at two sampling stations for Trace 99-122. These were Lantz Spring and Station 128 downstream of Lantz Spring on Horse Creek. The Barchet Trace helps define the recharge area boundary between the Lantz Spring and Fogelpole Cave groundwater systems. The straight-line distance from the Barchet sink to Lantz Spring is approximately 8,000 feet. The elevation loss is approximately 130 feet and the mean gradient is approximately 86 feet per mile. The mean groundwater velocity under these flow conditions was greater than 1,000 feet per day. Flow rates of the spring were moderate until a discharge spike occurred following about 1.5 inches of rainfall in two events on May 5, 1999.

The eosine dye concentration shown for the period April 14 to April 22 pre-dates the 99-122 dye introduction and represents residual dye from Trace 99-111; (the LL Road Trace). The dye concentration following the dye introduction is more than an order of magnitude greater than the residual value and thus satisfies the OUL's criteria for a new dye recovery. The Barchet Trace demonstrates that the sink and its environs recharge Lantz Spring.

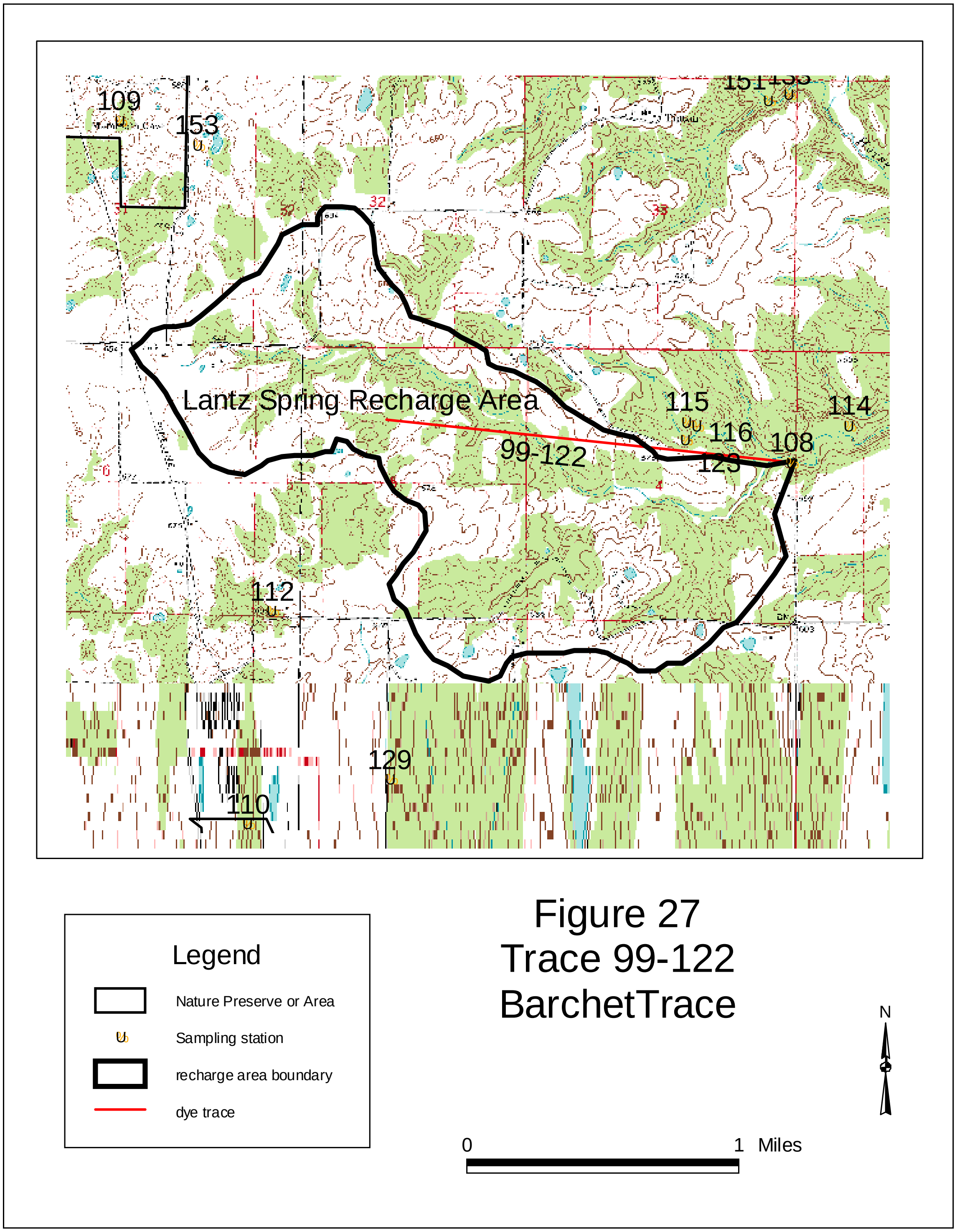


Figure 27
Trace 99-122
BarchetTrace

4.2.26 Trace 99-123: Illinois Caverns Natural Area Trace.

One pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1908 hours on May 5, 1999. Approximately five gpm was entering the groundwater system at the time of dye introduction. Flow was in response to a storm event. The elevation of the dye introduction point is approximately 670 feet msl and is in the NW ¼ NE ¼ of Section 31, T3S, R9W. The location is shown on the Renault 7.5-minute quadrangle map. The purpose of this trace was to help define the boundary between the Illinois Caverns recharge area and the Krueger recharge area. The trace is shown on Figure 28.

The sampling stations for this trace were: 107, 109, 128, 133, 135, 141, and 145.

Data on the dye recovery locations for Trace 99-123 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 114. Dye Spring

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B dye Concentration (ppb)
4/22 to 5/6/99	ND	ND
5/6 to 5/12/99	575.6	181
5/12/99 (water)	578.8	0.200
5/12 to 5/27/99	575.0	56.1
5/27/99 (water)	ND	ND
5/27 to 8/13/99	574.5	5.90
8/13/99 (water)	ND	ND
8/13 to 11/3/99	ND	ND

Station 115. Walsh Cave

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B dye Concentration (ppb)
5/4 to 5/6/99	ND	ND
5/6 to 5/12/99	576.0	505
5/12/99 (water)	578.5	28.3
5/12 to 5/21/99	575.4	166
5/21 to 5/27/99	575.1	20.6
5/27/99 (water)	576.4	0.377
5/27 to 6/4/99	574.7	14.8
6/4 to 6/23/99	574.5	18.7
6/23 to 7/22/99	574.0	1.96
7/22 to 8/13/99	NS	NS
8/13 to 9/3/99	ND	ND

Station 128. Horse Creek at MM Road Crossing in Section 2

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B dye Concentration (ppb)
4/14 to 5/4/99	ND	ND
5/4 to 5/12/99	574.0	5.72
5/12 to 5/21/99	574.0	4.47
5/21 to 5/27/99	572.8	0.859
5/27 to 8/13/99	ND	ND

Sulforhodamine B dye from the Illinois Caverns Natural Area (ICNA) Trace was recovered at three sampling stations. These were Walsh Cave, Dye Spring, and the downstream Station 128. In addition, a concentration of dye less than our reporting limit appears to have been present in one sample from Station 141 (Horse Creek at Ames Road Crossing. Dye at this station would have been derived from points upstream of Station 128.

The straight-line distance from the dye introduction point to Walsh Cave is approximately 11,800 feet. The elevation loss is approximately 155 feet to Walsh Cave, and the mean gradient for this groundwater flow path is approximately 69 feet per mile. We estimate that the first dye from this trace reached Dye Spring and Walsh Cave about 5 days after dye introduction. The mean groundwater velocity for the first arrival of dye at Walsh Cave under these flow conditions was approximately 2,360 feet per day. The straight-line distance to Dye Spring is approximately 14,600 feet and the elevation loss is approximately 195 feet. The mean gradient for the Dye Spring flow path is approximately 71 feet per mile. The mean groundwater velocity for the first arrival of dye at Dye Spring was about 2,920 feet per day. Flow conditions varied from normal to above normal flow in response to rain events on May 5 and May 12, 1999.

Trace 99-123 helps define the boundary between the Krueger and Illinois Caverns recharge areas. Part of the Illinois Caverns Natural Area has been shown by Trace 99-116 to recharge the Krueger groundwater system. This trace shows that this part of the Illinois Caverns Natural Area does recharge the Illinois Caverns groundwater system. However, this water leaves the ICNA after flowing approximately 100 feet.

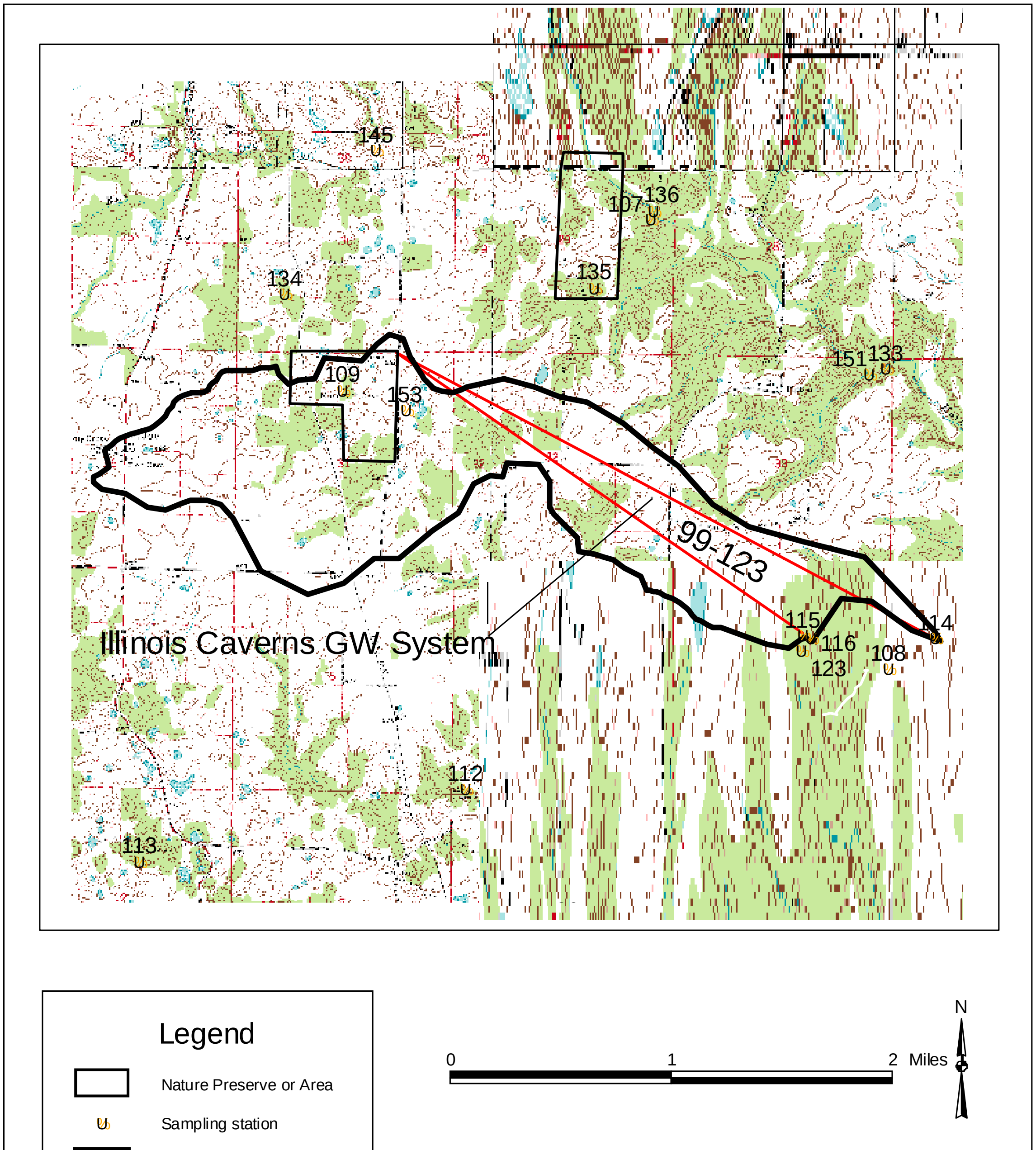


Figure 28
Trace 99-123
Illinois Caverns Natural Area Trace

4.2.27 Trace 99-124: Henning Road Trace.

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole at 1925 hours on May 5, 1999. Approximately 40 gpm of storm runoff was entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 560 feet msl and is in the NE ¼ NE ¼ of Section 19, T4S, R9W. The location is shown on the Renault 7.5 minute quadrangle map. The purpose of this trace was to help define the southern boundary of the Fogelpole Cave recharge area. The trace is shown on Figure 29.

The sampling stations for this trace were: 101, 102, 104, 111, 130, and 141.

Data on the dye recovery locations for Trace 99-124 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 101. Collier Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
4/16 to 5/4/99	ND	ND
5/6/99 (water)	ND	ND
5/4 to 5/12/99	564.4	5.56
5/12 to 5/21/99	ND	ND

Station 137. Collier Downstream

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
3/31 to 4/16/99	ND	ND
4/16 to 5/6/99	564.8	1.94
5/6 to 5/12/99	ND	ND

Rhodamine WT dye was recovered at two sampling stations: Collier Spring and Collier Downstream. These two stations both sample Collier Spring. The straight-line distance for the Henning Road Trace is approximately 8,950 feet. The elevation loss is approximately 102 feet and the mean gradient is approximately 59 feet per mile. The mean groundwater velocity under these flow conditions was approximately 1,500 feet per day. Trace 99-124 demonstrates that the boundary between the Fogelpole Cave and the Collier Spring recharge areas lies north of the Henning Road sinkhole.

The trace was conducted under somewhat elevated flow conditions. The dye was introduced during a storm event. The dye passed through the system quickly and was not detectable after about one week.

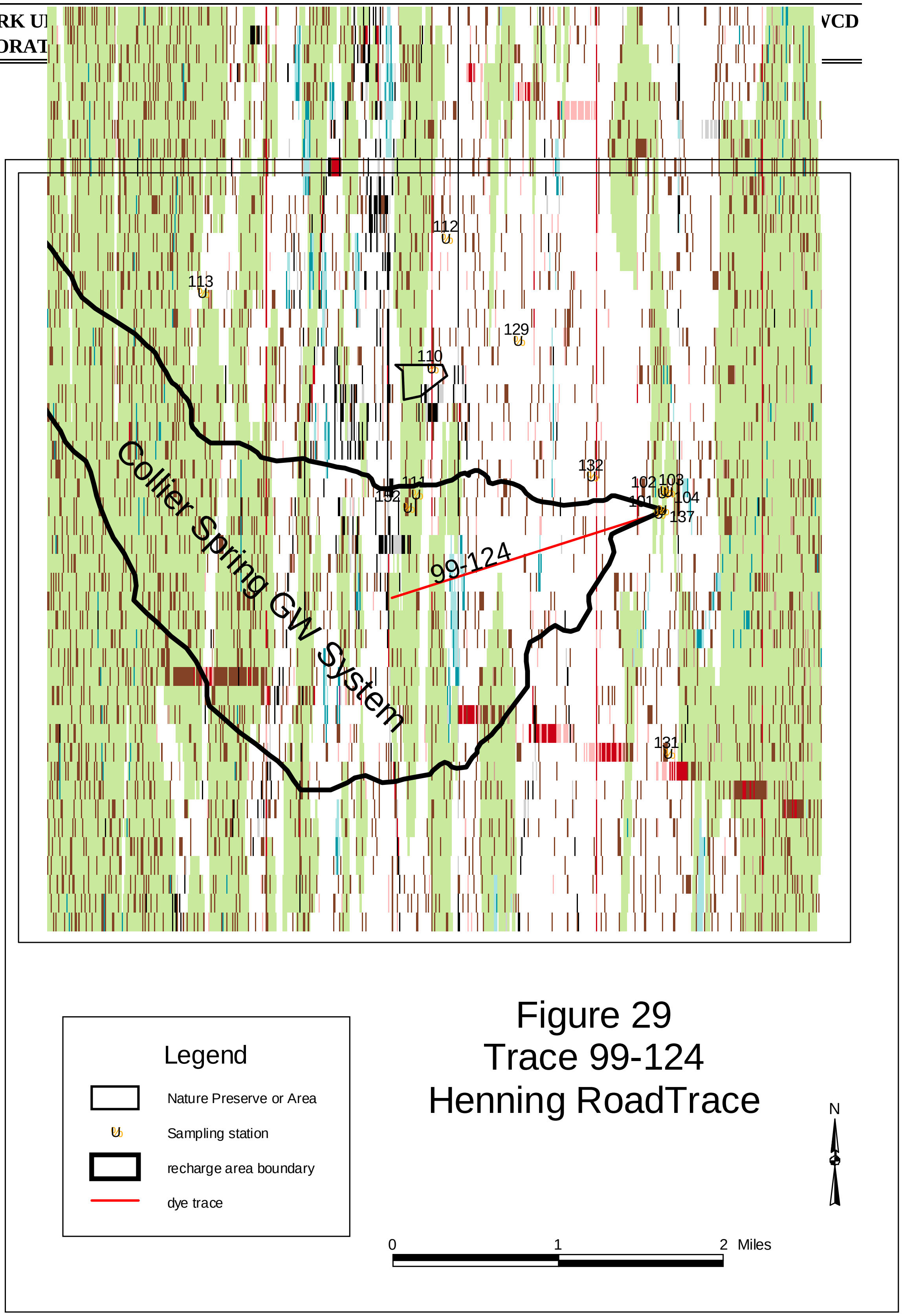


Figure 29
Trace 99-124
Henning RoadTrace

4.2.28 Trace 99-125: Gotto Trace.

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 2035 hours on June 21, 1999. Approximately one gpm was flowing through a small karst window at the time of dye introduction. The elevation of the dye introduction point is approximately 665 feet msl and is in the NW ¼ SE ¼ of Section 2, T4S, R10W. The location is shown on the Renault 7.5-minute quadrangle map. The purpose of this trace was to help define the western boundary of the Fogelpole Cave recharge area. The trace is shown on Figure 30.

The sampling stations for this trace were: 101, 102, 104, 110, 111, 113, 130, 137, and 141.

Data on the dye recovery locations for Trace 99-125 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 102. Tierce Spring

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
6/4 to 6/23/99	ND	ND
6/23 to 6/30/99	512.5	18.3
6/30/99 (water)	507.8	5.23
6/30 to 7/7/99	514.1	2,940
7/7/99 (water)	507.9	0.954
7/7 to 7/22/99	513.0	125
7/7 to 7/22/99 (dup.)	513.0	123
7/22/99 (water)	507.2	0.095
7/22 to 8/2/99	512.7	35.3
8/2/99 (water)	505.6	0.070
8/2 to 8/13/99	512.6	20.8
8/13/99 (water)	ND	ND
8/13 to 8/20/99 *	ND	ND

* Residual dye was discharged from Tierce Spring through the sampling period ending January 5, 2000. See Appendix A for analysis results.

Station 110. Junction Room

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
6/5 to 6/23/99	ND	ND
6/23 to 7/22/99	513.8	1,140
7/22/99 (water)	507.0	0.067
7/22 to 8/2/99	512.5	27.5
8/2/99 (water)	505.2 a	0.056
8/2 to 8/13/99	512.2	10.5
8/13/99 (water)	ND	ND
8/13 to 8/20/99	ND	ND
8/20/99 (water)	504.4 a	0.014
8/20 to 8/23/99	511.9	3.98
8/23/99 (water)	504.4 a	0.014
8/23 to 9/3/99	511.6	4.05
8/23 to 9/3/99 (dup.)	511.2	5.51
9/3 to 9/10/99	511.7	5.58
9/10 to 9/15/99	511.6	5.43
9/15/99 (water)	ND	ND
9/15 to 9/29/99	511.6	4.80
9/29/99 (water)	ND	ND
9/29 to 10/27/99	511.8	4.23
10/27/99 to 1/27/00	510.9	1.89
1/27/00 (water)	ND	ND

Station 113. Northwest Passage

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
4/5 to 5/12/99	ND	ND
5/12 to 7/22/99	513.8	239
5/12 to 7/22/99 (dup.)	513.9	312
7/22/99 (water)	507.2	0.090
7/22 to 8/2/99	512.6	25.9
8/2/99 (water)	507.3	0.116
8/2 to 8/13/99	512.6	17.2
8/13/99 (water)	ND	ND
8/13 to 8/23/99	512.2	5.91
8/23 to 9/10/99	512.5	11.3
9/10 to 9/29/99	511.6	9.91
9/29 to 11/4/99	512.6	8.18
11/4/99 to 1/27/00	511.4	2.60
1/27/00 (water)	ND	ND
1/27 to 3/6/00	511.0	2.19

Station 130. South Fork at Road Crossing in Section 15

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
5/27 to 6/23/99	ND	ND
6/23 to 7/22/99	512.7	51.6
7/22 to 8/13/99	511.4	4.20
8/13 to 8/20/99	ND	ND

Station 141. Horse Creek at Ames Road Crossing

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
4/14 to 5/21/99	ND	ND
5/21 to 8/13/99	511.8	4.10
8/13 to 9/3/99	ND	ND

Fluorescein dye from the Gotto Trace was recovered at five sampling stations. From upstream to downstream they are: Northwest Passage, Junction Room, Tierce Spring, Stations 130 and 141. The Gotto Trace dye recovery data suggest that there are two flow paths to the Junction Room; one that flows through the Northwest Passage sampling station and another that bypasses that station. Dye recoveries were appreciably higher in the distal Junction Room than at the more proximate Northwest Passage. Normal flow with its associated attenuation leads to a prediction that the more distal sampling point would have a lower concentration of dye. All of these dye recoveries are associated with the Fogelpole Cave groundwater system.

This trace was conducted under base flow conditions. The straight-line distance from the Gotto sink to Tierce Spring via the Northwest Entrance and the Junction Room is approximately 22,400 feet and the dye movement took approximately nine days under these flow conditions. A comparison of values between the carbon sampler and a grab sample of water suggests that dye was just beginning to arrive at Tierce Spring when it was sampled on June 30, 1999 (nine days after dye introduction). The mean groundwater velocity for the first arrival of dye at Tierce Spring was about 2,500 feet per day. The elevation loss is approximately 70 feet to the Northwest Entrance and 165 feet to the Junction Room. The mean gradient to the Northwest Entrance is approximately 59 feet per mile. The distance directly to the Junction Room is approximately 13,900 feet with a mean gradient of 63 feet per mile. This is very similar to the distance to the Junction room via the Northwest Entrance as is the average gradient (see Table 4).

The Gotto Trace demonstrates that this dye introduction point recharges the Fogelpole Cave Nature Preserve via the Northwest Passage and possibly via another flow path. This trace helps define the recharge area boundary between the Fogelpole Cave and Collier Spring groundwater systems. It also helps define the area which recharges the Fogelpole Cave Nature Preserve.

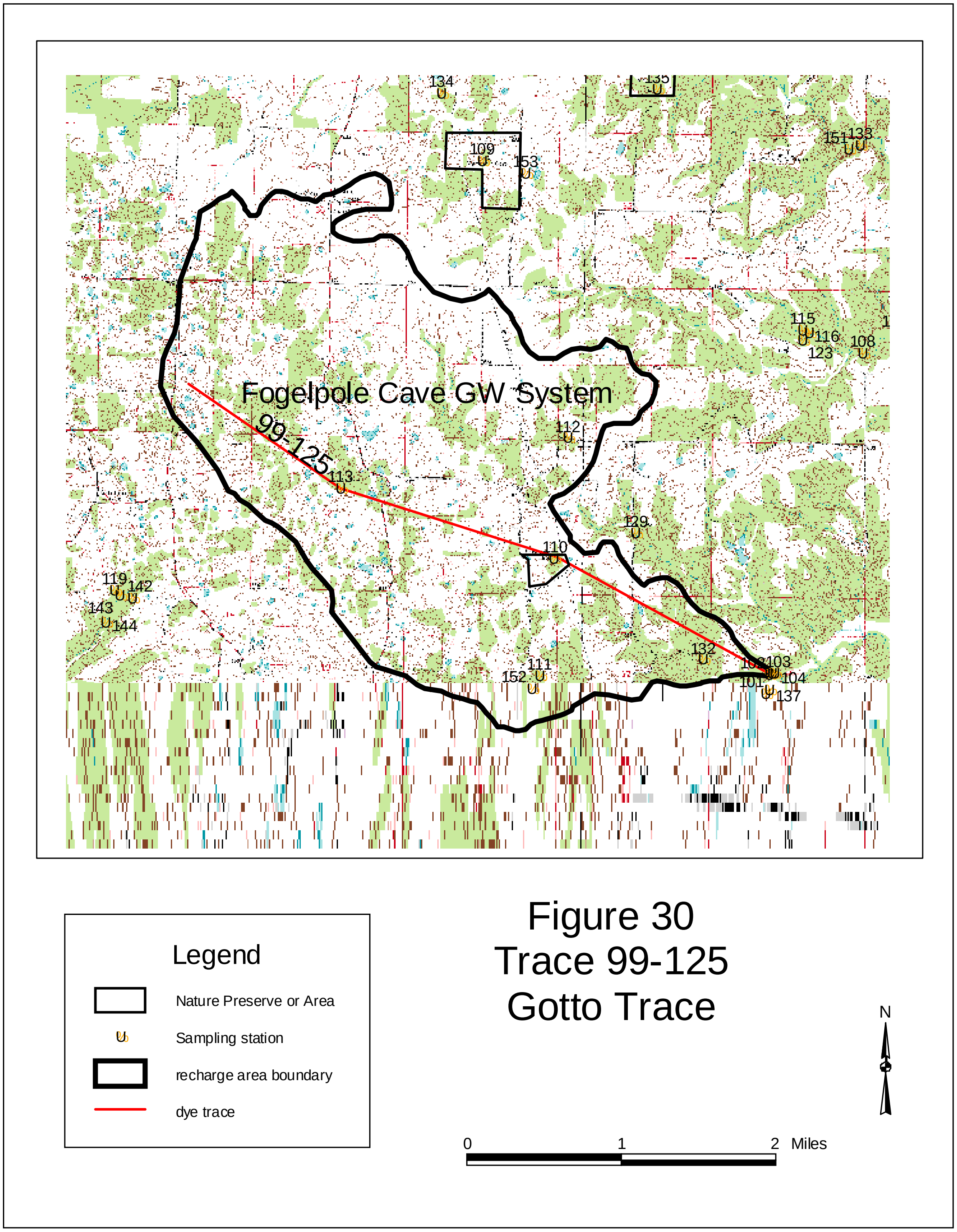


Figure 30
Trace 99-125
Gotto Trace

4.2.29 Trace 99-126: Garner Trace.

Two pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole at 0900 hours on August 15, 1999. The water was hauled to the sink in two loads of 1600 gallons each. Potable water was discharged to a ravine leading to the sink point. The first load entered the sink from 0856 to 0905 hours, the second load from 0954 to 1002 hours. The elevation of the dye introduction point is approximately 620 feet msl and is in the SE ¼ NE ¼ of Section 13, T4S, R10W. The location is shown on the Renault 7.5-minute quadrangle map. The purpose of this trace was to help define the southern boundary of the Fogelpole Cave groundwater system. The trace is shown on Figure 31.

The sampling stations for this trace were: 101, 102, 104, 110, 111, 130, 137, and 141.

Data on the dye recovery locations for Trace 99-126 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 101. Collier Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
8/13 to 8/20/99	ND	ND
8/20 to 8/24/99	564.0	773
8/20 to 8/24/99 (dup.)	563.7	845
8/24/99 (water)	570.6	22.4
8/24 to 9/3/99	564.4	699
9/3/99 (water)	569.2 a	0.199
9/3 to 9/10/99	563.7	54.7
9/10/99 (water)	567.6 a	0.053
9/10 to 9/15/99	563.8	9.73
9/15/99 (water)	ND	ND
9/15 to 9/22/99	563.1	12.2
9/22/99 (water)	ND	ND
9/22 to 9/29/99	566.4	SH
9/22 to 9/29/99 (dup.)	565.2	3.37
9/29/99 (water)	ND	ND
9/29 to 10/27/99	565.6	16.0
9/29 to 10/27/99 (dup.)	565.2	14.7
10/27/99 (water)	ND	ND
10/27 to 11/3/99	563.2	1.21
11/3 to 12/15/99	ND	ND
12/15/99 (water)	ND	ND

Station 130. South Fork at Road Crossing in Section 15

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
8/13 to 8/20/99	ND	ND
8/20 to 9/3/99	563.6	333
9/3 to 9/10/99	563.4	48.6
9/10 to 9/15/99	563.2	13.5
9/15 to 9/22/99	562.5	10.4
9/22 to 9/29/99	562.8	2.36
9/29 to 10/27/99	562.4	4.15
10/27 to 11/3/99	562.4	0.653
11/3 to 12/15/99	ND	ND

Station 137. Collier Downstream

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
8/13 to 8/20/99	ND	ND
8/20 to 8/24/99	564.2	969
8/24 to 9/3/99	564.4	770
9/3 to 9/10/99	563.8	29.4
9/10 to 9/15/99	563.0	10.0
9/10 to 9/15/99 (dup.)	563.2	10.5
9/15 to 9/22/99	562.3	8.89
9/22 to 9/29/99	ND	ND
9/22 to 9/29/99 (dup.)	565.2	3.79
9/29 to 10/27/99	565.2	12.1
10/27 to 11/3/99	563.2	0.880
11/3 to 12/15/99	ND	ND

Station 141. Horse Creek at Ames Road Crossing

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
5/21 to 8/13/99	ND	ND
8/13 to 9/3/99	564.0	95.2
9/3 to 9/15/99	564.0	17.8
9/15 to 9/29/99	562.8	6.17
9/29 to 10/27/99	563.6	3.75
10/27 to 12/15/99	ND	ND

Rhodamine WT dye was recovered from four sampling stations: Collier Spring, Collier Downstream, and the downstream Stations 130 and 141. All four stations derived their dye from Collier Spring. Garner Sink contributes water to the Collier Spring groundwater system. The straight-line distance of this trace is approximately 13,200 feet. The elevation loss is approximately 160 feet and the mean gradient is approximately 64 feet per mile. Dye first arrived at Collier Spring between five and nine days following dye introduction. Based on the concentration of dye in the water sample collected on August 24, 1999, the dye probably arrived about eight days after dye introduction. The mean velocity for the first arrival of dye at Collier Spring was approximately 1,700 feet per day under the low flow conditions which existed during the trace.

Based on the results of the Brinner Trace (99-127) and the discovery of the Sunfish Passage in Fogelpole Cave, the OUL believes that water from the Garner Sink flowed through the Sunfish Passage on its path to Collier Spring. The Sunfish Passage can overflow into Zebra Passage, which discharges at Tierce Spring (Trace 98-102). The OUL has interpreted the Garner Sink area as one of shared recharge between the Fogelpole Cave and Collier Spring groundwater systems.

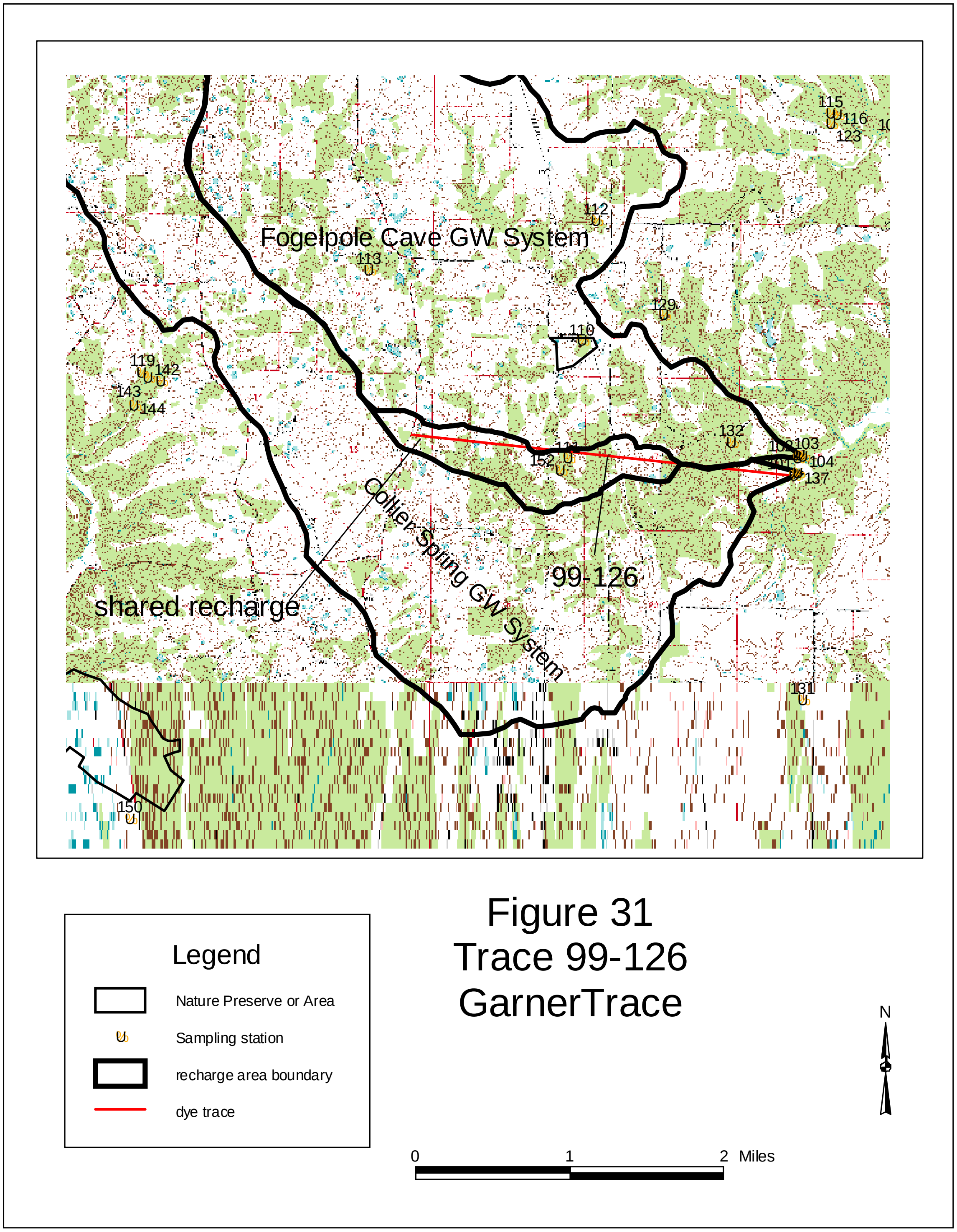


Figure 31
Trace 99-126
GarnerTrace

4.2.30 Trace 99-127: Brinner Trace.

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 0929 hours on September 12, 1999. Potable water was hauled to the sink in two loads of 1,600 gallons each. The water was discharged down the side of the sinkhole. The first load entered the sink from 0926 to 0937 hours, the second load from 1027 to 1038 hours. The elevation of the dye introduction point is approximately 560 feet msl and is in the SE ¼ SE ¼ of Section 18, T4S, R9W. The location is shown on the Renault 7.5-minute quadrangle map. The purpose of this trace was to help define the recharge area boundary between the Fogelpole and Collier Spring recharge areas. The trace is shown on Figure 32.

The sampling stations for this trace were: 101, 102, 104, 110, 111, 130, 137, 141, and 152.

Data on the dye recovery locations for Trace 99-127 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 101. Collier Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
9/15 to 9/22/99	ND	ND
9/22 to 9/29/99	538.8	49.9
9/22 to 9/29/99 (dup.)	538.1	22.2
9/29/99 (water)	532.7	0.394
9/29 to 10/27/99	538.6	38.4
9/29 to 10/27/99 (dup.)	538.6	30.5
10/27/99 (water)	ND	ND
10/27 to 11/3/99	535.6	0.744
11/3 to 12/15/99	538.2	35.2
12/15/99 (water)	532.2	1.36
12/15/99 to 1/5/00	538.2	35.9
12/15/99 to 1/5/00 (dup.)	538.8	71.6
1/5 to 1/20/00	538.5	45.3
1/20/99 (water)	530.8	0.179
1/20 to 2/3/00	538.0	13.6
1/20 to 2/3/00 (dup.)	538.3	29.4
2/3/00 (water)	529.6	0.066
2/3 to 2/13/00	536.9	3.57
2/13/99 (water)	530.0	0.082
2/13 to 2/22/00	538.2	28.1

(cont'd)

Station 101 (cont'd). Collier Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
2/13 to 2/22/00 (dup.)	537.7	23.0
2/22/00 (water)	530.0	0.224
2/22 to 3/6/00	536.9	13.0
3/6/00 (water)	533.6	SH
3/6 to 3/13/00	536.8	8.23
3/13/00 (water)	ND	ND
3/13 to 3/24/00	535.9	10.7
3/13 to 3/24/00 (dup.)	536.5	15.8
3/24 to 4/27/00	537.4	22.4
4/27/00 (water)	ND	ND
4/27 to 5/8/00	533.6	2.08
5/8 to 5/18/00	ND	ND

Station 111. Coon Pit

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
1/27 to 2/22/00	ND	ND
2/22 to 6/5/00	532.4 a,s	1.71
6/5/00 (water)	ND	ND

Station 130. South Fork at Road Crossing in Section 15

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
9/22 to 9/29/99	ND	ND
9/29 to 10/27/99	534.0	0.418
10/27 to 11/3/99	ND	ND
11/3 to 12/15/99	536.9	2.12
12/15/99 to 1/5/00	537.8	11.6
1/5 to 1/20/00	536.4	0.847
1/20 to 2/3/00	534.4	0.760
2/3 to 2/22/00	ND	ND

Station 137. Collier Downstream

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
9/15 to 9/22/99	ND	ND
9/22 to 9/29/99	538.4	20.4
9/22 to 9/29/99 (dup.)	538.3	19.4
9/29 to 10/27/99	538.6	26.0
10/27 to 11/3/99	535.6	0.527
11/3 to 12/15/00	537.5	19.8
12/15/99 to 1/5/00	538.3	50.2
12/15/99 to 1/5/00 (dup.)	538.6	50.4
1/5 to 1/20/00	538.2	28.3
1/20 to 2/3/00	538.0	21.6
2/3 to 2/13/00	537.7	10.9
2/13 to 2/22/00	538.0	35.5
2/22 to 3/6/00	537.8	26.2
3/6 to 3/13/00	537.5	23.0
3/13 to 3/24/00	536.0	12.0
3/24 to 4/27/00	536.9	14.7
4/27 to 5/8/00	536.0	2.33
5/8 to 5/18/00	ND	ND

Station 152. Zebra Passage Upstream of Coon Pit

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
11/2/99 (water)	533.0	366
11/4/99 (water)	533.0	370
11/4 to 11/29/99	539.2	9,780
11/29/99 (water)	532.8	368
11/29 to 12/10/99	539.0	4,210
12/10/99 (water)	532.6	458
12/10/99 to 1/27/00	539.3	23,500
1/27/00 (water)	532.4	598
1/27 to 2/22/00	538.7	17,000
2/22/00 (water)	532.2	251
2/22 to 6/5/00	538.4	10,400

Dye from the Brinner Trace was recovered from five sampling stations: Collier Spring and Collier Downstream sample water discharging from the Collier Spring groundwater system. Station 130 is downstream of Collier Spring and Collier Downstream. Dye was also recovered in Fogelpole Cave at Station 152 (Zebra Passage Upstream of Coon Pit) and at Station 111 (Coon Pit). The dye concentration at Coon Pit was very small, but underground stream passages connect Station 152 with Coon Pit. Coon Pit in turn contributes water to Tierce Spring and Indian Hole. Flow conditions were too low during this trace to recover appreciable amounts of dye from the Fogelpole Cave sampling stations other than at Station 152.

This was the first trace that produced dye recoveries in both the Collier and Fogelpole groundwater systems. The Brinner Trace also indicates some hydrologic linkage between the two systems. Dr. Rickard Toomey, III and Philip Moss, who were mapping in Zebra Passage after introducing dye to start Trace 99-128, discovered a pool with visible eosine dye on November 2, 1999. Station 152 was established and a water sample was collected that confirmed the presence of eosine dye. There was no flow in that part of Zebra Passage on November 2, and apparently no outflow into Zebra Passage during the remainder of the study.

While the Collier and Fogelpole groundwater systems are connected, the Brinner sink does not contribute water to the Fogelpole Cave Nature Preserve, and Zebra Passage does not contribute water to known parts of the main stream in Fogelpole Cave except at high flows through Mud Alley. Zebra Passage receives overflow from the Collier groundwater system and Zebra Passage can overflow, in turn, down Mud Alley into mainstream Fogelpole Cave. Zebra Passage also can overflow into the unnamed cave passage where the dry set for Trace 99-128 was placed.

Observations made on a subsequent cave mapping trip on November 29, 1999, suggest that the route that the dye followed to Station 152 was not via the base level conduit system. It appears that the dye solution traveled through the epikarst (which is the weathered upper portion of the bedrock). The evidence for this is that the Brinner Trace was initiated with 3,200 gallons of hauled water during a drought. The dye introduction sink is approximately 1,000 feet south of Station 152. The pool, which Station 152 samples, is at least three feet above the active stream passage immediately south of it. There was not a runoff-producing event between the dye introduction on September 12 and the discovery of the pool on November 2, 1999. The quantity of hauled water was insufficient to cause the stream to overflow into the Station 152 pool. The OUL interprets this set of conditions and results to indicate appreciable groundwater movement within the epikarst.

The dye solution traveled approximately 700 feet horizontally before dropping vertically to near base level. Small rain events following the first detection of dye in the Station 152 pool led to an increase in the dye concentration in the pool. It is likely that some dye was trapped in the epikarst and was being transported by these small rains. The small rains pushed more eosine dye into the pool, but were too small to flush the dye beyond the pool.

The distance from the Brinner Sink to Collier Spring is approximately 8,300 feet and the elevation loss is approximately 100 feet. The mean gradient is approximately 64 feet per mile. The dye first arrived at Collier Spring between 10 and 17 days after dye introduction. The OUL is interpreting the first arrival as approximately 13 days after dye introduction. Mean velocity for the first arrival of dye along this flow path under these very low flow conditions was approximately 640 feet per day. Dye continued to be detected at Collier Spring until early May 2000.

Figure 32 shows the flow path that the dye would have taken had there been sufficient flow to move the dye through Zebra Passage. The OUL's interpretation is based on the cave map (Hauck and Addison, 2000) and on the Zebra Passage Trace (98-102). The distance along this interpreted flow path is approximately 10,300 feet, and the elevation loss is approximately 105 feet. The mean gradient is approximately 54 feet per mile.

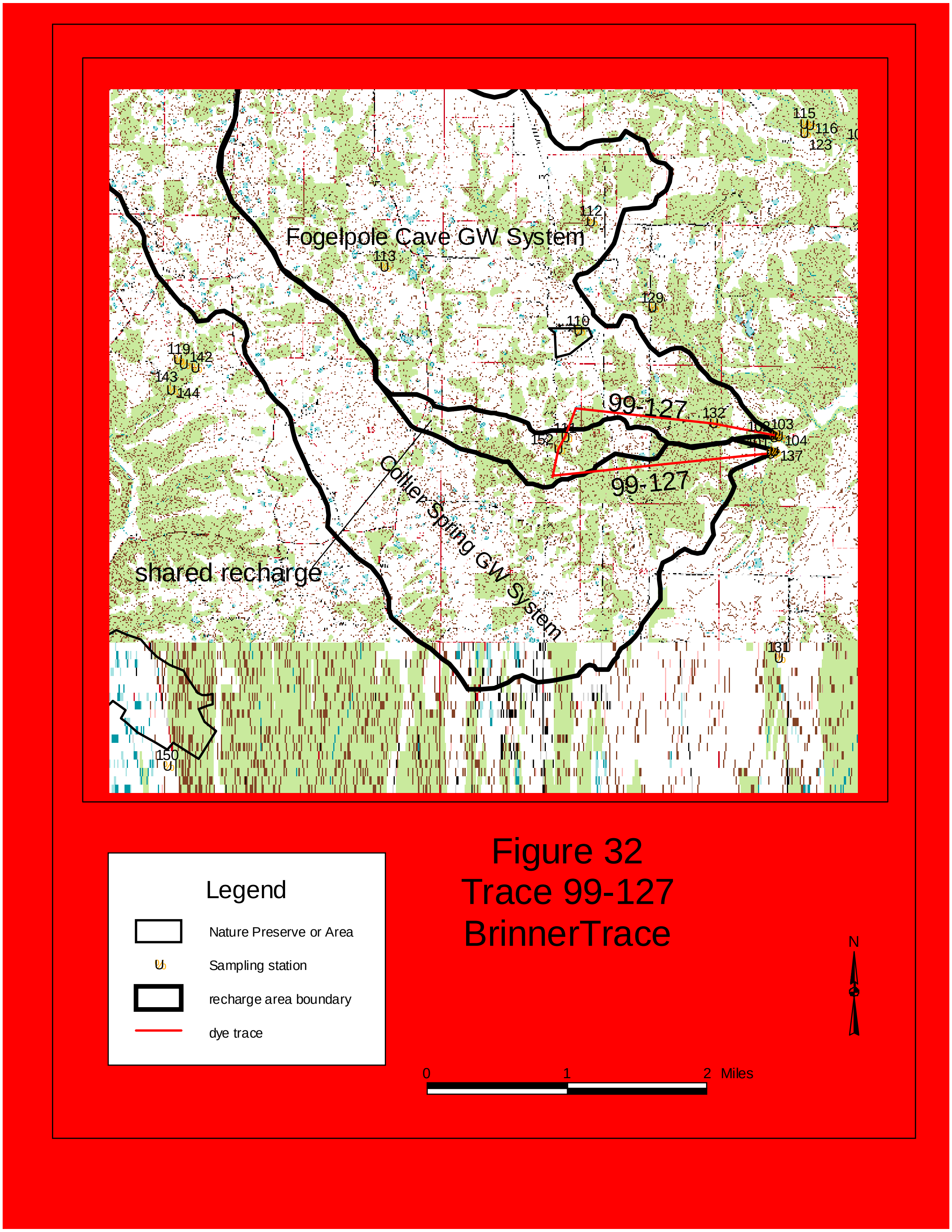


Figure 32
Trace 99-127
BrinnerTrace

4.2.31 Trace 99-128: Zebra Overflow Trace.

One pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced into a side passage connected to Zebra Passage in Fogelpole Cave. The dye was introduced at 1038 hours on November 2, 1999. There was no discernible flow at the time of dye introduction. This point is unreachable when there is flowing water due to a passage that has no air space at higher water levels. This passage has a drainage divide in it. Part of the passage flows south of the mapped extent of the cave.

This trace helps assess the hydrologic relationship between Fogelpole Cave and the Collier Spring groundwater systems. The elevation of the dye introduction point is approximately 537 feet msl and is in the NE ¼ SE ¼ of Section 18, T4S, R9W. The location is shown on the Renault 7.5-minute quadrangle map and on Map 1. This overflow passage was discovered on September 24, 1999 by Illinois Speleological Survey cooperators, Lea Claycomb, Joe Sikorski, and Philip Moss, who were mapping previously unknown passage from Coon Pit.

The sampling stations for this trace were: 101, 102, 104, 130, and 137.

As of the date of this report, the dye has not been mobilized by storm water and thus remains as a dry set. There have been no detections of this dye.

4.2.32 Trace 00-129: Brushy Prairie Trace.

Two pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole at 0802 hours on February 18, 2000. Approximately 10 gpm of storm runoff was entering the groundwater system at the time of dye introduction. The dye introduction point is at an elevation of approximately 740 feet msl, and is in the NE ¼ NE ¼ of Section 33, T3S, R10W. The location is shown on the Renault 7.5-minute quadrangle map. The trace is shown on Figure 34. The purpose of the trace was to help define the recharge area boundary between the Collier Spring recharge area and other recharge areas to the west.

The sampling stations for this trace were: 101, 117, 124, 130, and 137.

Data on the dye recovery location for Trace 00-129 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 124. Maeystown Creek at Baum Road

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
2/22 to 3/6/00	ND	ND
3/6 to 3/13/00	562.6	14.8
3/13/00 water	569.6	0.453
3/13 to 3/24/00	564.5	36.4
3/24 to 5/9/00	562.9	51.7
5/9/00 (water)	ND	ND

Rhodamine WT dye from Trace 00-129 was recovered in Maeystown Creek at Baum Road. Dye first arrived between 17 and 24 days following dye introduction. Station 124, Maeystown Creek at Baum Road, is a surface stream sampling station. Maeystown Creek very likely has several springs upstream portions of its four tributaries. The OUL does not know the locations of any of these probable springs. Underground travel distances and velocities are not determinable from the data obtained. The dye was recovered approximately 11,200 feet from the dye introduction point. This trace was conducted under low flow conditions.

The trace demonstrates that Maeystown Creek receives some groundwater discharge. It also demonstrates that the area near the intersection of Brushy Prairie Road and Altes Road discharges to unknown springs on Maeystown Creek. The area of the dye introduction is not recharging any of the three RSA biologically significant cave systems.

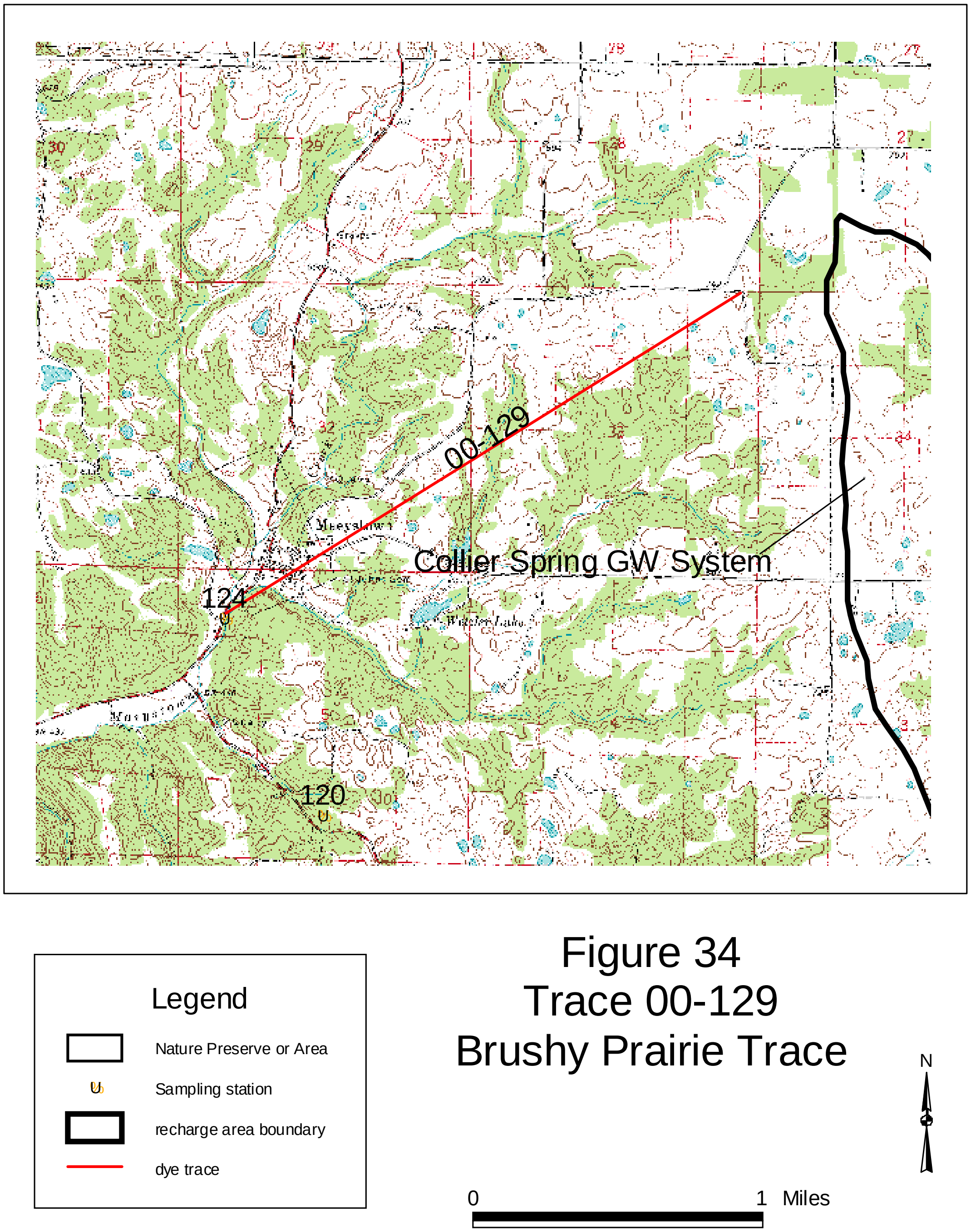


Figure 34
Trace 00-129
Brushy Prairie Trace

4.2.33 Trace 00-130: Kruse Trace.

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinking stream at 0840 on February 18, 2000. Approximately 80 gpm of storm runoff was entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 640 feet msl. The dye introduction point is in the NW ¼ SE ¼ of Section 31, T3S, R9W. The location is shown on the Renault 7.5-minute quadrangle map. The trace is shown on Figure 35. The purpose of the trace was to better define the recharge area of the Illinois Caverns Natural Area.

The sampling stations for this trace were: 102, 104, 109, 110, 114, 115, and 153.

Data on the dye recovery locations for Trace 00-130 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 114. Dye Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
8/13 to 11/3/99	ND	ND
11/3/99 to 2/22/00	538.5	47.8
2/22/00 water	532.8	2.83
2/22 to 3/13/00	538.9	206
3/13/00 (water)	ND	ND

Station 115. Walsh Cave

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
1/5 to 2/22/00	ND	ND
2/22 to 3/6/00	539.0	1,200
3/6/00 water	533.2	49.6
3/6 to 3/13/00	539.2	3,030
3/13/00 (water)	533.0	41.1
3/13 to 3/24/00	539.1	2,150
3/24/00 water	533.1	32.3
3/24 to 4/27/00	539.1	2,800
4/27 to 5/9/00	538.7	906
4/27 to 5/9/00 (dup.)	538.9	689
5/9/00 (water)	532.7	7.40

Station 128. Horse Creek at MM Road Xing Sec. 2

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
8/13/99 to 1/5/00	ND	ND
1/5 to 2/22/00	538.2	10.0
2/22 to 3/6/00	538.0	10.0
3/6 to 3/13/00	ND	ND

Station 141. Horse Creek at Ames Rd. Xing

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
10/27 to 12/15/99	ND	ND
12/15/99 to 1/5/00	536.8	1.16
1/5 to 2/22/00	ND	ND

Eosine dye from the Kruse Trace was recovered at four sampling stations: Walsh Cave, Dye Spring, Station 128 (Horse Creek at MM Road Crossing) and Station 141 (Horse Creek at Ames Road Crossing). In addition to the previously established Station 109, located in the cave stream near the bottom of the stairway in Illinois Caverns, the OUL established a sampling station in Cascade Canyon, a tributary cave stream passage within the Illinois Caverns Natural Area. No dye was detected at either of the sampling stations within the Illinois Caverns Natural Area sampling stations.

The Kruse Trace has a straight-line distance of approximately 14,000 feet to Dye Spring and an elevation loss of approximately 165 feet. The mean gradient along this flow path is approximately 62 feet per mile. Dye first arrived at Dye Spring approximately 3 days after dye introduction. The mean velocity under these flow conditions was approximately 4,700 feet per day.

The Kruse Trace has a straight-line distance of approximately 10,900 feet to Walsh Cave and an elevation loss of approximately 125 feet. The mean average gradient along this flow path is approximately 61 feet per mile. Dye first arrived at Walsh Cave within 17 days after dye introduction. The sample collection schedule was such that we do not have a good estimate of the time of first dye arrival from this trace at Walsh Cave. Except for a spike of high flow at the time of dye introduction, this trace was conducted under very low flow conditions.

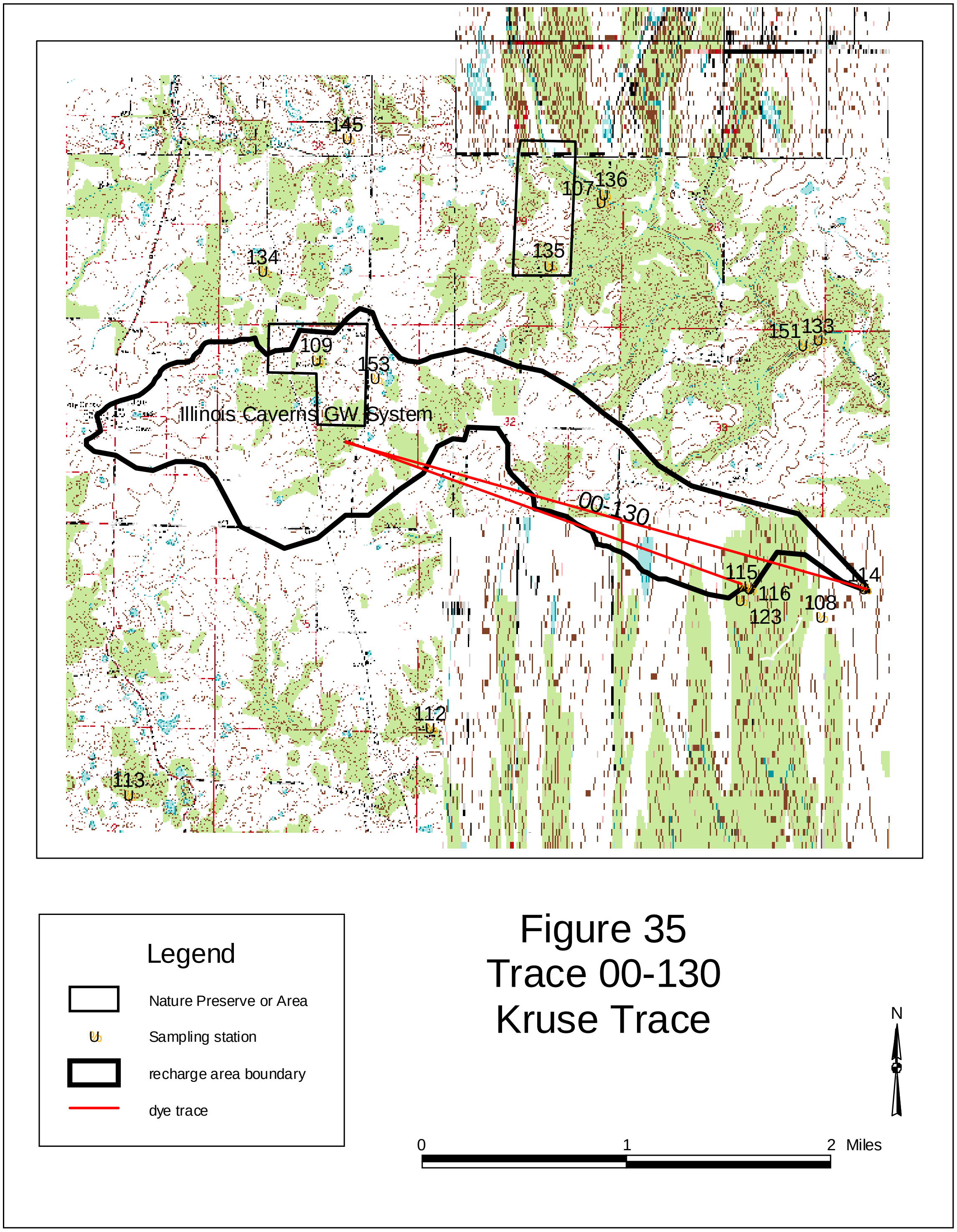


Figure 35
Trace 00-130
Kruse Trace

4.2.34 Trace 00-131: Kaskaskia Road Trace.

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 0948 hours on February 18, 2000. Approximately 30 gpm was entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 640 feet msl and in the SE ¼ SE ¼ of Section 12, T4S, R10W. The location is shown on the Renault 7.5-minute quadrangle map. The trace is shown on Figure 36. The purpose of the trace was to better define the recharge area for the Fogelpole Cave Nature Preserve.

The sampling stations for this trace were: 101, 102, 104, 110, 111, 130, 137, 141, and 152.

Data on the dye recovery locations for Trace 00-131 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 102. Tierce Spring

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
2/3 to 2/13/00	ND	ND
2/13 to 2/22/00	513.6	686
2/22/00 water	507.5	20.6
2/13 to 2/22/00 (dup.)	513.8	1,060
2/22 to 3/6/00	513.9	2,920
3/6/00 water	507.4	0.587
3/6 to 3/13/00	513.5	122
3/13/00 water	506.6	0.180
3/13 to 3/24/00	512.4	28.3
3/24/00 (water)	ND	ND
3/24 to 4/27/00	512.0	6.98
4/27/00 (water)	ND	ND
4/27 to 5/8/00	511.0 s	1.78
5/8 to 5/18/00	ND	ND

Station 104. Indian Hole (channel)

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/6 to 4/27/00	ND	ND
4/27 to 5/8/00	510.8 s	1.78
5/8 to 5/30/00	ND	ND

Station 110. Junction Room

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
10/27/99 to 1/27/00	510.9 S	1.89 (background)*
1/27 to 2/22/00	513.8	396
1/27 to 2/22/00 (dup.)	513.8	640
2/22/00 water	505.6	0.119
2/22 to 3/24/00	511.9	8.93
3/24/00 (water)	ND	ND
3/24 to 6/4/00	ND	ND

* = From Trace 99-125

Station 130. South Fork at Road Crossing in Section 15

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
1/20 to 2/3/00	ND	ND
2/3 to 2/22/00	513.0	43.4
2/22 to 3/6/00	513.5	826
3/6 to 3/13/00	512.9	15.2

Station 141. Horse Creek at Ames Road Crossing

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
1/5 to 2/22/00	ND	ND
2/22 to 3/13/00	513.0	71.6

Dye from the Kaskaskia Road Trace was recovered at five sampling stations. They are, from upstream to downstream: Junction Room, Tierce Spring, Indian Hole (Channel), Station 130 and Station 141. This trace demonstrates that the dye introduction sink is within the recharge area for the Fogelpole Cave Nature Preserve. In addition, the trace also makes it clear that the Fogelpole Cave Nature Preserve is vulnerable to potential spills along Kaskaskia Road.

The straight-line distance from the dye introduction point to the Junction Room is approximately 5,800 feet and the elevation loss is approximately 140 feet. The mean gradient is approximately 127 feet per mile. The dye was first detected at Tierce Spring, the Junction Room, and Station 130 within four days of dye introduction.

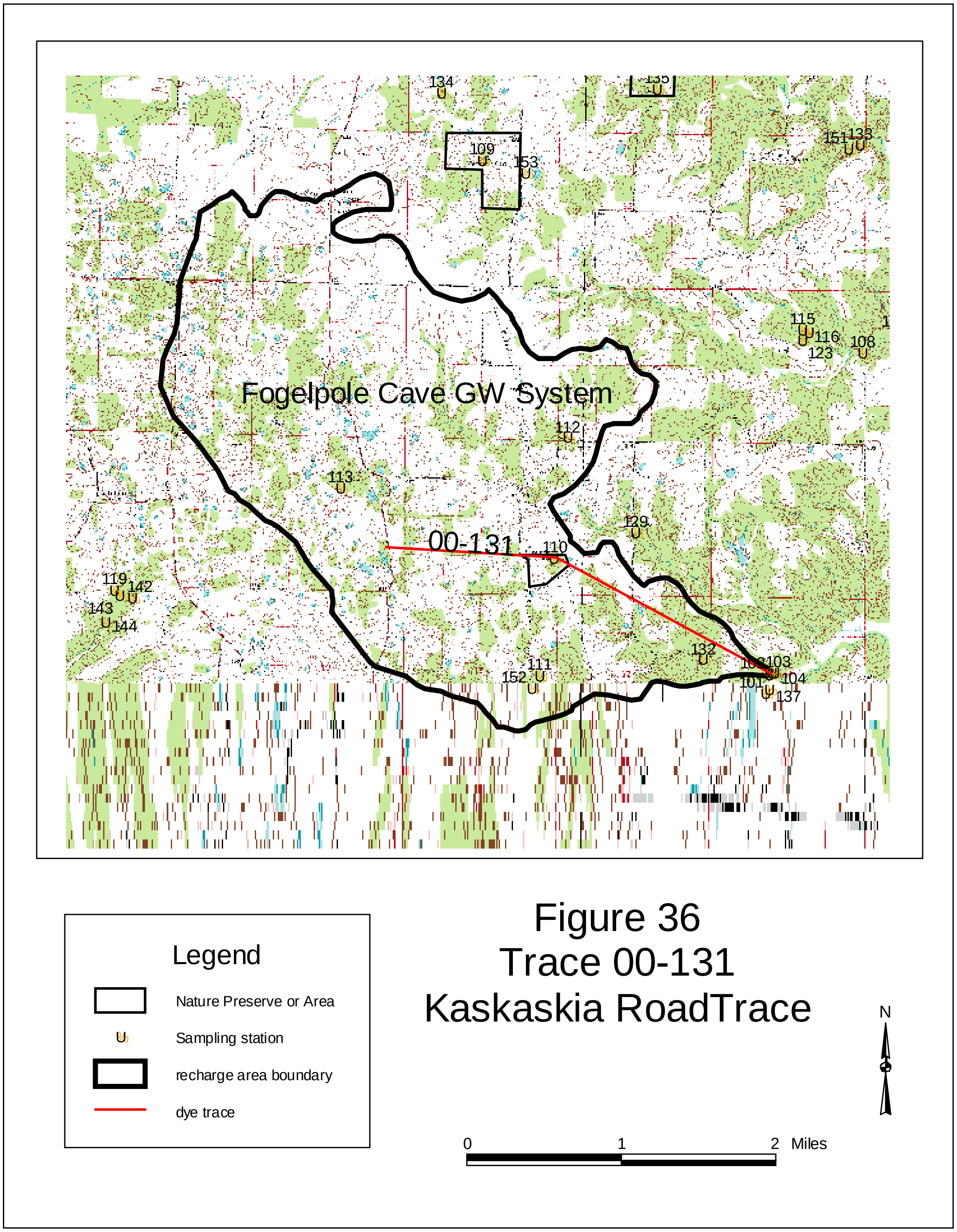


Figure 36
Trace 00-131
Kaskaskia RoadTrace

4.2.35 Trace 00-132: Tipton Trace.

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a surface stream at 1036 hours on March 27, 2000. The stream had a discharge of approximately two gpm at the time of dye introduction. The elevation of the dye introduction point is approximately 590 feet msl and is in the SW ¼ NW ¼ of Section 33, T3S, R9W. The location is shown on the Ames 7.5-minute quadrangle map. The trace is shown on Figure 37. The purpose of the trace was to better understand the recharge area divides between the Krueger system, the Illinois Caverns system, and the Curran Spring groundwater system.

The sampling stations for this trace were: 107, 114, 115, 128, 133, and 151.

Data on the dye recovery location for Trace 00-132 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 133. Curran Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
7/22/99 to 2/22/00	ND	ND
2/22 to 4/27/00	561.9	19.6
4/27 to 6/7/00	562.7	69.4
6/7/00 (water)	ND	ND

Dye from the Tipton Trace was recovered only from Curran Spring. This is the only trace recovered at Curran Spring. This trace helps define the recharge area for Curran Spring, which is on Horse Creek between Kelly Spring (Krueger System) and the Illinois Caverns groundwater system. This trace demonstrates that streams shown as surface streams on the USGS topographic maps often lose some (and at times all) of their flow into the karst groundwater system.

The straight line distance for this trace was 4,300 feet. The elevation difference between the dye introduction point and Curran Spring was 120 feet, which represents a mean gradient of 147 feet per mile. The sampling frequency was not adequate for a good estimate of the time of first dye recovery at Curran Spring.

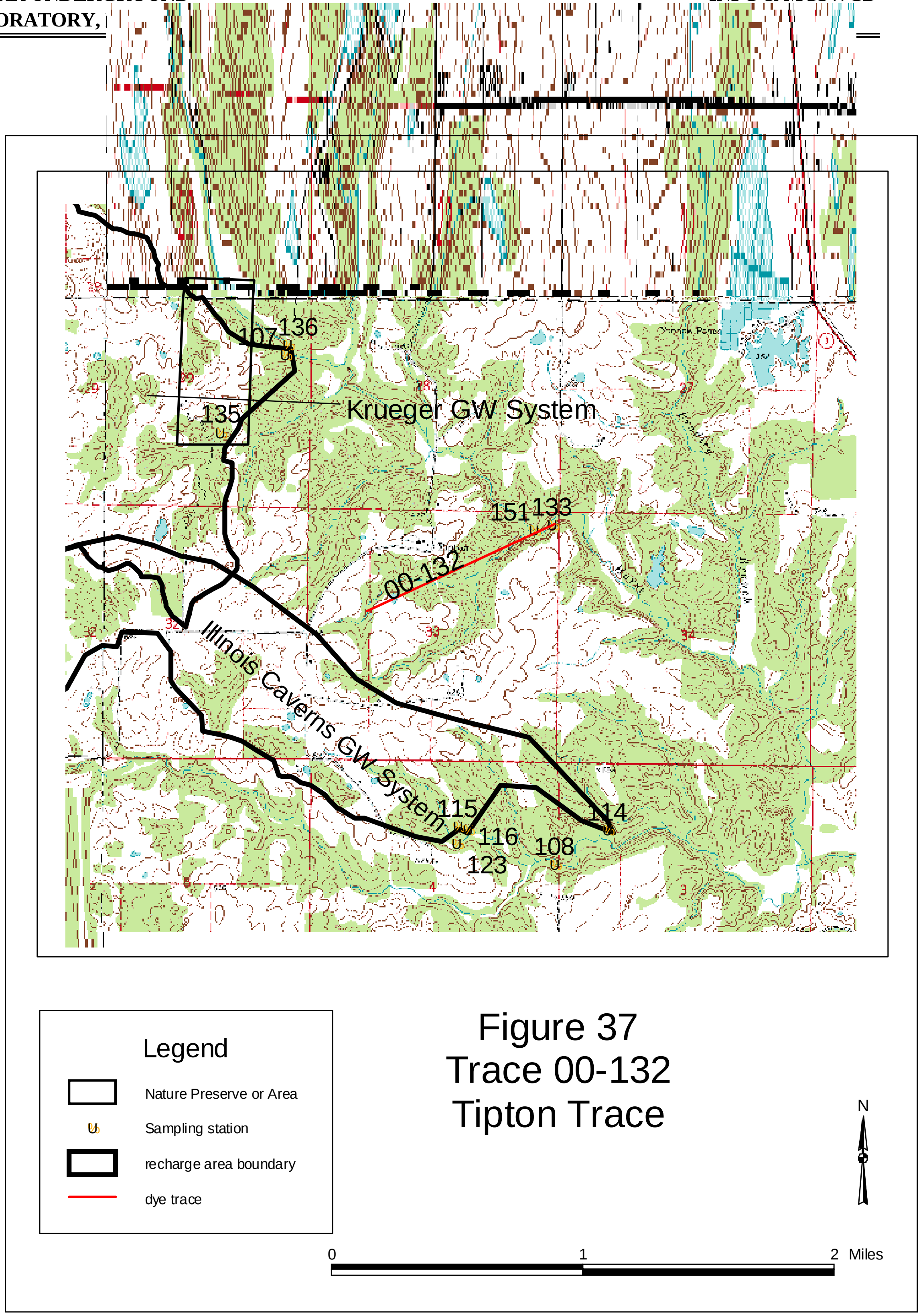


Figure 37
Trace 00-132
Tipton Trace

4.2.36 Trace 00-133: Metter Replicate Trace.

Three pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into Metter sinking stream at 1206 hours on May 7, 2000. A flow of approximately 150 gpm was entering the groundwater system at the time of dye introduction. The dye introduction elevation is approximately 670 feet msl and is in the SE ¼ NE ¼ of Section 34, T3S, R10W. This trace was initiated to test for a possible hydrologic link with the Krueger groundwater system. Trace 98-103 (section 4.2.7) produced some anomalous data. The location is shown of the Renault 7.5-minute quadrangle map. The trace is shown on Figure 38.

The sampling stations for this trace were: 101, 102, 104, 134, 135, and 137.

Data on the dye recovery locations for Trace 00-133 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 101. Collier Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
5/8 to 5/18/00	ND	ND
5/18 to 5/30/00	563.9	111
5/30/00 water	ND	ND
5/30 to 6/7/00	ND	ND

Station 137. Collier Downstream

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
5/8 to 5/18/00	ND	ND
5/18 to 5/30/00	564.1	136
5/30 to 6/7/00	ND	ND

Rhodamine WT dye was recovered from the Metter Replicate Trace at two sampling stations: Collier Spring, and Collier Downstream. The results of this trace are the same as that of the trace it replicates (Trace 98-105) except for the dye persistence and the mean groundwater velocity. The majority of the dye was discharged from Collier Spring between May 18 and 30, 2000. If we assume the first arrival of dye at Collier Spring occurred on May 22, this would represent a mean velocity for the first dye arrival of 1,980 feet per day. This trace was conducted under drought conditions. This is in contrast to the velocity of the earlier Trace 98-105, which had a mean velocity of approximately 2,280 feet per day. The dye was flushed out of the system much more quickly in the replication. This may be a result of differences in the two dyes since rhodamine WT is more subject to adsorption than fluorescein.

This trace did not demonstrate a hydrologic connection between the Metter sinking stream and the Krueger System.

Figure 38 makes it appear that the flow path for this trace is through the Fogelpole Cave groundwater system. However, the flow path representation is diagrammatic. It is likely that the flow path curves around the Fogelpole Cave recharge area and does not actually flow near Stations 110 and 132.

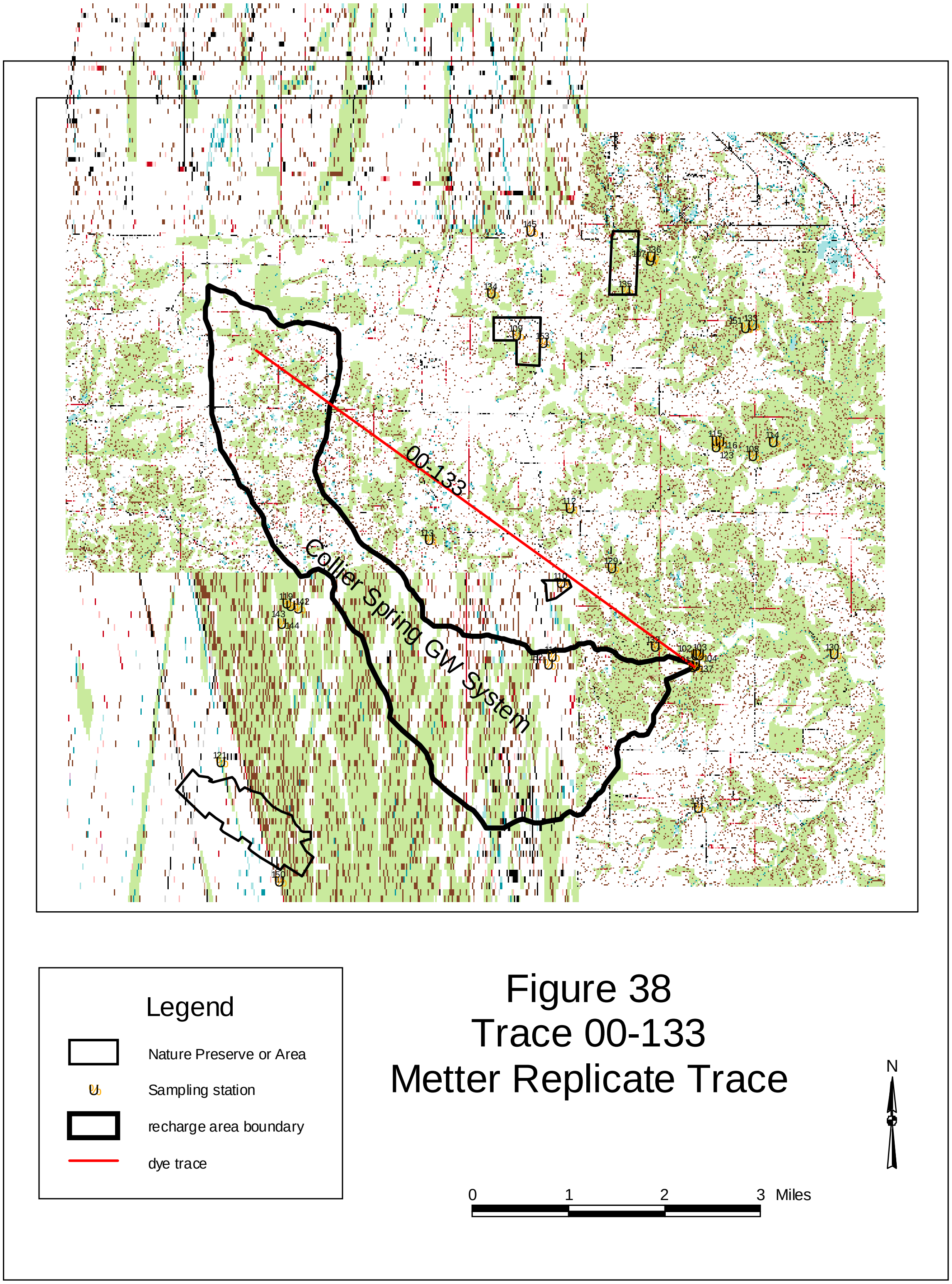


Figure 38
Trace 00-133
Metter Replicate Trace

4.2.37. Summary of Selected Trace Data, RSA.

Table 4 provides some selected data on RSA dye trace lengths, gradients, and velocities.

Trace lengths and gradients are based upon straight line distances between dye introduction and dye recovery locations. An exception to this generalization is when the flow route is known to pass through particular points which do not represent a straight line. An illustration of this would be when the flow is known to follow a particular cave stream which has been mapped by cavers.

Estimated mean groundwater velocities are based upon the estimated time of first dye arrival at the detection station. Mean velocity is not indicated for traces where we lack a good estimate of the likely time of first dye arrival. It should be noted that the purposes of this study did not include developing detailed information on time of travel velocities through the groundwater system. Instead, the fundamental purpose was to delineate recharge areas. Time of travel information and other data shown in Tables 4 and 5 represent incidental information gathered during the study.

Table 5 is similar to Table 4 except that it provides selected data on CSA traces. Table 5 is located at the end of Section 4.3.

Table 4. Summary of selected RSA dye trace lengths, gradients, and estimated mean velocities for the first arrival of tracer dyes

From	To	Distance (feet)	Elevation loss (feet)	Gradient (feet/mile)	Est. mean Velocity (feet/day)	Trace number associated w/velocity	Notes
Krueger System							
Nobbe Sinking Stream	Spider Cave	2,275	15	35	7,250	98-103	based on arrival at Kelly Spring
Spider Cave	Fruth's Pump Hole	4,000	50	66	7,250	98-103	based on arrival at Kelly Spring
Nobbe Sinking Stream	Kelly Spring	14,525	120	44	7,250	98-103	distance based on intermediate recovery sites.
Walsh Sink	Fruth's Pump Hole	5,050	70	73		99-116	
Fruth's Pump Hole	Big Sink	6,150	35	30		99-103	based on arrival at Kelly Spring
Big Sink	Kelly Spring	2,100	25	63	7,250	99-103	based on arrival at Kelly Spring
Big Sink	Kelly Spring	2,100	25	63	4,200	98-110	
Schuchardt Sinking Stream	Big Sink	6,500	45	37	2,600	98-110	
Dry Run	Big Sink	7,125	45	33	NA	cave map	
Illinois Caverns							
Illinois Caverns Ent.	Walsh Cave	12,300	85	36	1,540	98-101	
Illinois Caverns Ent.	Walsh Spring	12,400	85	36	1,240	98-101	
Illinois Caverns Ent.	Dye Spring	15,350	125	43	2,560	98-101	
St. Joe Sink	Illinois Caverns Ent.	3,700	90	129	3,700	99-112	
St. Joe Sink	Walsh Cave	15,800			5,270	99-112	
ICNA Sink	Walsh Cave	11,800	155	69	2,360	99-123	
ICNA Sink	Dye Spring	14,600	195	71	2,920	99-123	
Kruse Sink	Walsh Cave	10,900	125	61		00-130	
Kruse Sink	Dye Spring	14,000	165	62	4,700	00-130	
Fogelpole Cave							
Gotto Sink	Northwest Passage	6,300	70	59	2,500	99-125	velocity based on Tierce Spring recovery
Gotto Sink	Junction Room	13,900	165	63		99-125	

Table 4. Summary of selected RSA dye trace lengths, gradients, and estimated mean velocities for the first arrival of tracer dyes

From	To	Distance (feet)	Elevation loss (feet)	Gradient (feet/mile)	Est. mean Velocity (feet/day)	Trace number associated w/velocity	Notes
(cont'd)							
(cont'd)							
Gotto Sink	Junction Room via NW Ent	14,000	165	62		99-125	
Gotto Sink	Tierce Spring	22,400			2,500	99-125	
Northwest Passage	Junction Room	7,700	95	65	1,540	96-04	
Fogelpole Entrance	Tierce Spring	8,400	146	92	4,200	97-05	
Junction Room	Tierce Spring	8,400	51	32	4,200	97-05	
Northwest Entrance	Tierce Spring	15,500	141	48	?	96-04	
Zebra Passage	Tierce Spring	7,575	80	56	945	98-102	
St. Joe Sink	Tierce Spring	26,000			1,400	99-112	
Schultheis Sinking Stream	Northwest Passage	4,600	40	46	6,770	99-115	velocity based on Tierce Spring recovery
Schultheis Sinking Stream	Junction Room	11,900	135	60	6,770	99-115	velocity based on Tierce Spring recovery
Schultheis Sinking Stream	Tierce Spring	20,300	181	47	6,770	99-115	
Polka Sink	Tierce Spring	15,475	175	60	6,190	99-121	
Polka Sink	Lemonade Passage	2,900	50	91		99-121	
Lemonade Passage	Junction Room	4,175	70	89		99-121	
Kaskaskia Road Sink	Junction Room	5,800	140	127		00-131	
Brinner Sink	Station 152 (Zebra Pass.)	1,025	50	258		99-127	
Sta. 152 (Zebra Pass.)	Tierce Spring	9,170	55	32		99-127	via Stations 111, and 132
Collier Spring							
Rolling Hills Sink	Collier Spring	26,000	210	43	2,170	96-02	
Metter Sinking Stream	Collier Spring	29,700	210	37	2,280	98-105	

Table 4. Summary of selected RSA dye trace lengths, gradients, and estimated mean velocities for the first arrival of tracer dyes

From	To	Distance (feet)	Elevation loss (feet)	Gradient (feet/mile)	Est. mean Velocity (feet/day)	Trace number associated w/velocity	Notes
Metter Sinking Stream	Collier Spring	29,700	210	37	1,980	00-133	
(cont'd)							
(cont'd)							
Wittenauer Sinking Stream	Collier Spring	8,900	130	77	740	98-106	
Fults Road Sink	Collier Spring	14,600	142	51	4,870	99-113	
Henning Road Sink	Collier Spring	8,950	102	59	1,500	99-124	
Garner Sink	Collier Spring	13,200	160	64	1,700	99-126	
Brinner Sink	Collier Spring	8,300	100	64	640	99-127	
Lantz Spring							
LL Road Corner Trace	Lantz Spring	1,100	20	95	365	99-111	distance is from the sink point
Frees Sink	Lantz Spring	2,370	50	111	>500	99-119	
MM Rd Sink	Lantz Spring	5,075	115	120	5,000	99-120	
Barchet Sink	Lantz Spring	8,000	130	86	>1,000	99-122	
Misc. RSA Traces							
Jacob's Sink	Spring #1	4,000	130	171	2,740	98-107	
Nottmeier's Sink	Steam Thresher Spring (Lower)	1,775	130	387	900	98-109	
Church Sink	Couch's Spring	3,000	120	211	375	99-118	
Tipton Branch of Horse Creek	Curran Spring	4,300	120	147		00-132	

4.3 Dye Tracing Results by Individual Traces, Columbia Study Area

Each of the dye traces in the Columbia Study Area (CSA) is discussed in the following section of this report. For each trace, the analytical results for the relevant stations are shown. Four dye traces were conducted for the Columbia Quarry Company and were reported by Aley and Moss (1999a). Three additional traces were conducted for the City of Columbia, Illinois and were reported by Aley and Moss (1999b). These seven traces are included because they provide relevant data for the delineation and understanding of the Stemler Cave groundwater system.

Groundwater trace distances, elevation losses, gradients, and travel times for CSA traces are summarized in Table 5 at the end of Section 4.3. Actual velocity is somewhat higher than reported here. The actual flow paths are longer than the straight line distances used in this report for calculation of mean groundwater flow velocity. However, the velocities reported are the practical velocity for predicting time of travel for any traced flow path under similar conditions. Gradients are somewhat lower than reported since gradient is elevation loss divided by flow path length and the actual flow path length is longer than the straight-line distances used in this report.

The only recharge area delineated in the CSA is for Stemler Cave. The Stemler Cave entrance is part of the Stemler Cave Nature Preserve. There is no air-filled passage upstream of the entrance. In contrast, there is approximately one mile of passage downstream. Only about 125 feet of Stemler Cave is part of the Nature Preserve. However, the entire cave is an INAI site.

Located near the Stemler Cave Nature Preserve are some other important tracts of land. The Stemler Cave Woods Nature Preserve and several other state-managed tracts are within the Stemler Cave INAI site. Another important area in the CSA is Falling Springs, which is also an INAI site. While the contract does not require dye tracing for Falling Springs, the two areas are proximate enough, that, in the course of the study, one trace was recovered from Falling Springs. That trace is discussed in Section 4.3.21.

Figures showing traces flowing through Stemler Cave are drawn as passing through the in-cave sampling stations established for the Columbia Quarry work. Station 220 and 221 are in-cave sampling stations that are located on tributary streams. They are not exposed to dye flowing from the Stemler Cave Nature Preserve to Sparrow Spring. Sparrow Spring is the only discharge point for water from Stemler Cave.

4.3.1 Trace 98-201: Cossil Fast Trace.

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced in Cossil Fast Pit at 2015 hours on June 22, 1998. The dye was introduced into a deep pool of water at the bottom of a pit. There was no obvious flow. The dye introduction elevation is approximately 585 feet msl and the dye introduction point is in the SE ¼ NW ¼ of Section 12, T1S, R10W. The area of the dye location is shown on the Columbia 7.5-minute quadrangle map. The trace is shown on Figure 39. The purpose of this trace was to help define the Stemler Cave recharge area.

The sampling stations for this trace were: 201, 202, 206, 211, 212, 216, and 217.

Data on the dye recovery locations for Trace 98-201 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 201. Stemler Cave.

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
6/20 to 6/29/98	ND	ND
6/29 to 7/8/98	538.6	22.2
7/8 to 7/21/98	ND	ND
7/21/98 (water)	ND	ND

Station 202. Sparrow Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
6/20 to 6/29/98	ND	ND
6/29 to 7/8/98	538.8	35.6
6/29 to 7/8/98 (dup.)	538.6	36.6
7/8 to 7/17/98	ND	ND

Eosine dye from the Cossil Fast Trace was recovered from Stemler Cave and Sparrow Spring. Sparrow Spring has long been considered the discharge point for the Stemler groundwater system. This trace confirms that relationship as well as demonstrating that the area around Cossil Fast contributes water to the Stemler Cave Nature Preserve. Trace 98-201 demonstrated that Sparrow Spring is the only discharge point for the Stemler Cave groundwater system.

The straight-line groundwater flow path distance to the entrance of Stemler Cave is 3,100 feet and the elevation loss is approximately 35 feet. The mean groundwater flow path gradient is approximately 60 feet per mile. The straight-line groundwater flow path distance from the Stemler Cave entrance to Sparrow Spring is approximately 10,800 feet and the elevation loss is approximately 55 feet. The mean groundwater gradient from the Stemler

Cave entrance station to Sparrow Spring is approximately 27 feet per mile. All detectable dye passed through the Stemler Cave Nature Preserve 7 to 16 days after dye introduction. All dye had been discharged through Sparrow Spring in that same time period. Trace 98-201 was conducted during high flow conditions.

Assuming that the first dye arrival occurred at the Stemler Cave entrance 11 days after dye introduction, then the mean groundwater velocity for this portion of the trace was about 280 feet per day. Assuming that the travel time for the first arrival of dye from the Stemler Cave entrance to Sparrow Spring was one day, then the mean groundwater velocity for this portion of the trace was about 10,800 feet per day.

The mean flow rate from Cossil Fast Pit to the Stemler Cave entrance was much slower than the rates for most other groundwater traces in the region. We suspect that the slower than typical flow rate is due to localized conditions in the vicinity of Cossil Fast Pit and is not characteristic of most other sinkholes in the area.

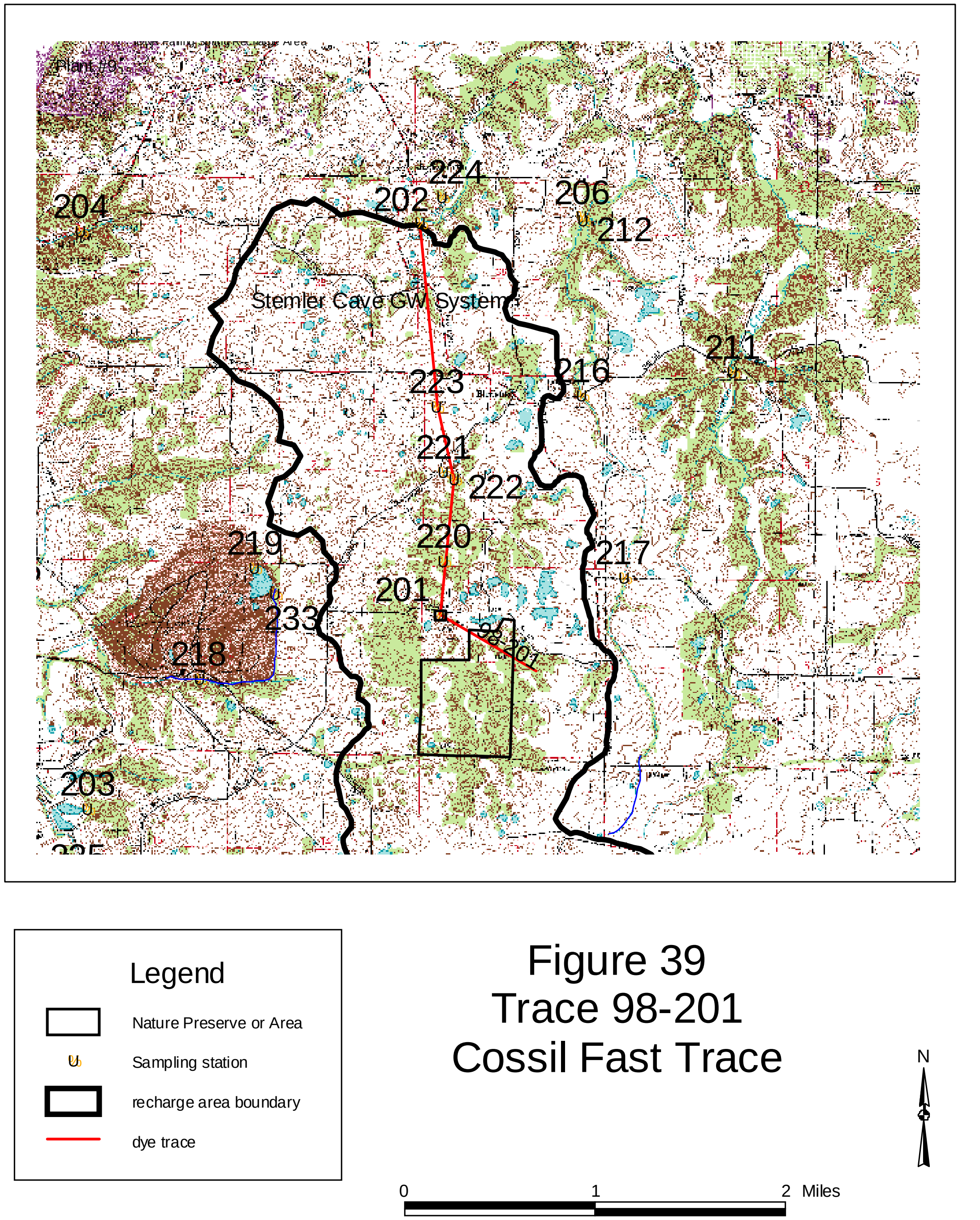


Figure 39
Trace 98-201
Cossil Fast Trace

4.3.2 Trace 98-202: Charles Sink Trace.

Seven tenths of a pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into Charles Sink at 1311 hours on July 14, 1998. The dye was introduced into a small subsurface stream with a flow rate of approximately 0.5 gpm. The dye introduction elevation is approximately 635 feet msl and is located in the NE ¼ SE ¼ of Section 13, T1S, R9W. The location is shown on the Columbia 7.5-minute quadrangle map. The trace is shown on Figure 40. The purpose of this trace was to help define the recharge area boundary southeast of the entrance to Stemler Cave. Dye for this trace was introduced under moderate flow conditions

The sampling stations for this trace were: 201, 202, 206, 211, 212, 216, 217, 222, and 223.

Data on the dye recovery locations for Trace 98-202 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 201. Stemler Cave

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein dye Concentration (ppb)
6/29 to 7/8/98	ND	ND
7/8 to 7/21/98	513.4	245
7/21/98 (water)	507.5	4.74
7/21 to 7/24/98	513.5	257
7/24/98 (water)	ND	ND
7/24 to 7/29/98	512.3	4.04
7/29 to 9/1/98	NS	NS
9/1 to 9/9/98	512.7	3.80
9/9 to 9/18/98	512.4	5.59
9/18 to 9/30/98	512.9	7.17
9/30 to 10/7/98	512.8	7.35
10/7 to 10/15/98	511.7	4.19
10/15 to 10/21/98	511.8	5.09
10/21 to 10/28/98	511.4	2.85
10/28 to 11/4/98	511.7	2.47
10/28 to 11/4/98 (dup.)	511.7	2.75
11/4 to 11/10/98	ND	ND
11/10 to 11/16/98	511.2	3.79
11/16 to 11/20/98	510.8 s	1.44
11/20 to 12/3/98 *	512.6	5.60

* Residual dye was detected at Stemler Cave periodically through March 9, 2000. See Appendix A for details.

Station 202. Sparrow Spring

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein dye Concentration (ppb)
7/8 to 7/17/98	ND	ND
7/17 to 7/21/98	513.0	43.9
7/21/98 (water)	507.7	3.78
7/21 to 7/24/98	513.3	81.3
7/24/98 (water)	ND	ND
7/24 to 7/29/98	512.2	4.06
7/29/98 (water)	ND	ND
7/29 to 9/1/98	ND	ND
9/1 to 9/9/98	511.3 s	1.15
9/9 to 9/18/98	511.0 s	1.07
9/18 to 9/30/98	511.8	2.04
9/18 to 9/30/98 (dup.)	511.8	1.22
9/30 to 10/7/98	511.7	1.50
10/7 to 10/15/98	511.0	1.48

Station 222. Stemler Cave-4

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein dye Concentration (ppb)
9/18/98 (water)	**510.7 a**	**SH**
9/18 to 10/11/98	512.8	7.17
10/11 to 11/20/98	511.3	3.75
10/11 to 11/20/98 (dup.)	511.3	4.42
11/20/98 (water)	ND	ND
11/20/98 to 1/26/99	511.4	4.69
1/26/99 to 6/8/00	ND	ND

Station 223. Stemler Cave-5

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein dye Concentration (ppb)
9/18/98 (water)	**510.0**	**SH**
9/18 to 10/11/98	512.9	7.85
9/18 to 10/11/98 (dup.)	513.0	8.92
10/11 to 11/20/98	511.4	4.62
11/20/98 (water)	ND	ND

Fluorescein dye from the Charles Sink Trace was recovered at four sampling stations. All the sampling stations except Stemler Cave (Station 201) are downstream of the Stemler Cave Nature Preserve and derived their dye from water passing through the Nature Preserve. Two stations where dye was recovered, Stemler Cave-4 and Stemler Cave-5, were not part of the routine sampling network for the delineation of the Stemler Cave recharge area.

Figure 40 shows a sampling station, Station 220, which appears to be on the line representing the dye trace flow path. The line is diagrammatic; Station 220 is not on the actual flow path. Station 220 is located on a tributary stream to the main stream in Stemler Cave.

The straight-line groundwater flow path distance from the dye introduction point to the Stemler Cave entrance is approximately 8,300 feet. The elevation loss to the entrance is approximately 85 feet. The mean groundwater flow path gradient from Charles Sink to the entrance of Stemler Cave is approximately 54 feet per mile. The mean groundwater gradient from the Stemler Cave entrance station to Sparrow Spring is approximately 27 feet per mile.

The straight-line distance from the dye introduction point to Sparrow Spring is approximately 19,100 feet. The total elevation loss is approximately 140 feet.

Dye from Trace 98-202 arrived at Stemler Cave within seven days of dye introduction. The dye first arrived at Sparrow Spring between three and seven days after dye introduction. We estimate that the first dye arrival at the Stemler Cave entrance was five days after dye introduction, and that dye first arrived at Sparrow Spring 6 days after dye introduction. The mean groundwater velocity to the Preserve for this trace was approximately 1,700 feet per day. Dye was recovered throughout an extended drought period, and detectable dye concentrations persisted for about 18 months.

Trace 98-202 helps define the southeast boundary of the Stemler recharge area. The long period of residual dye detection from this trace suggests that the Stemler Cave groundwater system could remain contaminated for a considerable period of time following the introduction of a pulse of contaminants.

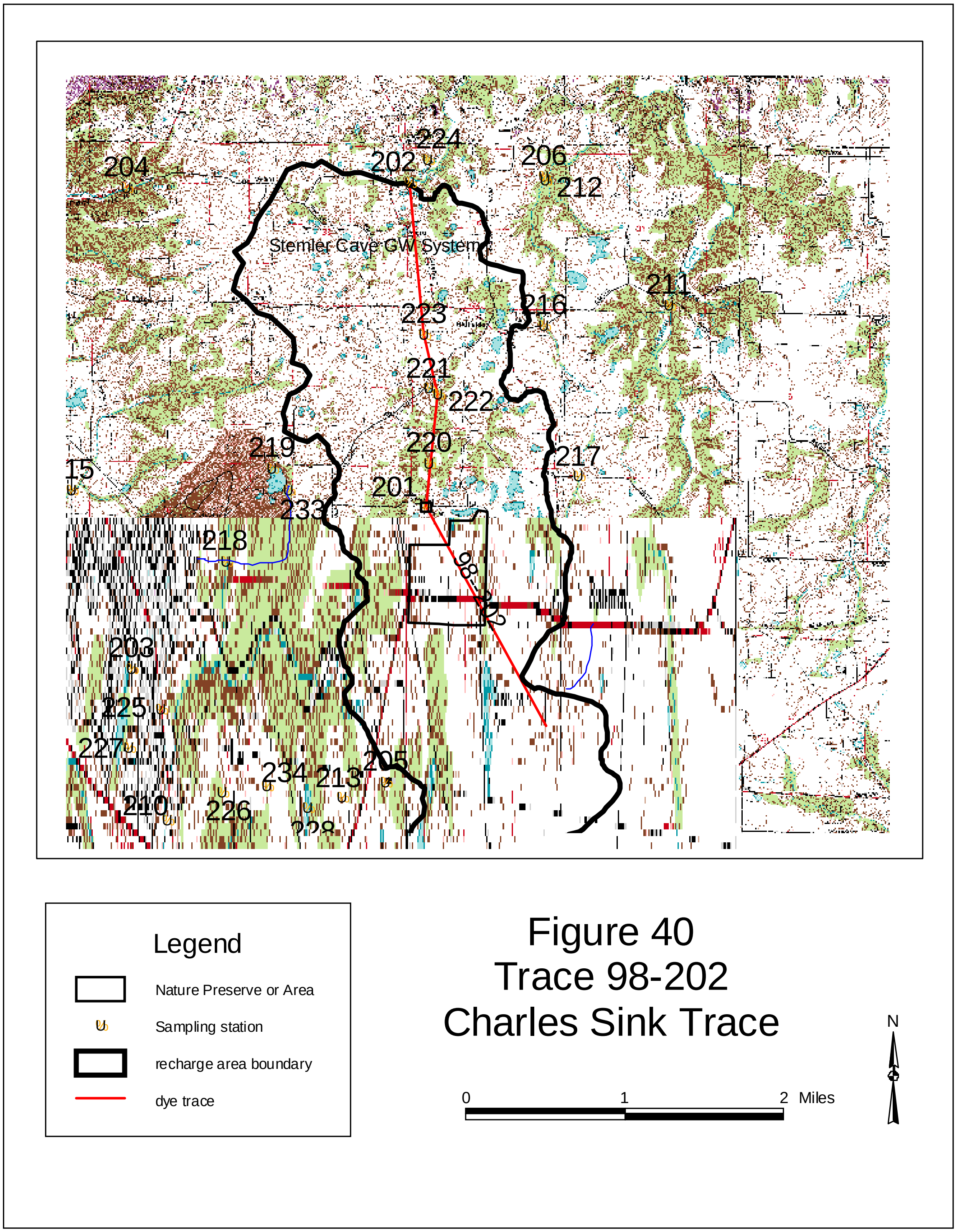


Figure 40
Trace 98-202
Charles Sink Trace

4.3.3 Trace 98-203: Gilmore Lakes Sink Trace.

Two pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced in Gilmore Lakes Sink at 0932 hours on July 21, 1998. The dye was introduced into a sinkhole fed by a lake spillway. A flow of approximately six gpm was entering the groundwater system at the time of dye introduction. The dye introduction elevation is approximately 630 feet msl and is in the SW ¼ NE ¼ of Section 25, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The trace is shown on Figure 41. The purpose of the trace was to help define the southern boundary of the Stemler Cave recharge area. The trace was conducted under moderate flow conditions.

The sampling stations for this trace were: 201, 202, 203, 205, 209, 210, 211, 212, 213, 216, 217, 218, and 219.

Data on the dye recovery locations for Trace 98-203 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 201. Stemler Cave

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
7/8 to 7/21/98	ND	ND
7/21/98 (water)	ND	ND
7/21 to 7/24/98	562.8	79.8
7/24/98 (water)	569.1 a	5.76
7/24 to 7/29/98	563.8	245
7/29 to 9/1/98	NS	NS
9/1 to 9/9/98	ND	ND

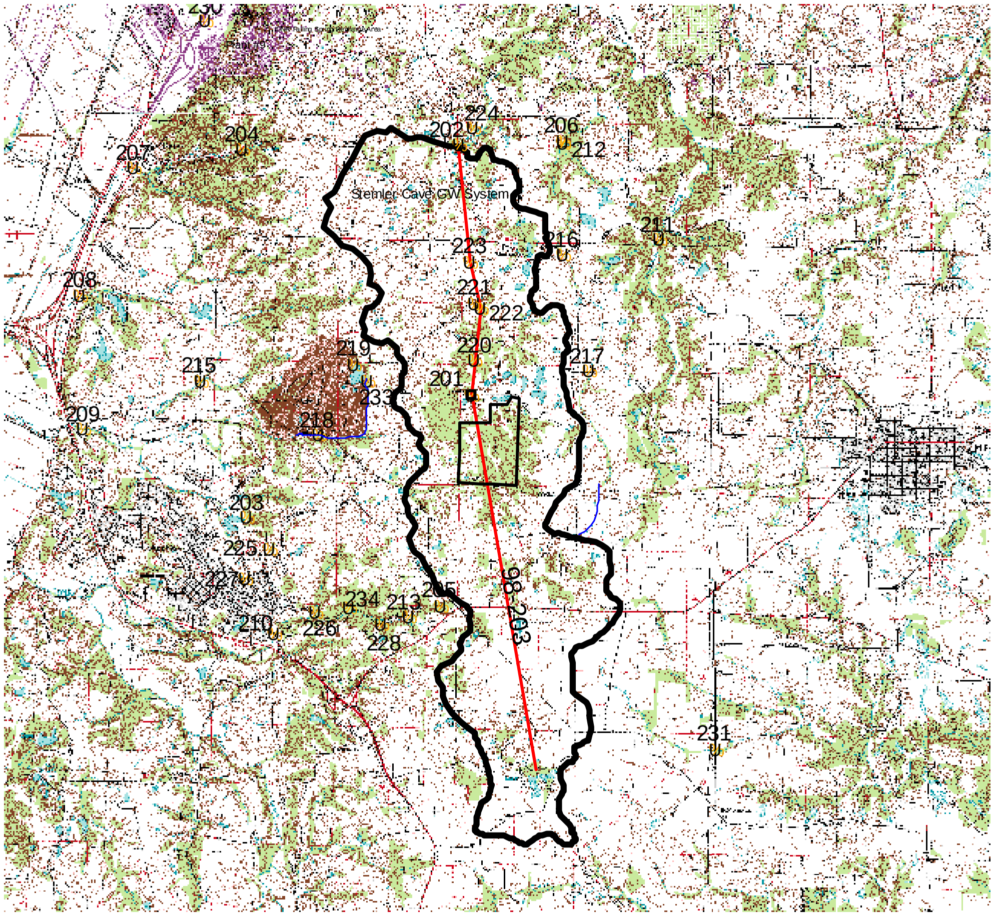
Station 202. Sparrow Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
7/17 to 7/21/98	ND	ND
7/21/98 (water)	ND	ND
7/21 to 7/24/98	562.3	12.7
7/24/98 (water)	567.8 a	1.44
7/24 to 7/29/98	563.8	123
7/29/98 (water)	567.6 a	0.136
7/29 to 9/1/98	565.0	SH
9/1 to 9/9/98	ND	ND

Rhodamine WT dye from the Gilmore Lakes Trace was recovered at two sampling stations: Stemler Cave and Sparrow Spring. The straight-line groundwater flow path distance to Stemler Cave entrance is approximately 16,500 feet; and to Sparrow Spring is approximately 27,300 feet. The elevation loss to the Stemler Cave entrance is approximately 80 feet and to Sparrow Spring is approximately 135 feet. The mean groundwater flow path gradient is approximately 26 feet per mile from Gilmore Lakes Sink to the Stemler Cave entrance. In comparison, the mean groundwater gradient from the Stemler Cave entrance to Sparrow Spring is nearly identical at 27 feet per mile.

The time of first arrival at both the Stemler Cave Nature Preserve and Sparrow Spring was three days or less. If we assume that the first arrival of dye at the Stemler Cave entrance occurred 2 days after dye introduction, the mean groundwater velocity for the first arrival of dye at the cave entrance was 8,250 feet per day. If we assume that the first arrival of dye at Sparrow Spring occurred 3 days after dye introduction, the mean groundwater velocity for the first arrival of dye at this spring was 9,100 feet per day.

The dye from Trace 98-203 moved through the system quickly. A 1.3-inch rainstorm on July 23, 1998 probably enhanced this fast flow. The Gilmore Lakes Trace demonstrates that runoff along with contaminants such as septic effluent from the Gilmore Lakes Subdivision rapidly migrates to the Stemler Cave Nature Preserve and Sparrow Spring.



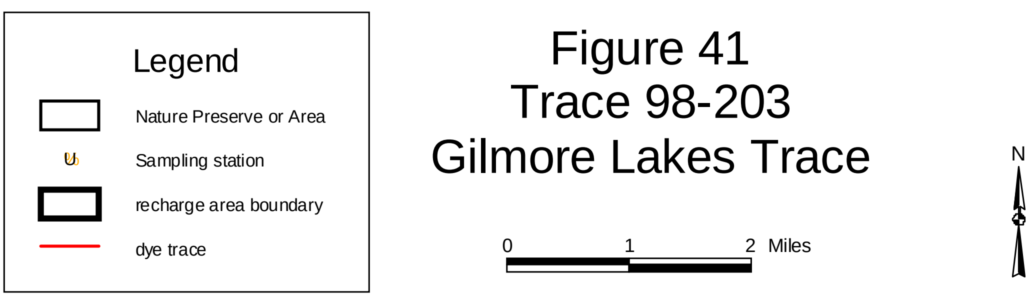


Figure 41
Trace 98-203
Gilmore Lakes Trace

4.3.4 Trace 98-204: Gummerscheimer Northeast Trace.

Approximately one-half pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was placed as a dry set at 0920 hours on September 24, 1998. The dye introduction elevation is 645 feet msl and is in the NE ¼ SW ¼ of Section 2, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The dye probably was introduced into the groundwater system by a storm event on October 17, 1998. It is not clear whether all the dye was introduced into the groundwater system in that runoff event. A subsequent storm on the morning of November 2, 1998 produced approximately 10 gpm of runoff that entered the groundwater system through this sinkhole. The trace is shown on Figure 42. The purpose of this trace was to determine whether or not land in the vicinity of the dye introduction point lies within the Stemler Cave recharge area.

The sampling stations for this trace were: 201, 202, 204, 205, 207, 208, 209, 210, 213, 214, 215, 218, 219, 220, 221, 222, 223, and 224.

Data on the dye recovery location for Trace 98-204 is listed below. All data are for charcoal samplers unless otherwise noted.

Station 202. Sparrow Spring

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein dye Concentration (ppb)
10/7 to 10/15/98	**511.0**	**1.48**
10/15 to 10/21/98	511.7	2.50
10/21 to 10/28/98	512.6	14.4
10/28 to 11/3/98	512.7	22.7
10/28 to 11/3/98 (dup.)	512.9	14.9
11/3 to 11/10/98	512.5	8.32
11/10 to 11/16/98	512.3	12.3
11/16 to 11/20/98	510.6 a,s	1.18
11/20/98 (water)	ND	ND
11/20 to 12/3/98	511.4	2.95
12/3 to 12/14/98	511.5	5.13
12/14 to 12/21/98	510.6 a,s	1.31
12/21/98 to 1/5/99	511.8	3.97
12/21/98 to 1/5/99 (dup.)	511.8	4.25
1/5 to 1/12/99	512.1	2.95

Dye was recovered from Trace 98-204 only at Sparrow Spring. The OUL established four in-cave sampling stations (Stations 220 to 223) to help bracket the input point for dye that might enter Stemler Cave. No new fluorescein dye was detected at any of these four stations. Some residual dye was present at Stations 222 and 223 from Trace 98-202. These two stations are located in the main stream of Stemler Cave. Station 223 is located near the sump (no air space) at the end of exploration in Stemler Cave. Stations 220 and 221 are located in significant side passages carrying tributary streams on the west side of the cave.

The straight-line groundwater flow path distance for Trace 98-204 is approximately 7,165 feet. The elevation loss for this groundwater flow path is approximately 150 feet. The mean groundwater flow path gradient is approximately 111 feet per mile. The data suggest that the first dye arrived at Sparrow Spring about 4 days after the initial dye mobilization. Based on this, the mean groundwater flow path velocity is approximately 1,790 feet per day. It is possible that a significant portion of dye did not enter the groundwater system until the November 2 storm event. This is supported by the fact that the peak concentration of fluorescein dye discharge from Sparrow Spring during this trace occurred in the sampling interval containing the later storm event.

It is not clear from the data whether the residual dye detected at Sparrow Spring after November 16, 1998 is from this trace, 98-204, or from the earlier Charles Sink Trace (98-202), or both traces. Residual dye from Trace 98-202 was detectable at Sparrow Spring at the beginning of the much larger dye pulse associated with Trace 98-204. Trace 98-204 demonstrates that, while the Gummerscheimer Northeast sinkhole is in the Stemler Cave groundwater system, water from this site does not pass through any of the air-filled portion of Stemler Cave.

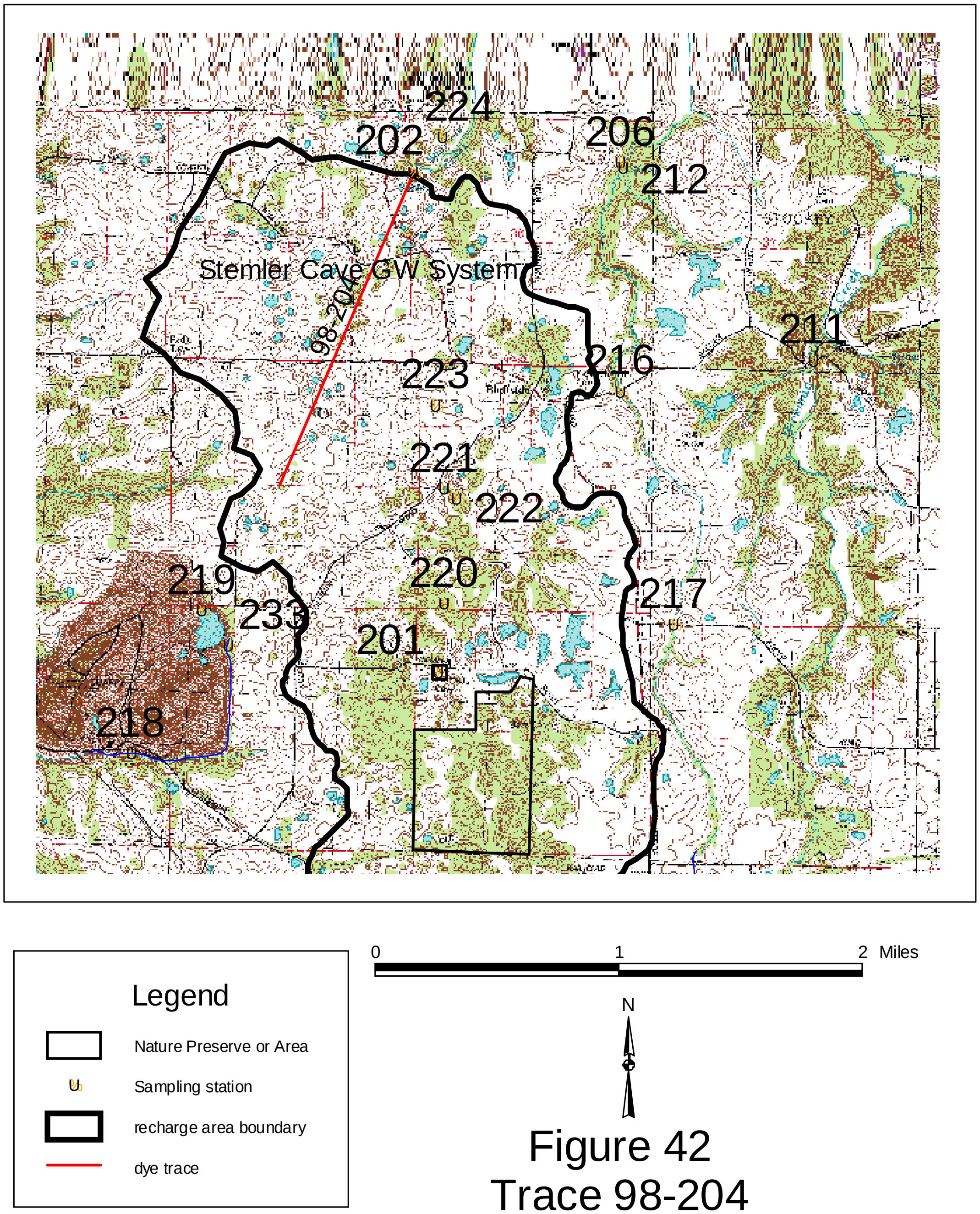


Figure 42
Trace 98-204
Gummerscheimer NortheastTrace

4.3.5 Trace 98-205: Gummerscheimer South Trace.

One pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was placed as a dry set at 0945 hours on September 24, 1998. The dye introduction elevation is 635 feet msl and the site is in the SE ¼ SE ¼ of Section 2, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The dye probably was introduced into the groundwater system by a storm event on October 17, 1998. It is not clear whether all the dye was introduced into the groundwater system in that event. A subsequent storm on the morning of November 2, 1998 produced approximately 25 gpm of runoff that entered the groundwater system through this sinkhole. The trace is shown on Figure 43. The purpose of this trace was to help determine whether or not land in the vicinity of the dye introduction point lies within the Stemler Cave groundwater system recharge area.

The sampling stations for this trace were: 201, 202, 204, 205, 207, 208, 209, 210, 213, 214, 215, 218, 219, 220, 221, 222, 223, and 224.

Data on the dye recovery location for Trace 98-205 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 218. Quarry Discharge

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B dye Concentration (ppb)
12/21/98 to 1/19/99	ND	ND
1/19 to 3/3/99	574.4	SH
3/3 to 3/23/99	570.8	0.957
3/23 to 3/31/99	574.2	2.70
3/31 to 4/21/99	573.8	6.77
3/31 to 4/21/00 (dup.)	573.8	6.83
4/21 to 5/13/99	573.2	1.97
5/13 to 5/19/99	ND	ND

Station 219. Quarry Pond

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B dye Concentration (ppb)
7/29 to 9/1/98	ND	ND
9/1 to 10/7/98	NS	NS
10/7/98 (water)	575.0 a	0.470
10/7 to 10/21/98	573.3	3.96
10/21 to 11/3/98	573.5	5.09
11/3 to 11/10/98	571.2	1.15
11/10 to 11/16/98	572.8	0.510
11/16 to 11/20/98 *	572.8	1.12

* Residual dye was recovered at Quarry Pond through September 9, 1999. See Appendix A for details.

Dye was recovered from Trace 98-204 at two locations; these were Quarry Discharge and Quarry Pond. Both are within Columbia Quarry's Plant No. 1, adjacent to the Gummerscheimer property. The quarry periodically pumps water out of the pond to a tributary of Palmer Creek; pond water is also used for dust control.

The groundwater flow path distance for Trace 98-205 is approximately 1,300 feet. The elevation loss is approximately 147 feet to the top of the pond. The pond is approximately 32 feet deep (S. Lewis, personal communication, 1998). The OUL has no data regarding the elevation at which dye entered the pond.

The time of first dye arrival was about four days. This indicates a mean groundwater velocity for the first dye arrival of about 325 feet per day. The dye persisted in the pond in relatively stable concentrations for about 13 months. The Gummerscheimer South Trace demonstrates that this dye introduction point is outside the Stemler Cave groundwater system recharge area. The trace also demonstrates that the Quarry Pond receives groundwater discharge.

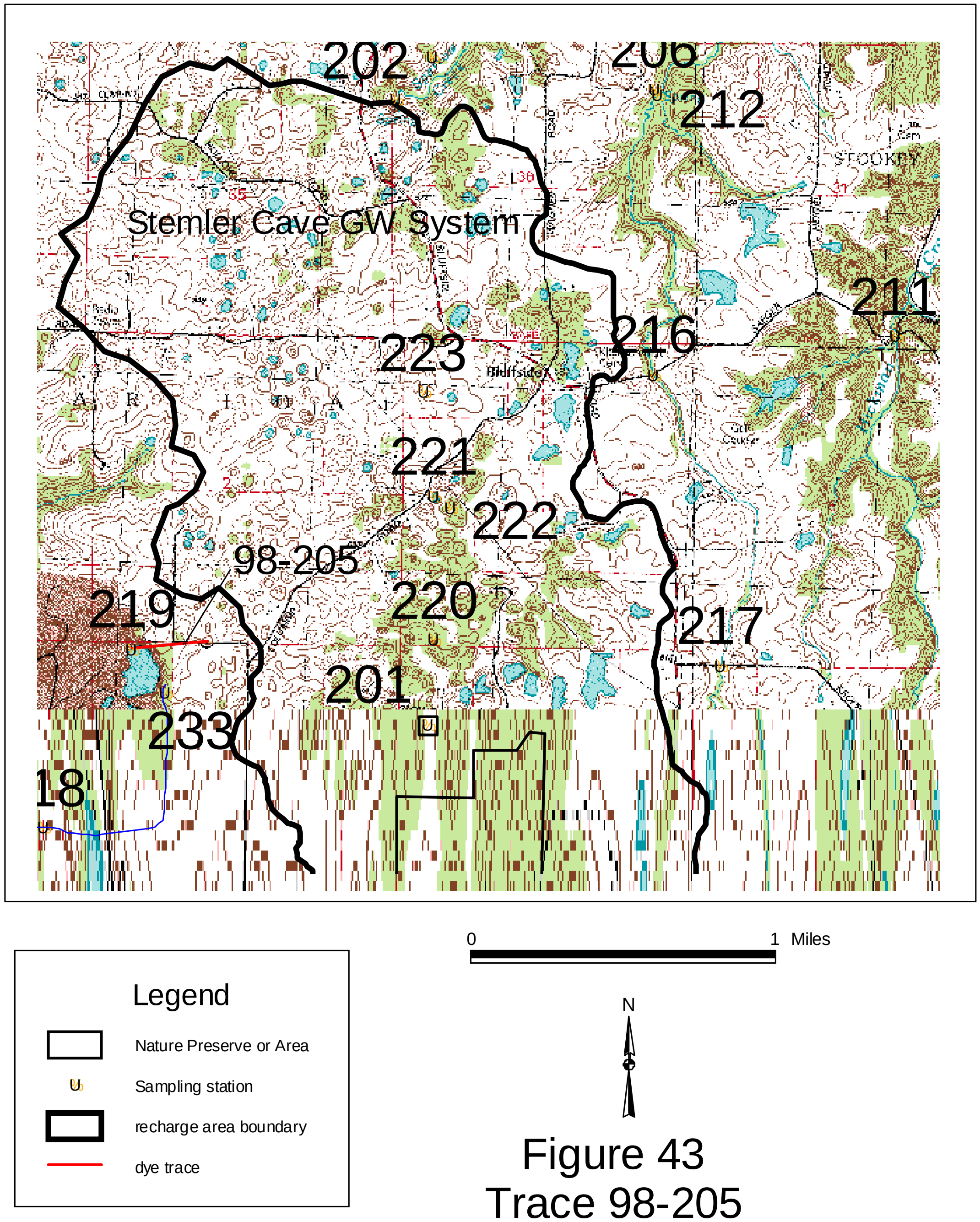


Figure 43
Trace 98-205
Gummerscheimer South Trace

4.3.6 Trace 98-206: Cemetery Trace.

Approximately one-half pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into the Cemetery Sink between 1432 and 1442 hours on December 12, 1998. The water was hauled to the sink in two loads of 1600 gallons each. The water was discharged to a ditch leading to the sink. The first load entered the sink from 1430 to 1442 hours, the second load from 1502 to 1520 hours. The dye solution bypassed the standpipe that was installed to stabilize the sinkhole. There was no pooling of water in the sink. The dye introduction elevation is approximately 540 feet msl and is in the NE ¼ SW ¼ of Section 15, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The trace is shown on Figure 44.

Figure 44 shows all three traces (98-206, 98-207, and 99-208) recovered at Ritter Spring. These traces were conducted close together in both time and space. The OUL has included all of these traces on one figure for easy comparison. Figure 44 is at the end of Section 4.3.6.

This trace, as well as Traces 98-207 and 99-208, were done under contract to the City of Columbia, Illinois. They are included here because they help define the southwestern recharge area boundary for the Stemler Cave recharge area. The purpose of this trace was to test whether or not a topographic drainage divide along Bluffside Road has a corresponding groundwater divide.

The sampling stations for this trace were: 201, 202, 203, 205, 209, 210, 213, 218, 219, 226, and 227.

Dye recovery data for Trace 98-206 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 203. Ritter Spring

Sampling period	Peak Emission Wavelength (nm)	Fluorescein dye concentration (ppb)
12/3 to 12/14/98	ND	ND
12/14 to 12/21/98	514.4	6,280
12/21/98 (water)	507.7	9.49
12/21/98 to 1/6/99	514.4	4,850
1/6/99 (water)	507.8	6.49
1/6 to 1/12/99	514.1	1,590
1/12/99 (water)	507.6	7.91
1/12 to 1/19/99	513.5	3,840
1/19/99 (water)	504.4 a,s	0.064
1/19 to 1/28/99	512.8	46.7
1/28 to 2/2/99	512.8	41.5
2/2 to 2/9/99	512.4	17.9
2/9 to 2/16/99	512.5	17.3
2/16 to 2/22/99	512.7	13.2
2/22 to 3/3/99	512.5	13.0
3/3 to 3/10/99	512.6	12.9
3/10 to 3/16/99 *	511.5	2.47

* Residual fluorescein dye was detected at Ritter Spring through January 4, 2000. See Appendix A for the complete data.

Station 209. Palmer Creek at Ghent Road

Sampling period	Peak Emission Wavelength (nm)	Fluorescein dye concentration (ppb)
12/14 to 12/21/98	ND	ND
12/21/98 to 5/13/99	511.0 s	1.89
5/13/99 (water)	ND	ND

Fluorescein dye was recovered from two sampling stations; Ritter Spring and Station 209, which is located downstream of the spring. The straight-line groundwater flow path distance for this trace is approximately 1,700 feet. The elevation loss is approximately 60 feet. The mean groundwater flow path gradient is approximately 186 feet per mile. We estimate that the time of first arrival of dye was approximately three days after the dye introduction. The groundwater velocity of Trace 98-206 under these conditions was approximately 570 feet per day. The Cemetery Trace demonstrates that the area around Immaculate Conception Cemetery is outside of the Stemler Cave recharge area.

Ritter Spring has a base flow discharge on the order of 60 gpm, which is much less than the discharge from Sparrow Spring, the resurgence for the Stemler Cave groundwater system.

Sparrow Spring has a base flow discharge on the order of 1,000 gpm. This lower discharge from Ritter Spring accounts for much of the high concentrations of dye recovered as there is much less dilution in the Ritter Spring groundwater system than in the Stemler Cave groundwater system. This trace was initiated under low flow conditions. However, starting on January 14, 1999, high flow conditions were created by snowmelt.

The long period (over one year) in which residual dye was detected at Ritter Spring indicates its vulnerability, along with the commercial fishing pond that it feeds, to contamination from the section of Cherry Street that drains to the Cemetery Sinkhole. This series of traces (98-206, 98-207, and 99-208) demonstrate that the topographic divide along Bluffside Road does not correspond to a groundwater divide.

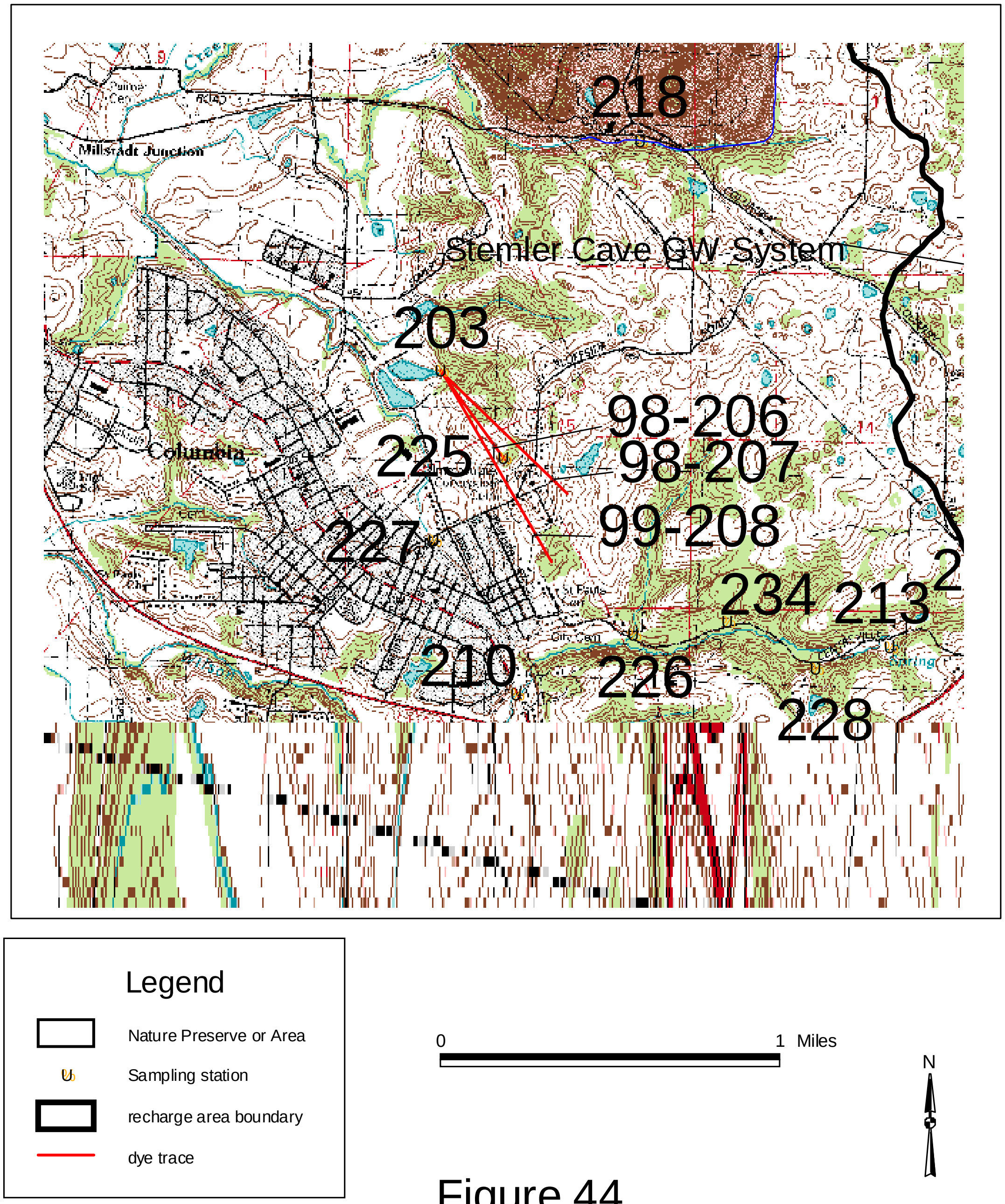


Figure 44
Trace 98-206, 98-207, and 99-208
Cemetery, Pioneer Ridge, and BreideckerTraces

4.3.7 Trace 98-207: Pioneer Ridge Trace.

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole located in Pioneer Ridge Subdivision at 1224 hours on December 12, 1998. Water was hauled to the sink in two loads of 1,600 gallons each. The first load was discharged to the sink between 1221 and 1231 hours. The second load was discharged to the sink between 1325 and 1330 hours. The dye solution bypassed the standpipes installed to help stabilize the sinkhole. There was no pooling of water in the sink due to the introduction of hauled water. The introduction elevation is approximately 560 feet msl and is in the NW ¼ NE ¼ of Section 15, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The trace is shown on Figure 44.

Figure 44 shows all three traces (98-206, 98-207, and 99-208) recovered at Ritter Spring. These traces were conducted close together in both time and space. The OUL has included all of these traces on one figure for easy comparison. Figure 44 can be found at the end of Section 4.3.6.

This trace, as well as Traces 98-206 and 99-208 were done under contract to the City of Columbia, Illinois. They are included here because they help define the southwest border of the recharge area for the Stemler Cave recharge area. The purpose of this trace was to test whether or not a topographic drainage divide along Bluffside Road has a corresponding groundwater divide.

The sampling stations for this trace were: 201, 202, 203, 205, 209, 210, 213, 218, 219, 225, 226, and 227.

Data on the dye recovery locations for Trace 98-207 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 203. Ritter Spring

Sampling period	Peak Emission Wavelength (nm)	Rhodamine WT dye concentration (ppb)
12/3 to 12/14/98	ND	ND
12/14 to 12/21/98	562.0	6,970
12/21/98 (water)	570.8	223
12/21/98 to 1/6/99	562.2	15,800
1/6/99 (water)	570.5	15.4
1/6 to 1/12/99	562.5	1,520
1/12/99 (water)	569.2	4.55
1/12 to 1/19/99	ND r	ND
1/19/99 (water)	ND	ND
1/19 to 1/28/99 *	565.2	11.3

* Residual rhodamine WT dye was detected into September 1999. See Appendix A for the complete data.

Station 209. Palmer Creek at Ghent Road

Sampling period	**Peak Emission Wavelength (nm)**	**Rhodamine WT dye concentration (ppb)**
12/14 to 12/21/98	ND	ND
12/21/98 to 5/13/99	564.4	3.23
5/13/99 (water)	ND	ND
5/13 to 5/19/99	ND	ND

Rhodamine WT dye from the Pioneer Ridge Trace was recovered from two stations; Ritter Spring and the downstream Station 209. The straight-line groundwater flow path distance for this trace is approximately 2,750 feet. The elevation loss is approximately 80 feet. The mean groundwater flow path gradient is approximately 154 feet per mile. The dye first arrived at Ritter Spring between two and nine days after dye introduction, and we estimate that the first arrival was about 3 days after dye introduction. This represents a mean groundwater velocity for the first dye arrival of about 920 feet per day.

Peak dye discharge from Ritter Spring was approximately nine days after dye introduction. The long period (about nine months) in which residual dye was detected at Ritter Spring, indicates its vulnerability, along with the commercial fishing pond that it feeds, to contamination from the Pioneer Ridge Subdivision.

Trace 98-207 demonstrates that the Pioneer Ridge subdivision does not contribute water to the Stemler Cave groundwater system. This series of traces (98-206, 98-207, and 99-208) demonstrate that the topographic divide along Bluffside Road does not correspond to a groundwater divide.

4.3.8 Trace 99-208: Breidecker Trace.

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole in the Pioneer Ridge Subdivision at 1635 hours on January 6, 1999. There was a flow of approximately 10 gpm entering the groundwater system from snowmelt at the time of dye introduction. The introduction elevation is 530 feet msl and is in the SW ¼ SE ¼ of Section 15, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The trace is shown on Figure 44.

Figure 44 shows all three traces (98-206, 98-207, and 99-208) recovered at Ritter Spring. These traces were conducted close together in both time and space. The OUL has included all of these traces on one figure for easy comparison. Figure 44 is at the end of Section 4.3.6.

This trace, as well as Traces 98-206 and 98-207 were done under contract to the City of Columbia, Illinois. They are included here because they help define the southwestern boundary of the Stemler Cave recharge area. The purpose of this trace was to test whether or not a topographic drainage divide along Bluffside Road has a corresponding groundwater divide.

The sampling stations for this trace were: 201, 202, 203, 205, 209, 210, 213, 218, 219, 225, 226, and 227.

Data on the dye recovery locations for Trace 99-208 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 203. Ritter Spring

Sampling period	Peak Emission Wavelength (nm)	Eosine dye concentration (ppb)
1/6 to 1/12/99	ND	ND
1/12/99 (water)	ND	ND
1/12 to 1/19/99	536.8	3,280
1/19/99 (water)	ND	ND
1/19 to 1/28/99	539.2	20.3
1/28 to 2/2/99	538.4	11.7
2/2 to 2/9/99	538.0	2.28
2/9 to 2/16/99	536.4	3.34
2/16 to 2/22/99	536.4	2.32
2/22 to 3/3/99	ND	ND

Station 209. Palmer Creek at Ghent Road

Sampling period	Peak Emission Wavelength (nm)	Eosine dye concentration (ppb)
12/14 to 12/21/98	ND	ND
12/21/98 to 5/13/99	537.6	4.45
5/13/99 (water)	ND	ND
5/13 to 5/19/99	ND	ND

Eosine dye was recovered from two sampling stations: Ritter Spring and the downstream Station 209. The straight-line groundwater flow path distance for this trace is approximately 3,400 feet. The elevation loss is approximately 50 feet. The mean gradient for this flow path is approximately 78 feet per mile. The time of first arrival of dye and the peak dye discharge at Ritter Spring between 6 and 13 days after dye introduction. We estimate that the first arrival of dye occurred about 9 days after dye introduction. This represents a mean groundwater velocity for the first day arrival of about 380 feet per day. Trace 99-208 lies southwest of the Stemler Cave recharge area. This series of traces (98-206, 98-207, and 99-208) demonstrate that the topographic divide along Bluffside Road does not correspond to a groundwater divide.

There is an inverse correlation between distance and groundwater flow path gradients among the traces that have been recovered at Ritter Spring. That is, the longer the flow path, the lower the gradient. This suggests that there is a conduit system with a gradient less than any of the mean calculated gradients plus more steeply inclined flow paths from the sinks to that conduit system.

4.3.9 Trace 99-209: Gummerscheimer House Trace.

Two pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole starting at 1415 hours on January 12, 1999. There was a flow of approximately 2 gpm from snowmelt entering the groundwater system at the time of dye introduction. This was followed by 0.3 inches of rain on snow overnight. The dye introduction elevation is approximately 640 feet msl and is in the NE ¼ SW ¼ of Section 2, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The trace is shown on Figure 45. The trace was conducted under high flow conditions.

The purpose of this trace was to refine the Stemler Cave groundwater system recharge area boundary as developed by the earlier Traces 98-204 and 98-205.

The sampling stations for this trace were: 201, 202, 204, 205, 207, 208, 209, 210, 213, 214, 215, 218, 219, 220, 221, 222, 223, and 224.

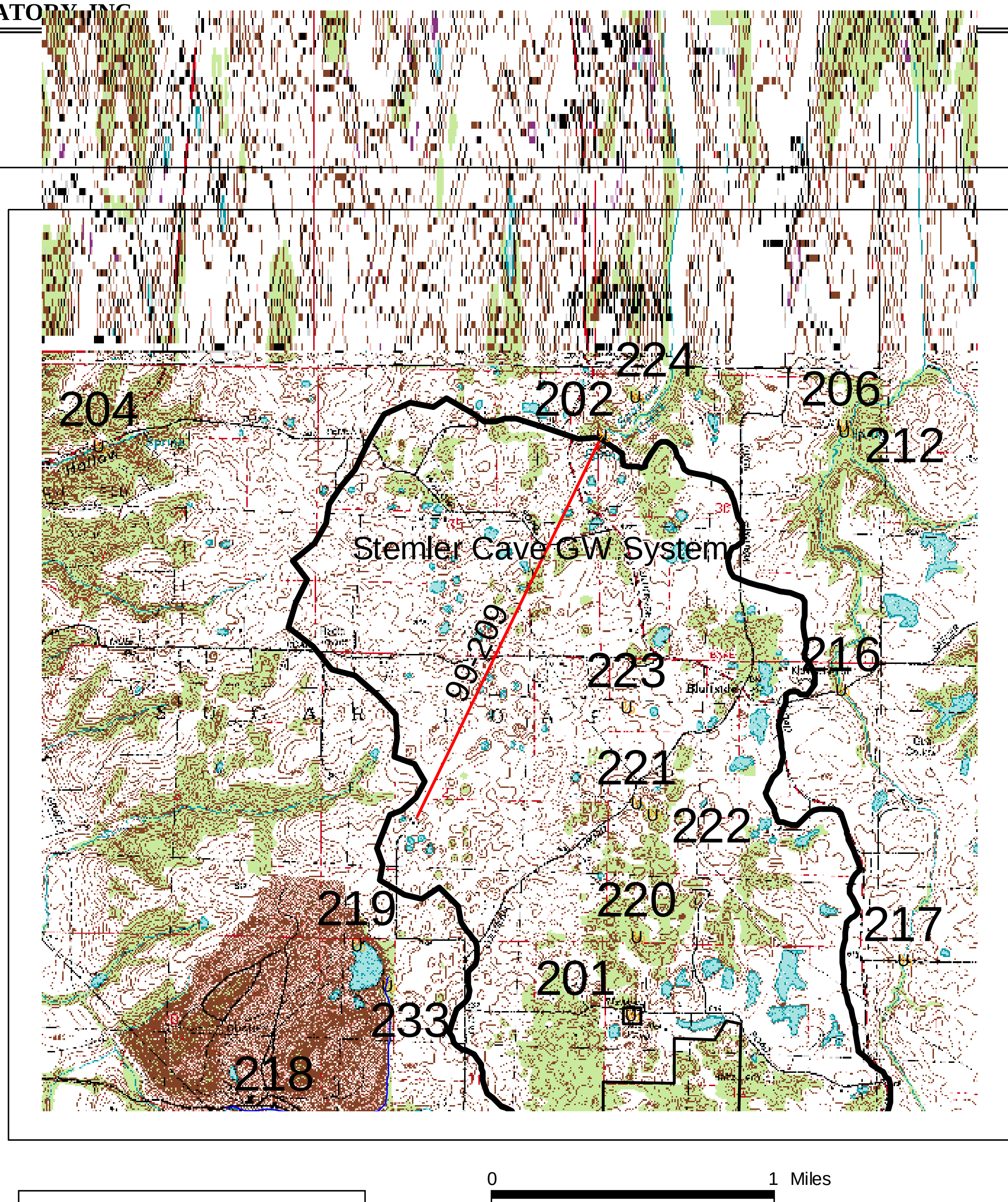
Data on the dye recovery location for Trace 99-209 is listed below. All data are for charcoal samplers unless otherwise noted.

Station 202. Sparrow Spring

Sampling period	Peak Emission Wavelength (nm)	Rhodamine WT dye concentration (ppb)
1/5 to 1/12/99	ND	ND
1/12 to 1/18/99	563.3	74.9
1/18 to 1/29/99	565.0	SH
1/18 to 1/29/99 (dup.)	565.0	SH
1/29/99 (water)	ND	ND
1/29 to 2/2/99	ND	ND

Rhodamine WT dye from Trace 99-209 was recovered only from Sparrow Spring. The Gummerscheimer House Trace demonstrates that this sinkhole contributes to the Stemler Cave groundwater system, but that it does not flow through the air-filled section of the cave. This trace follows a similar diagrammatic flow path to Trace 98-204.

The straight-line groundwater flow path distance for this trace is approximately 7,750 feet and the elevation loss is approximately 45 feet. The mean groundwater flow path gradient is approximately 31 feet per mile. Dye first arrived at Sparrow Spring less than six days after dye introduction. We estimate that dye first arrived 3 days after dye introduction, which would represent a mean groundwater velocity for the first dye arrival of about 2,580 feet per day. The peak dye concentration at Sparrow Spring occurred within 6 days of the time of dye introduction.



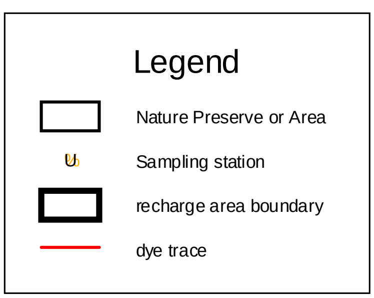


Figure 45
Trace 99-209
Gummerscheimer House Trace

4.3.10 Trace 99-210: Gummerscheimer Central Trace.

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 0728 hours on January 13, 1999. Approximately 4 gpm of snowmelt and storm runoff was entering the sinkhole at the time of dye introduction. The introduction elevation is approximately 660 feet msl and is in the SE ¼ SW ¼ of Section 2, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The trace is shown on Figure 46. The purpose of this trace was to refine the Stemler Cave recharge area boundary as developed by the earlier Traces 98-204 and 98-205.

The sampling stations for this trace were: 201, 202, 204, 205, 207, 208, 209, 210, 213, 214, 215, 218, 219, 220, 221, 222, 223, and 224.

Data on the dye recovery locations for Trace 99-210 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 202. Sparrow Spring

Sampling period	Peak Emission Wavelength (nm)	Fluorescein dye concentration (ppb)
1/5 to 1/12/99	512.1	2.95 *
1/12 to 1/18/99	513.1	855
1/18 to 1/29/99	ND	ND
1/18 to 1/29/99 (dup.)	ND	ND
1/29/99 (water)	ND	ND

* Residual dye from Trace 98-204.

Station 221. Stemler Cave-3

Sampling period	Peak Emission Wavelength (nm)	Fluorescein dye concentration (ppb)
10/11 to 11/20/99	ND	ND
11/20 to 1/26/99	513.7	5,000

Station 223. Stemler Cave-5

Sampling period	Peak Emission Wavelength (nm)	Fluorescein dye concentration (ppb)
10/11 to 11/20/99	511.4 *	4.62
11/20 to 1/26/99	513.0	72.7
1/26/99 to 6/8/00	ND	ND

* Residual dye from Trace 98-202.

Fluorescein dye from Trace 99-210 was recovered from three sampling stations, all of which are associated with Stemler Cave. Station 221 is located in a side passage (tributary stream) of Stemler Cave approximately 4,600 feet downstream of the Stemler Cave Nature Preserve. Station 223 is located near the downstream sump in the main passage of Stemler Cave. Station 223 is downstream of Station 221 and Sparrow Spring is downstream of both sampling Stations 221 and 223. The fluorescein dye detected at Sparrow Spring in the sampling period January 5 to January 12, 1999 is residual dye from earlier dye traces. Based upon results at Sparrow Spring, all detectable concentrations of the dye were discharged from the groundwater system within five days of the dye introduction. This indicates little attenuation of the dye. Based upon the dye results, it is likely that a pulse of contaminants from this area would be flushed out of the system quickly.

The straight-line groundwater flow path distance from the dye introduction point to Station 221 is approximately 4,400 feet. The elevation loss is approximately 120 from the dye introduction point to Station 221. The mean groundwater flow path gradient to Station 221 is approximately 144 feet per mile. The entire groundwater flow path distance to Sparrow Spring is approximately 10,700 feet and the gradient averages 32 feet per mile. Fluorescein dye from Trace 99-210 arrived at Sparrow Spring in less than five days. We estimate that dye first arrived at Sparrow Spring 2 days after dye introduction. As a result, the mean groundwater velocity for the first dye arrival was about 5,350 feet per day.

Trace 99-210, along with Traces 98-204 and 98-205, reveals the complexity of karst groundwater systems in the CSA. In an 80 acre tract there are three different flow paths to two different groundwater systems. While the majority of this tract lies within the Stemler Cave groundwater system, none of it contributes water to the Stemler Cave Nature Preserve.

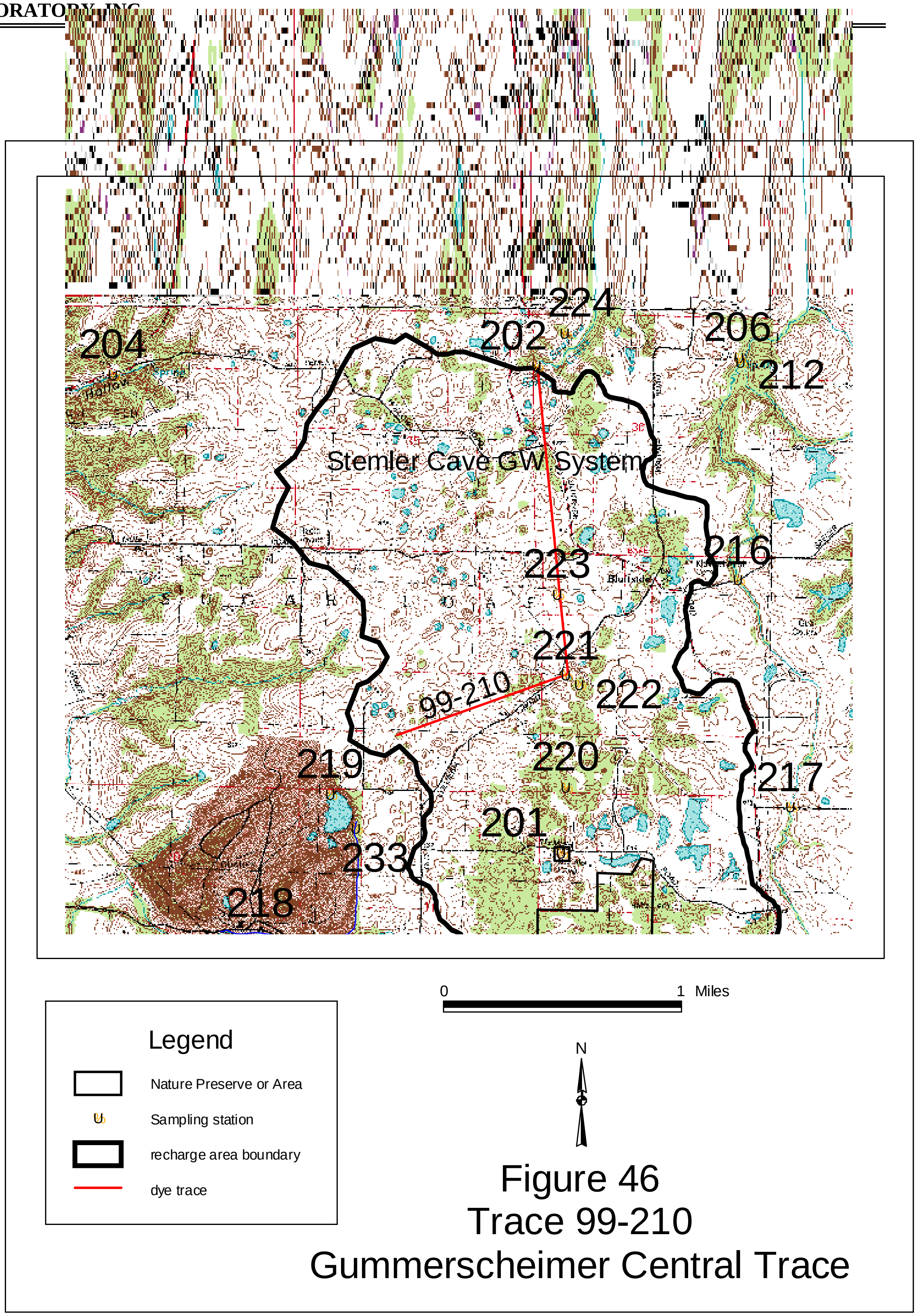


Figure 46
Trace 99-210
Gummerscheimer Central Trace

4.3.11 Trace 99-211: Rodemich Trace.

Approximately fifteen ounces of pyranine dye mixture containing approximately 77% dye and 23% diluent was introduced into a sinkhole at 1632 hours on January 22, 1999. A flow rate of about 15 gpm was sinking at the time of dye introduction. The introduction elevation is 635 feet msl and is in the SE ¼ SE ¼ of Section 13, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The trace is shown on Figure 47. The purpose of this trace was to help define the southeastern border of the Stemler Cave recharge area. This trace was conducted under moderate flow conditions.

The sampling stations for this trace were: 201, 202, 206, 211, 212, 216, and 217.

Data on the dye recovery locations for Trace 99-211 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 201. Stemler Cave

Sampling Period	Peak Emission Wavelength (nm)	Pyranine dye Concentration (ppb)
1/12 to 1/19/99	ND	ND
1/19 to 1/26/99	501.5	64.0
1/19 to 1/26/99 (dup.)	502.0	53.1
1/26/99 (water)	ND	ND
1/26 to 2/2/99	ND	ND

Station 202. Sparrow Spring

Sampling Period	Peak Emission Wavelength (nm)	Pyranine dye Concentration (ppb)
1/12 to 1/18/99	ND	ND
1/18 to 1/29/99	502.4	149
1/18 to 1/29/99 (dup.)	502.8	114
1/29/99 (water)	ND	ND
1/29 to 2/2/99	ND	ND

Pyranine dye was recovered from two sampling stations: Stemler Cave and Sparrow Spring. The dye first arrived at Stemler Cave within four days of the dye introduction. We estimate that the time of first dye arrival at the Stemler Cave sampling station was 2 days after dye introduction. The straight-line distance from the dye introduction point to the Stemler Cave sampling station is approximately 10,200 feet and the elevation loss is approximately 85 feet. The mean groundwater flow path gradient to Stemler Cave is approximately 44 feet per mile. The estimated mean groundwater velocity for the first arrival of dye at the Stemler Cave Nature Preserve was 5,100 feet per day.

The dye first arrived at Sparrow Spring within 7 days of dye introduction. We estimate that the time of first dye arrival at Sparrow Spring was 3 days after dye introduction. The flow path route from the dye introduction point to the Stemler Cave entrance and then to Sparrow Spring is approximately 21,000 feet, and the elevation loss is approximately 140 feet. The mean groundwater flow path gradient to from the dye introduction point to Sparrow Spring is approximately 35 feet per mile. The estimated mean groundwater velocity for the first arrival of dye at Sparrow Spring was 7,000 feet per day.

The dye concentrations at Sparrow Spring were approximately double the concentrations at Stemler Cave. This suggests that some of the dyed water may have bypassed the Stemler Cave sampling station en route to Sparrow Spring. In contrast, flow measurements at Stemler Cave (Taylor et al., in press) and at Sparrow Spring are very similar. These data suggest that little, if any, water from the Rodemich sink bypasses the Stemler Cave entrance.

The dye introduction point is a large sinkhole with a well-developed channel that carries an intermittent stream. This intermittent stream drains across and along State Route 158. Road runoff follows this flow path into the Stemler Cave groundwater system and has the potential to carry contaminants in the event of a spill. The Rodemich Trace demonstrates that the Illinois Route 158 corridor crosses the recharge area for the Stemler Cave Nature Preserve. The Illinois Department of Transportation is considering up-grading Route 158 from two lanes to four lanes and keeping it in the same corridor in the vicinity of the dye introduction site.

It is also important to note that the dye reached the cave quickly and that detectable concentrations persisted for only a short period. Dye is a surrogate for water-soluble contaminants. Comprehensive monitoring for pulses of contamination in Stemler Cave would require very frequent sampling.

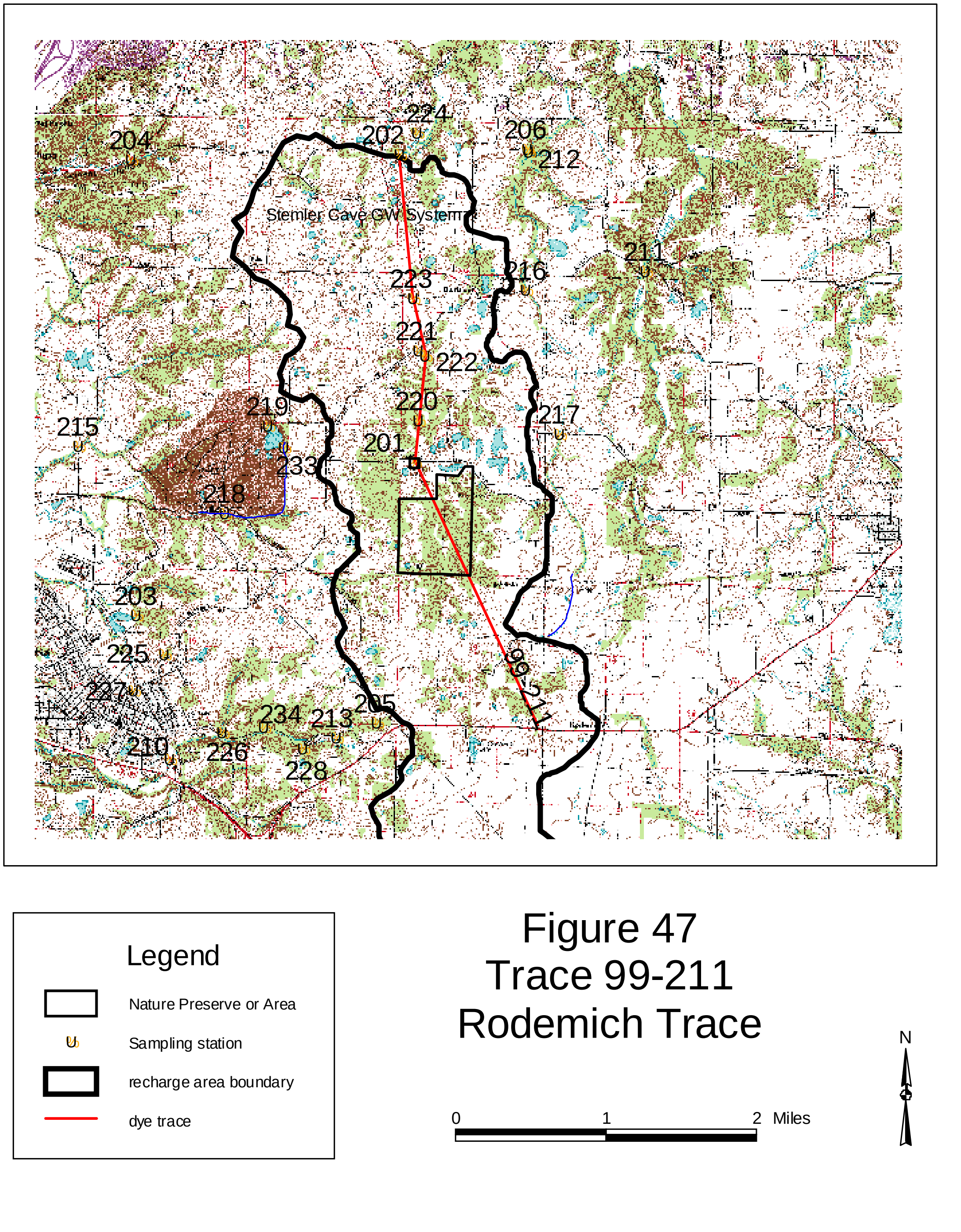


Figure 47
Trace 99-211
Rodemich Trace

4.3.12 Trace 99-212: Spring Valley Trace.

Two pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into the headwaters of Spring Valley at 1413 hours on February 11, 1999. Approximately 25 gpm of storm runoff was flowing in this surface stream at the time of dye introduction. The dye introduction elevation is approximately 685 feet msl and is near the section line in the SW ¼ NW ¼ of Section 18, T1S, R9W. The location is shown on the Columbia 7.5-minute quadrangle map. The purpose of this trace was to determine if Spring Valley contributes water to the Stemler Cave groundwater system or whether it is effectively an eastern boundary. The trace is shown on Figure 48. The trace was conducted under normal to slightly above normal flow rate conditions.

The sampling stations for this trace were: 201, 202, 206, 211, 212, 216, and 217.

Data on the dye recovery locations for Trace 99-212 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 212. Spring Valley Upstream of Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
1/28 to 2/2/99	ND	ND
2/2 to 2/16/99	538.7	234
2/16/99 (water)	532.6	0.833
2/16 to 2/23/99	538.5	33.2
2/23 to 3/3/99	538.2	7.24
3/3 to 3/23/99	538.3	4.74
3/23 to 4/16/99	536.3	2.45
3/23 to 4/16/99 (dup)	536.3	2.18
4/16 to 5/13/99	536.0	0.764
5/13 to 5/19/99	534.8	0.651
5/19 to 5/26/99	ND	ND
5/26 to 6/29/99	535.6	0.239
6/29 to 9/9/99	ND	ND

Station 216. Spring Valley at Saeger Road

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
1/28 to 2/2/99	ND	ND
2/2 to 2/16/99	538.8	341
2/16/99 (water)	531.7	1.18
2/16 to 2/23/99	538.6	58.3
2/23 to 3/3/99	538.2	18.0
3/3/ to 3/23/99	538.2	10.6
3/23 to 4/21/99	537.5	7.89

Station 217. Spring Valley at Kropp Road

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
1/28 to 2/2/99	ND	ND
2/2 to 2/16/99	538.6	165
2/16/99 (water)	531.9	1.78
2/16 to 2/23/99	538.6	44.7
2/23 to 3/3/99	538.2	6.54
3/3 to 3/23/99	538.2	6.25
3/23 to 4/21/99	537.9	7.57

Eosine dye from Trace 99-212 was recovered from three sampling stations in Spring Valley. The Spring Valley Trace demonstrates that the stream in Spring Valley is not contributing water to the Stemler Cave groundwater system. The topographic border of the Spring Valley basin is used as the eastern boundary of the Stemler recharge area

Station 216 is downstream of Station 217. The consistently lower eosine concentrations at Station 217 compared to Station 216 suggest that a significant component of Spring Valley's flow is bypassing Station 217.

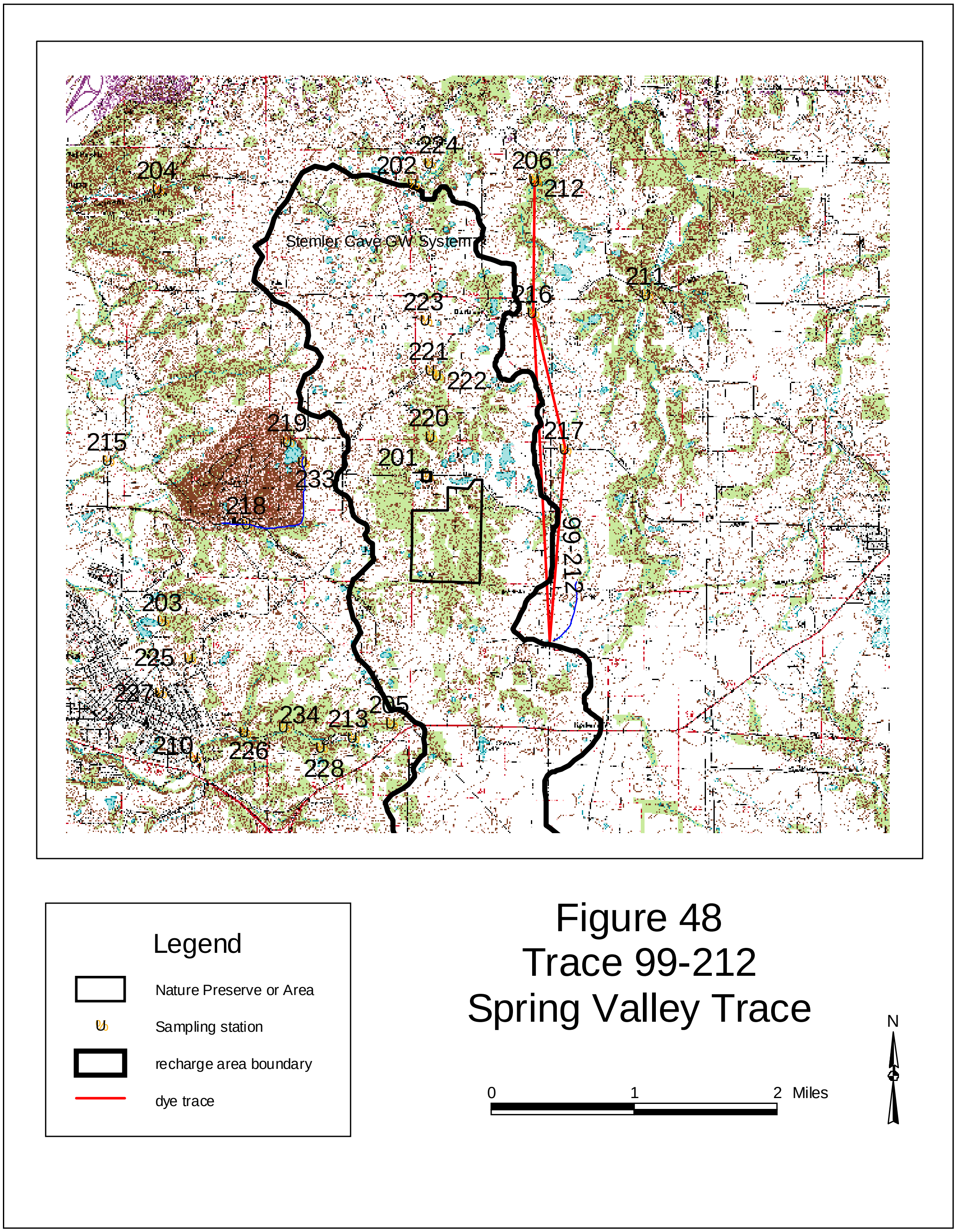


Figure 48
Trace 99-212
Spring Valley Trace

4.3.13 Trace 99-213: Stumpf Trace.

Approximately two and one-half pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole at 1614 hours on February 11, 1999. Approximately 8 gpm of storm runoff was entering the groundwater system at the time of dye introduction. The introduction elevation is approximately 620 feet msl and the dye introduction point is in the NE ¼ NE ¼ of Section 26, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The trace is shown on Figure 49. The purpose of this trace was to help define the southwestern boundary of the Stemler Cave recharge area. The trace was conducted under moderate flow conditions.

The sampling stations for this trace were: 201, 202, 203, 205, 210, 213, and 228.

Data on the dye recovery locations for Trace 99-213 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 210. Wilson Creek at Old Route 3

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
1/12 to 2/2/99	ND	ND
2/2 to 2/16/99	564.2	391
2/16 to 2/22/99	564.2	599
2/22 to 3/3/99	564.8	38.6
3/3 to 3/10/99	563.8	16.5
3/10 to 3/16/99	562.1	4.50
3/16 to 3/23/99	563.0	11.9
3/23 to 3/31/99	564.4	1.06
3/31 to 4/16/99	562.4	8.79
4/16 to 4/21/99	561.6 a	2.65
4/21 to 5/13/99	562.0	5.06
5/13 to 5/19/99	562.0	1.92
5/19 to 9/27/99	ND	ND
5/19 to 9/27/99 (dup.)	564.8	1.09
9/27/99 (water)	ND	ND
9/27 to 10/1/99	ND	ND

Station 213. Haney Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
12/21/98 to 2/2/99	ND	ND
2/2 to 2/13/99	563.6	15.4 [1]
2/13/99 (water)	570.9	252
2/13 to 2/16/99	562.7	8,480
2/16/99 (water)	570.6	33.1
2/16 to 2/22/99	564.5	2,100
2/22/99 (water)	570.6	2.27
2/22 to 3/3/99	565.3	110
3/3 to 3/10/99	563.7	29.0
3/10/99 (water)	ND	ND
3/10 to 3/16/99	561.9	6.36
3/16 to 3/23/99	562.6	17.4
3/23 to 3/31/99	564.4	2.99
3/31 to 4/7/99	561.8	8.56
4/7/99 (water)	572.4	0.140
4/7 to 4/16/99	561.0 a	5.62
4/16/99 (water)	ND	ND
4/16 to 4/21/99	562.2	8.01
4/21/99 (water)	ND	ND
4/21 to 5/5/99	562.8	7.23 [2]

[1] Packets not in the water when recovered. [2] Residual dye was detected through December, 1999. See Appendix A for details.

Dye from Trace 99-213 was recovered at two sampling stations: Haney Spring and Station 210, which is downstream from Haney Spring. Rhodamine WT dye was visible at Haney Spring (Station 213) and at Wilson Creek at Old Route 3 (Station 210) on February 13, 1999 before 1645 hours (C. Haney, personal communication, 1999). P. Moss also observed the dye and sampled the spring on that date.

The straight-line groundwater flow path distance from the dye introduction point to Haney Spring is approximately 6,460 feet and the elevation loss is approximately 30 feet. The mean groundwater flow gradient from the Stumpf sinkhole to Haney Spring is approximately 25 feet per mile. The first dye arrived at Haney Spring in two days. The mean groundwater velocity for the first dye arrival for this trace was approximately 3,230 feet per day.

Detectable concentrations of dye from the Stumpf Trace persisted at Haney Spring for eight months. Contaminants introduced into this spring system (for example, along Gilmore Lakes Road or Centreville Road) could similarly persist for a substantial period of time in

Haney Spring. Haney Spring is located about 15 feet from the Haney's house and historically has been used as a water source. Wilson Creek flows through Columbia and some of its suburban area; it is likely that children play in this creek at times.

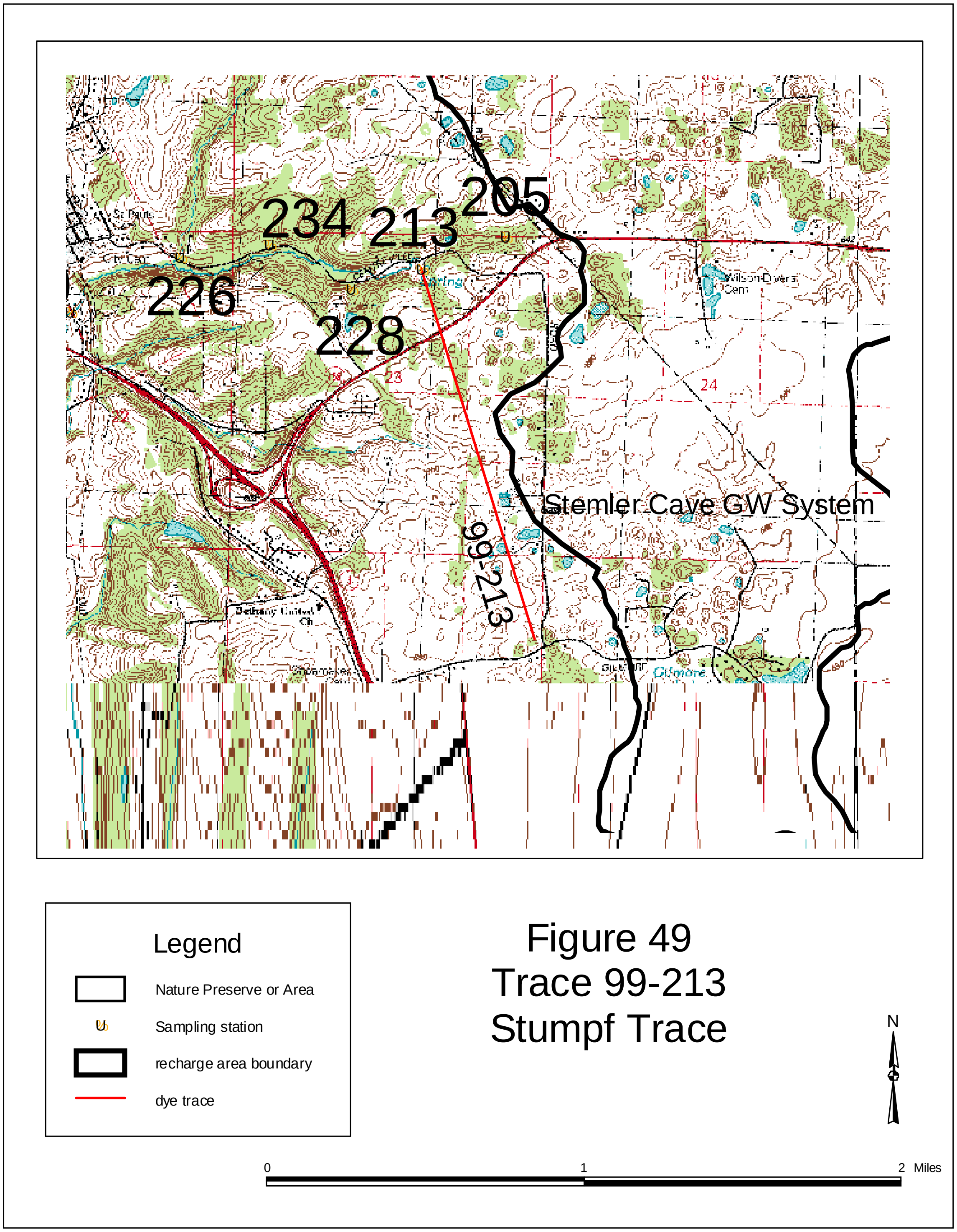


Figure 49
Trace 99-213
Stumpf Trace

4.3.14 Trace 99-214: Harvell Hill Trace.

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole at 1300 hours on February 27, 1999. Approximately 4 gpm of storm runoff was entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 605 feet msl and is in the SE ¼ NW ¼ of Section 35, T1N, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The trace is shown on Figure 2. The purpose of this trace was to help define the northwestern boundary of the Stemler recharge area. The trace is shown on Figure 50.

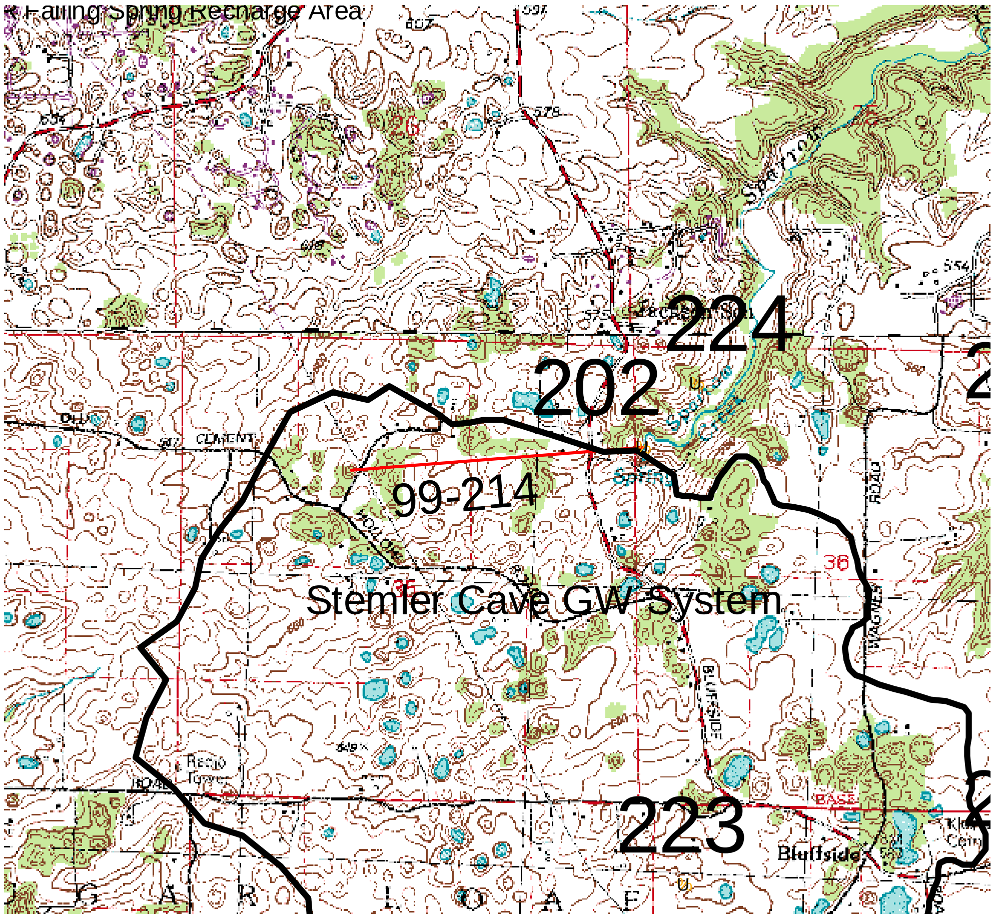
The sampling stations for this trace were: 202, 204, 207, 208, 214, 224, and 229.

Data on the dye recovery location for Trace 99-214 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 202. Sparrow Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
2/16 to 2/23/99	ND	ND
2/23 to 3/3/99	563.7	33.5
3/3/99 (water)	566.0 a	0.174
3/3 to 3/10/99	563.2	15.0
3/10/99 (water)	ND	ND
3/10 to 3/16/99	ND	ND
3/16/99 (water)	ND	ND

Dye from Trace 99-214 was recovered only from Sparrow Spring. The Harvell Hill Trace demonstrates that the area in the vicinity of the dye introduction point contributes water to the Stemler Cave groundwater system. The straight-line distance for this groundwater flow path is approximately 3,300 feet. The elevation loss is approximately 110 feet, and the mean gradient is 176 feet per mile. The dye first arrived in four days or less. We estimate the first dye arrival 3 days after dye introduction and that the mean groundwater velocity for the first dye arrival was 1,100 feet per day. This was the northernmost trace recovered at Sparrow Spring.



Legend

- Nature Preserve or Area
- Sampling station
- recharge area boundary
- dye trace

Figure 50
Trace 99-214
Harvell Hill Trace

N

0 1 Miles

4.3.15 Trace 99-215: Stemler Road Trace.

One pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole along Stemler Road at 0543 hours on March 23, 1999. Approximately one-half gpm was discharging from a culvert into the sinkhole. The dye was placed in a disposable plastic container and the culvert discharge was allowed to fall into the container. The dissolved dye then overflowed the container and entered the groundwater system. The elevation of the dye introduction point is approximately 640 feet msl and is in the SE ¼ NE ¼, Section 11, T1S, R10W. The purpose of this trace was to help define the western boundary of the Cave recharge area. The location is shown on the Columbia 7.5-minute quadrangle map. Trace 99-215 is shown on Figure 51.

The sampling stations for this trace were: 201, 202, 203, 204, 207, 208, 209, 215, 218, 219, 220, and 229.

Data on the dye recovery location for Trace 99-215 is listed below. All data are for charcoal samplers unless otherwise noted.

Station 202. Sparrow Spring

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B dye Concentration (ppb)
3/16 to 3/23/99	ND	ND
3/23/99 (water)	ND	ND
3/23 to 3/31/99	573.0	3.49
3/31/99 (water)	ND	ND
3/31 to 4/7/99	ND	ND
4/7/99 (water)	ND	ND

Station 220. Stemler Cave-2

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B dye Concentration (ppb)
11/20/98 to 1/26/99	ND	ND
1/26/99 to 6/8/00	574.1	22.4

Sulforhodamine B dye from Trace 99-215 was recovered from two sampling stations. These were Sparrow Spring, and Station 220 (Stemler Cave-2). Station 220 is located in Stemler Cave and is the first tributary stream entering the cave from the west side downstream of the Stemler Cave Nature Preserve.

The straight-line distance for this trace to Sparrow Spring is approximately 10,800 feet. The elevation loss is approximately 145 feet and the mean gradient is approximately 71 feet per mile. The dye was first recovered at Sparrow Spring within eight days of the dye introduction. The mean groundwater velocity for the first arrival of dye for this trace was at least 1,350 feet per day.

The activated carbon sampler in place at Station 220 detected appreciably more sulforhodamine B dye than did the sampler at Sparrow Spring. This is consistent with the fact that Station 220 was monitoring a small tributary to the main Stemler Cave stream. It is the main cave stream which discharges from Sparrow Spring. The dye tracing results demonstrate that probably all of the dye from Trace 99-215 entered the main stream in Stemler Cave through the tributary stream sampled by Station 220.

There was a slight increase in the concentration of sulforhodamine B dye recovered at Quarry Pond, Station 219, shortly after this trace was initiated (Appendix A). The increase at Station 219 does not satisfy the OUL criteria for a new dye recovery. However, the increase was similar to the concentration detected at Sparrow Spring. It is possible that the Stemler Road Trace sinkhole is part of a shared recharge area between the Quarry Pond and Sparrow Spring.

The Stemler Road Trace demonstrates that the dye introduction point contributes water to the Stemler Cave groundwater system, but not to any of the lands within the Nature Preserves.

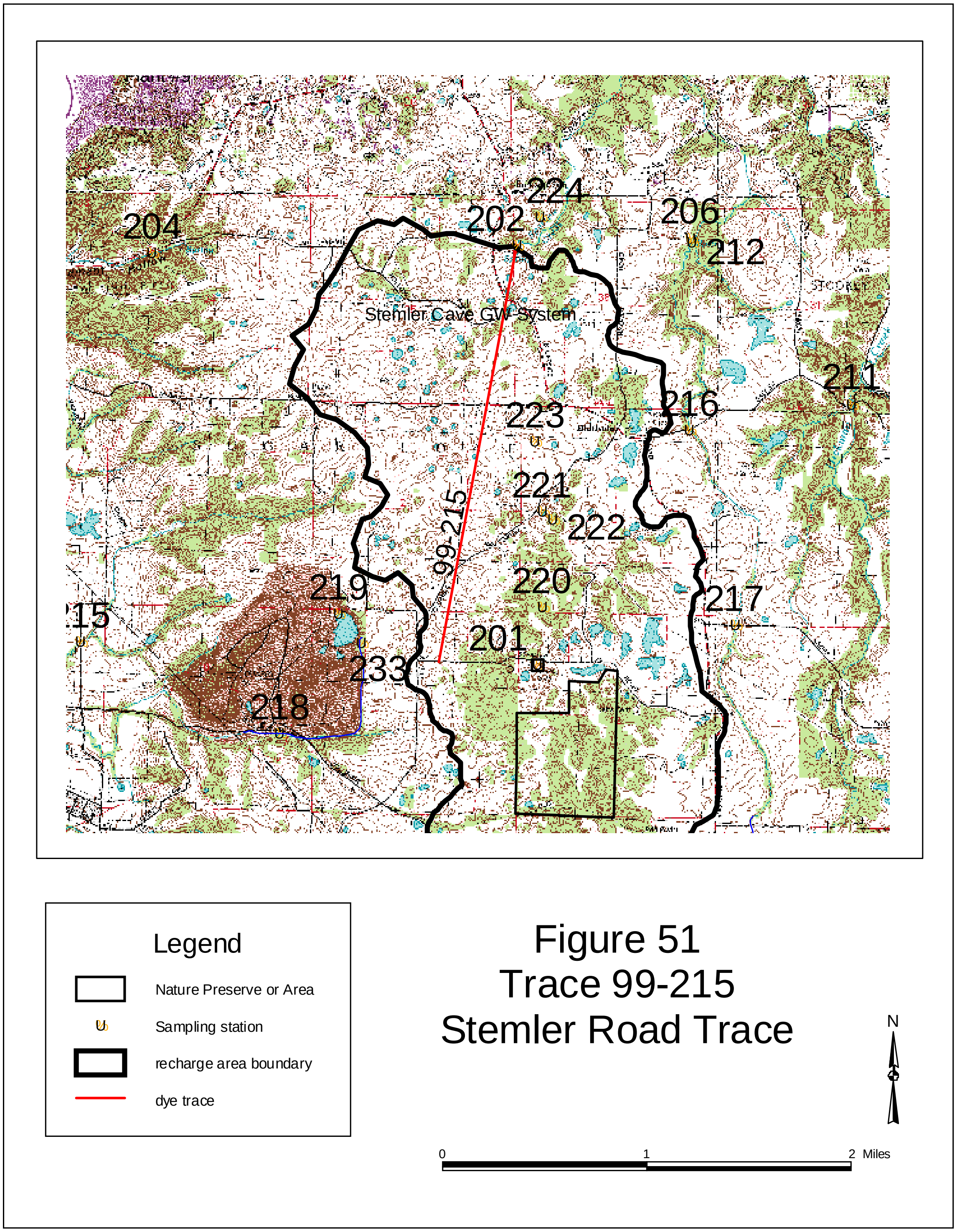


Figure 51
Trace 99-215
Stemler Road Trace

4.3.16 Trace 99-216: Jost Trace.

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1050 hours on April 3, 1999. There was approximately 15 gpm of storm runoff entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 635 feet msl and is in the NW ¼ NW ¼ of Section 24, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The purpose of this trace was to help define the boundary between the Stemler Cave recharge area and recharge areas for Haney Spring and County Line Spring. The trace is shown is on Figure 52.

The sampling stations for this trace were: 201, 202, 203, 205, 209, 210, 213, and 218.

Data on the dye recovery locations for Trace 99-216 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 201. Stemler Cave

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
3/23 to 3/31/99	ND	ND
3/31 to 4/7/99	537.8	16.1
3/31 to 4/7/99 (dup.)	537.7	9.55
4/7/99 (water)	ND	ND
4/7 to 4/16/99	534.5	1.68
4/16/99 (water)	ND	ND
4/16 to 4/21/99	536.4	0.790
4/21/99 (water)	ND	ND
4/21 to 5/5/99	ND	ND

Station 202. Sparrow Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
3/23 to 3/31/99	ND	ND
3/31 to 4/7/99	538.1	21.7
3/31 to 4/7/99 (dup.)	537.8	9.18
4/7/99 (water)	ND	ND
4/7 to 4/16/99	538.8	SH
4/16/99 (water)	ND	ND
4/16 to 4/21/99	ND	ND
4/21/99 (water)	ND	ND

Eosine dye was recovered from Trace 99-216 at Stemler Cave and at Sparrow Spring. The straight-line distance from the dye introduction point to Sparrow Spring is approximately 20,400 feet. The elevation loss is approximately 140 feet and the mean gradient is approximately 36 feet per mile. The first arrival of dye at Sparrow Spring occurred within four days of the introduction. Based on this, the mean groundwater velocity for the first arrival of dye at Sparrow Spring was at least 5,100 feet per day.

The Jost Trace demonstrates that the Jost Sink contributes water to the Stemler Cave groundwater system and specifically to the Stemler Cave Nature Preserve. The Jost Sink receives runoff from both State Route 158 and Centreville Road.

The dye introduction point is close to County Line Spring (Station 205) and to Haney Spring (Station 213). However, no dye from the Jost Trace was recovered at these springs.

Station 222 (Stemler Cave-4) and Station 223 (Stemler Cave-5) both sample the main stream in Stemler Cave between the cave entrance and Sparrow Spring. Charcoal packets in place at these stations for nearly a year and a half (from 1/26/99 to 6/8/2000) contained eosine dye derived from Traces 99-216 and 00-222.

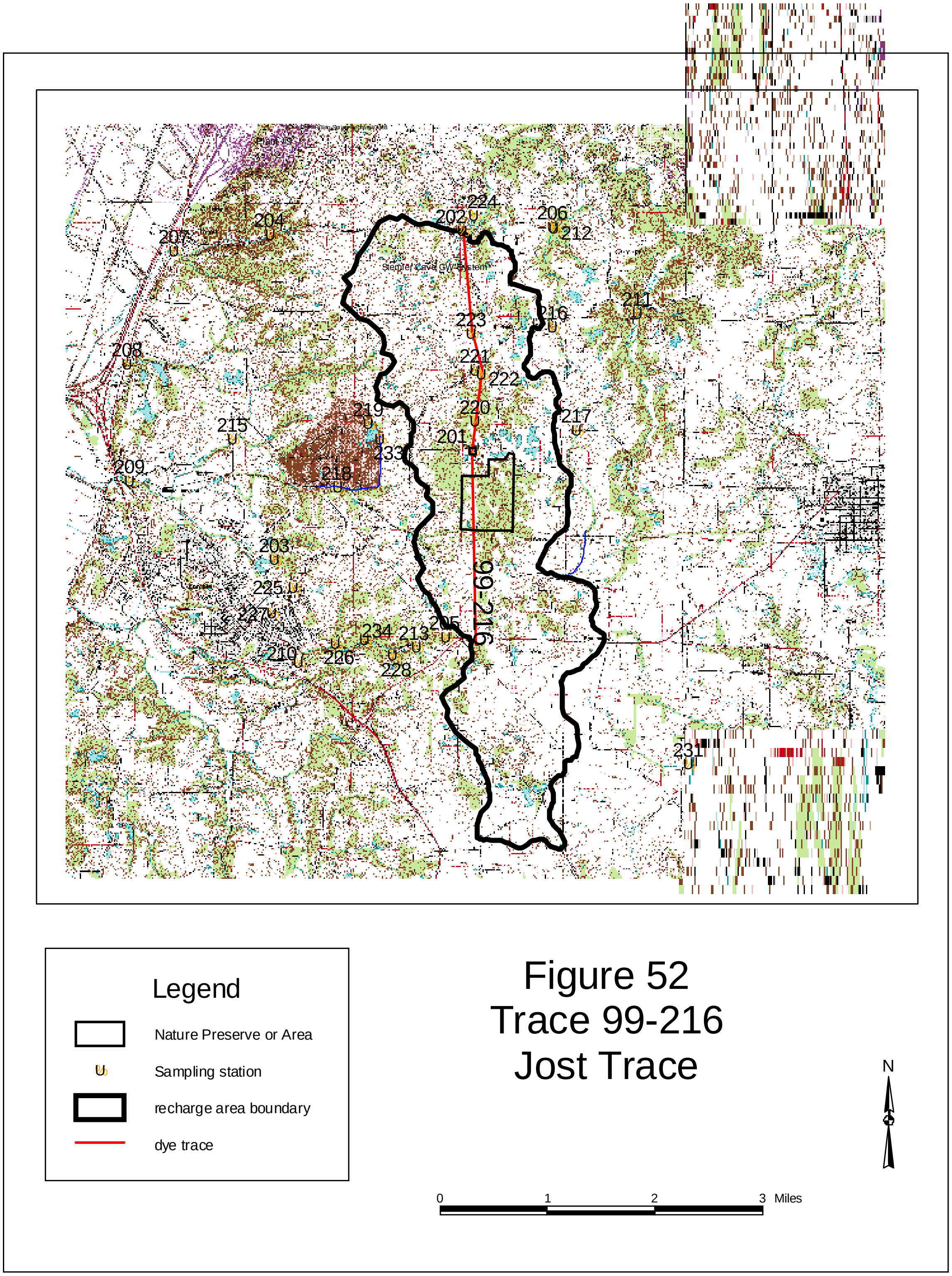


Figure 52
Trace 99-216
Jost Trace

4.3.17 Trace 99-217: Wagner Road Trace

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole at 1804 hours on May 12, 1999. There was approximately one-half gpm of storm runoff entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 555 feet msl and is in the SW ¼ SE ¼ of Section 36, T1N, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The purpose of this trace was to help define the recharge area boundary between Stemler Cave and Spring Valley Spring. The trace is shown on Figure 53. Flow conditions during the trace were moderately low.

The sampling stations for this trace were: 202, 206, 212, and 229.

Data on the dye recovery locations for Trace 99-217 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 202. Sparrow Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
5/5 to 5/13/99	ND	ND
5/13 to 5/19/99	564.1	491
5/19/99 (water)	570.0	0.105
5/19 to 5/26/99	563.5	7.47
5/19 to 5/26/99 (dup.)	564.0	3.74
5/26/99 (water)	ND	ND
5/26 to 6/4/99	561.6 a	1.55
5/26 to 6/4/99 (dup.)	561.5 a	3.40
6/4/99 (water)	ND	ND
6/4 to 6/10/99	564.8	1.17
6/10 to 6/29/99	ND	ND

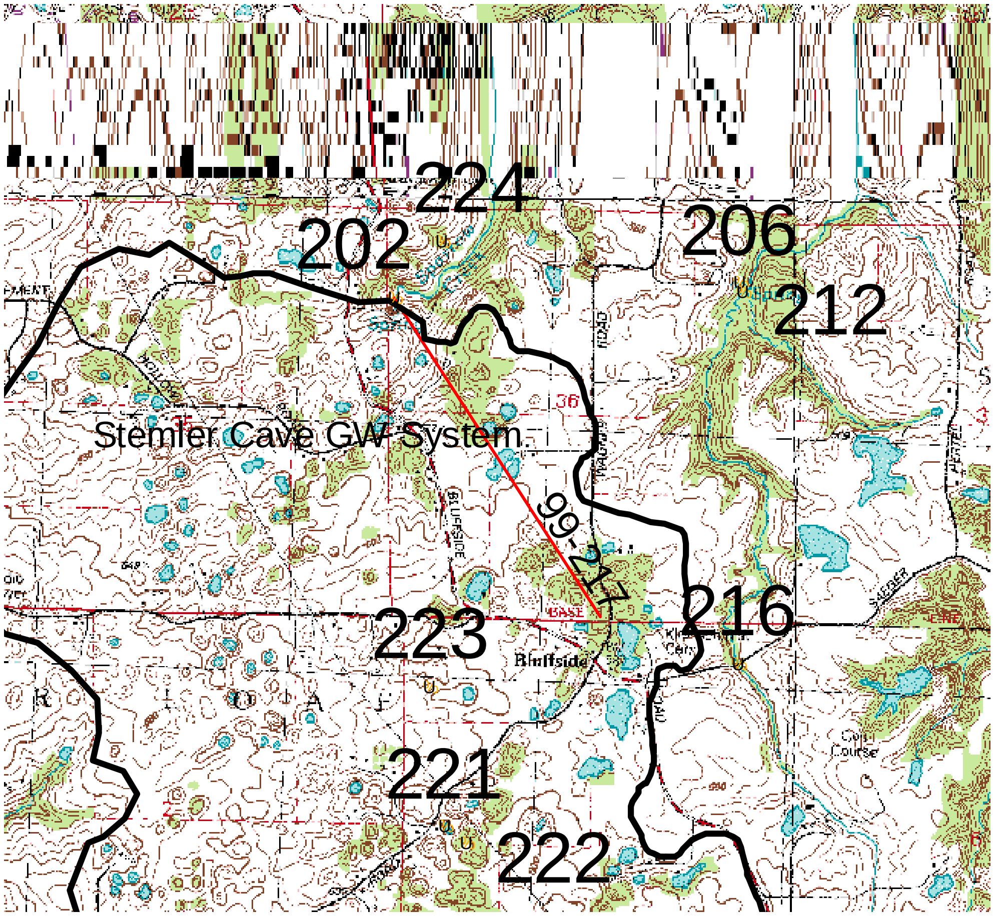
Station 229. Prairie du Pont Creek at Imbs Station Road

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
4/21 to 5/13/99	ND	ND
5/13 to 5/19/99	563.8	40.3
5/19 to 5/26/99	563.2	3.35
5/26 to 9/9/99	ND	ND

Rhodamine WT dye from Trace 99-217 was recovered from two stations: Sparrow Spring and from Station 229 (which is downstream from Sparrow Spring). Dye was first recovered at both sampling stations between one and seven days following dye introduction.

The straight-line distance from the Wagner Road Sink to Sparrow Spring is approximately 4,800 feet and the elevation loss is approximately 60 feet. The mean gradient is approximately 66 feet per mile. The mean velocity for this trace was at least 700 feet per day.

The Wagner Road Trace demonstrates that the area around the dye introduction point contributes water to the Stemler Cave groundwater system, but not through the Stemler Cave Nature Preserve. This trace helps define the northern and eastern boundary of the Stemler Cave recharge area.



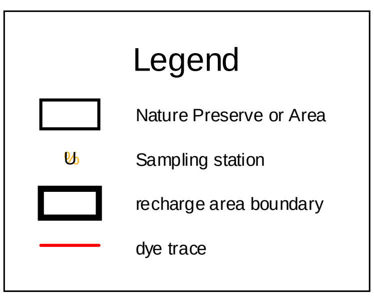
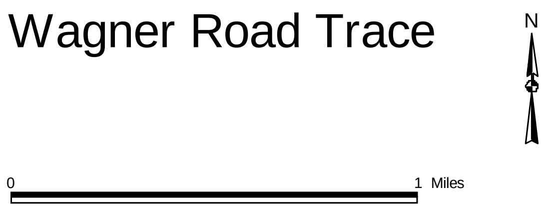


Figure 53
Trace 99-217
Wagner Road Trace



4.3.18 Trace 99-218: Bremser Road Trace.

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1845 hours on May 12, 1999. There was approximately one-half gpm of storm runoff entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 645 feet msl and is in the NW ¼ NW ¼ of Section 14, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The purpose of this trace was to help define the western boundary of the Stemler Cave recharge area. The trace is shown on Figure 54. The trace was conducted under relatively low flow conditions.

The sampling stations for this trace were: 201, 202, 209, 210, 218, 219, 229, and 233.

Data on the dye recovery locations for Trace 99-218 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 209. Palmer Creek at Ghent Road

Sampling period	Peak Emission Wavelength (nm)	Fluorescein dye concentration (ppb)
5/13/99 (water)	ND	ND
5/13 to 5/19/99	512.8	14.1
5/19 to 5/26/99	ND	ND

Station 218. Quarry Discharge

Sampling period	Peak Emission Wavelength (nm)	Fluorescein dye concentration (ppb)
4/21 to 5/13/99	ND	ND
5/13 to 5/19/99	513.8	1,830
5/19 to 5/26/99	512.5	28.7
5/26 to 6/4/99	NS	NS
6/4 to 6/10/99	512.6	15.6
6/10 to 6/29/99	512.7	26.9
6/29 to 7/21/99	512.9	24.5
6/29 to 7/21/99 (dup.)	512.6	32.9
7/21 to 9/9/99	512.8	10.7
9/9 to 9/15/99	511.9	3.51
9/15 to 9/20/99	512.3	5.46
9/20 to 9/27/99	510.6 a	1.12
9/27/99 (water)	504.0 a	0.009
9/27 to 10/1/99	512.2	4.52
9/27 to 10/1/99 (dup.)	510.8 s	0.655

Station 233. Plant No.1 Spring

Sampling period	Peak Emission Wavelength (nm)	Fluorescein dye concentration (ppb)
6/4/99 (water)	507.8	0.203
6/4/99 (water) (rep.)	507.5	0.227
6/4 to 6/10/99	513.4	174
6/10 to 6/29/99	513.1	102
6/29/99 (water)	507.9	0.125
6/29 to 7/21/99	513.0	91.6
7/21 to 8/11/99	513.0	69.5
8/11 to 8/23/99	512.7	27.0
8/23 to 9/9/99	512.9	48.2
9/9/99 (water)	507.3	0.026
9/9 to 9/15/99	512.5	32.9
9/15/99 (water)	506.0	0.020
9/15 to 9/20/99	512.4	24.8
9/20/99 (water)	505.6	0.018
9/20 to 9/27/99	512.6	29.3
9/27/99 (water)	506.0	0.020
9/27 to 10/1/99	512.8	19.2
10/1/99 (water)	505.6	0.017
10/1 to 10/27/99	513.0	24.8
10/27/99 (water)	507.5	0.019
10/27 to 11/4/99	512.8	17.0
11/4 to 12/13/99	513.4	25.0
12/13/99 to 1/4/00	513.4	23.6
1/4 to 1/11/00	513.3	12.4
1/11 to 2/3/00	513.8	15.6
2/3 to 2/17/00	513.4	14.9
2/3 to 2/17/00 (dup.)	513.0	21.7
2/17 to 2/25/00	513.1	22.7
2/25 to 3/3/00	513.1	12.2
3/3 to 3/9/00	513.2	9.99
3/9 to 3/27/00	512.6	9.32

Fluorescein dye from the Bremser Road Trace was recovered from three sampling stations: Plant No.1 Spring is upstream of Station 218 (Quarry Discharge) which in turn is upstream of Station 209. Plant No.1 Spring was not known to the OUL prior to the positive dye recovery at the Quarry Discharge sampling station. The creek was walked upstream until Plant No.1 Spring was encountered. Water was collected at that time and charcoal packets placed in the flow. The discharge flows around the rim of the Quarry Pond and may leak into the pond under some conditions.

The straight-line distance from the Bremser Road sink to Plant No.1 Spring is approximately 2,950 feet and the elevation difference is approximately 35 feet. The mean gradient is approximately 63 feet per mile. Dye first was recovered between one and seven days following dye introduction. It is our estimate that the first arrival of dye at the Plant No.1 Spring occurred 2 days after dye introduction. This would yield a mean groundwater velocity for the first dye arrival of 1,475 feet per day.

The Bremser Road Trace brought another spring to the OUL's attention, which enhances our understanding of the regional groundwater patterns. It also demonstrated that the area around the intersection of Bremser Road and Cherry Street lies outside of the Stemler Cave recharge area. Detectable dye concentrations from this trace persisted at Plant No.1 Spring for at least ten months.

Figure 54 shows a diagrammatic flow path from the Bremser Road sink to Plant No.1 Spring. However, it is unlikely that this representation correlates well with the actual flow path. Plant No.1 Spring discharges from a west-facing slope. The conduit feeding the spring probably curves significantly to the east to flow around the valley into which the spring discharges. The land overlying this implied curved flow path is part of the recharge area for Plant No.1 Spring.

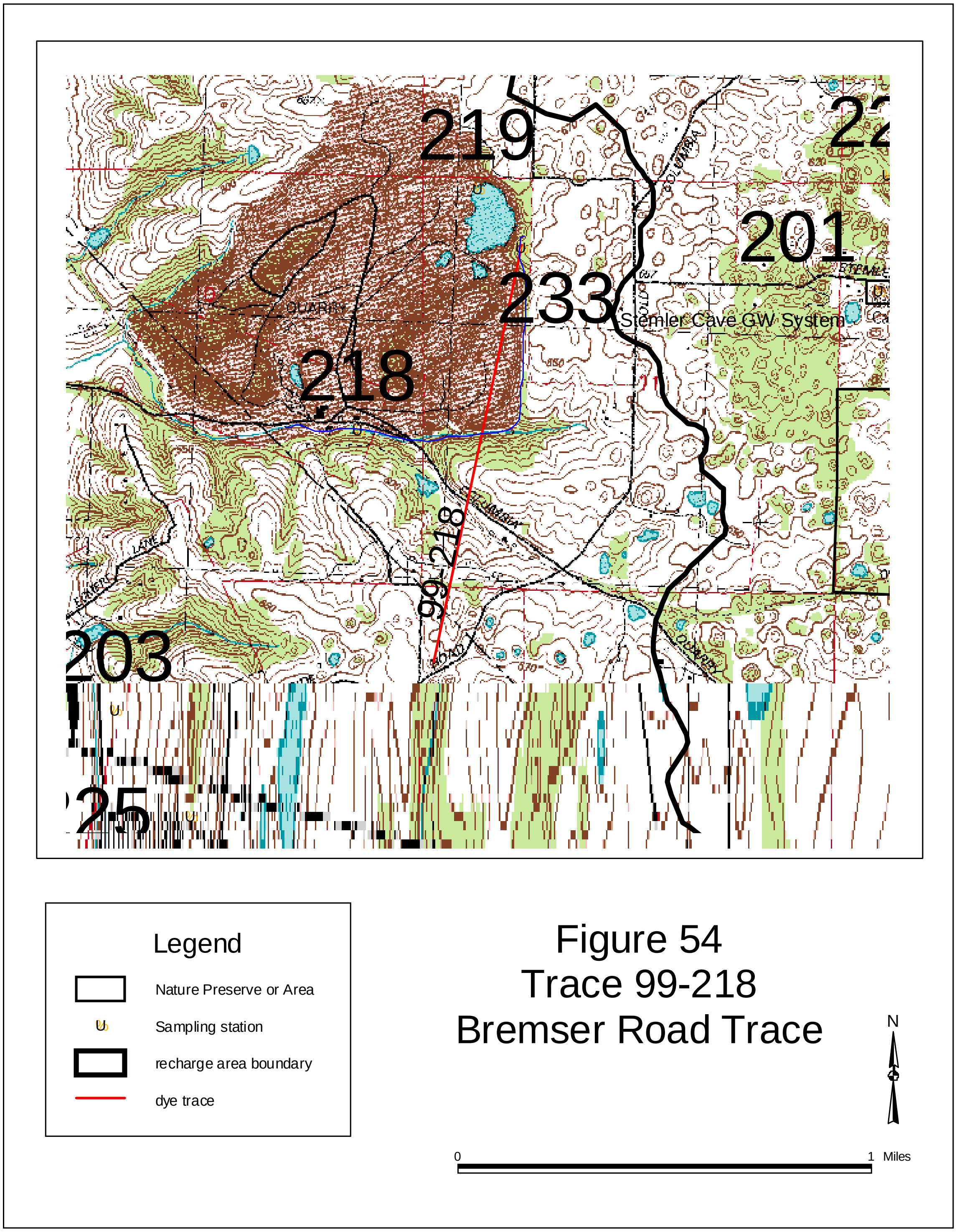


Figure 54
Trace 99-218
Bremser Road Trace

4.3.19 Trace 99-219: Prairie du Long Trace.

Two pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into Prairie du Long Creek at 1920 hours on June 23, 1999. There was about 70 gpm flow in the stream at the time of dye introduction. The elevation of the dye introduction point is approximately 615 feet msl and is in the SE ¼ NE ¼ of Section 36, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The purpose of this trace was to determine if Prairie du Long Creek contributed water to the Stemler Cave groundwater system. The trace is shown on Figure 55.

The sampling stations for this trace were: 210, 202, 205, 210, 212, 213, 229, and 232.

Data on the dye recovery location for Trace 99-219 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 232. Prairie du Long Creek at Bohleysville Road

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
5/27 to 6/4/99	ND	ND
5/27 to 6/4/99 (dup.)	ND	ND
6/4 to 6/29/99	536.0	0.377
6/29 to 7/21/99	536.8	1.69
6/29 to 7/21/99 (dup.)	537.2	1.56
7/24 to 8/11/99	ND	ND

Dye from the Prairie du Long Trace was only recovered downstream in the creek at Station 232. The trace demonstrates that Prairie du Long Creek does not contribute water to the Stemler Cave groundwater system. Taking into account the results of Traces 98-203, 99-213, and 99-219, it is our conclusion that the topographic watershed for Prairie du Long Creek forms the southern boundary of the Stemler Cave recharge area.

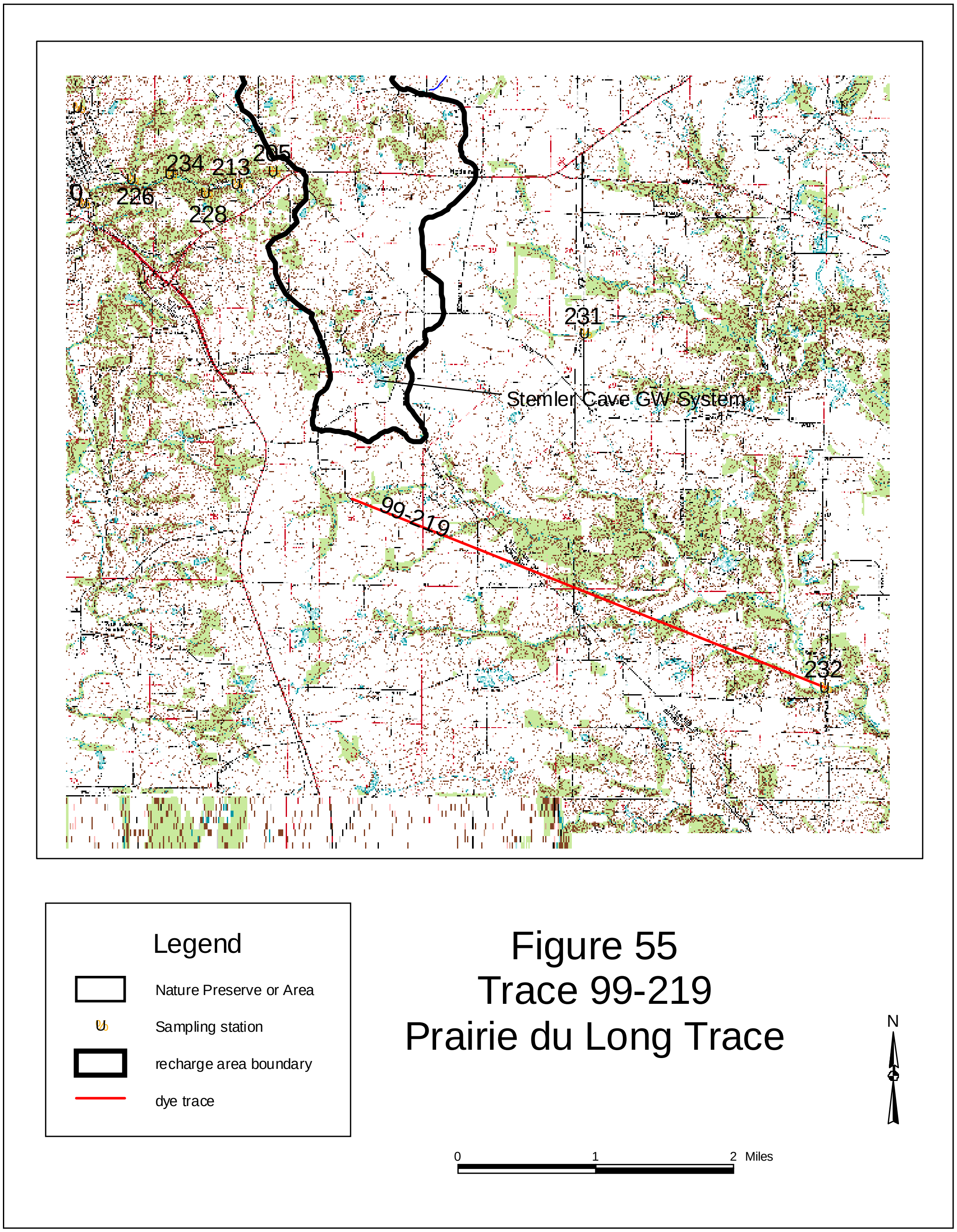


Figure 55
Trace 99-219
Prairie du Long Trace

4.3.20 Trace 99-220: Krause Trace.

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole at 1144 hours on September 12, 1999. Potable water was hauled to the sink in two loads of 1,600 gallons each. The water was discharged down the side of the sinkhole. The first load entered the sink from 1142 to 1150 hours, the second load from 1220 to 1230 hours. There was no ponding of water in the sinkhole. The elevation of the dye introduction point is approximately 625 feet msl and is in the NW ¼ NE ¼ of Section 14, T1S, R10W. The location is shown on the Columbia 7.5-minute quadrangle map. The purpose of this trace was to help define the recharge between the Stemler Cave recharge area and the recharge area for Plant No.1 Spring. The trace is shown on Figure 56.

The sampling stations for this trace were: 201, 202, 203, 205, 209, 210, 213, 218, 229, 233, and 234.

Data on the dye recovery locations for Trace 99-220 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 201. Stemler Cave

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
9/15 to 9/20/99	ND	ND
9/20 to 9/27/99	564.6	607
9/27/99 (water)	570.3	11.7
9/27 to 10/1/99	563.8	63.4
10/1/99 (water)	570.3	2.84
10/1 to 10/27/99	563.9	60.1
10/27/99 (water)	569.6	0.024
10/27 to 11/4/99	562.7	27.7
11/4/99 (water)	570.4	0.028
11/4 to 12/13/99	562.4	6.11
12/13/99 (water)	ND	ND
12/13/99 to 1/4/00	563.6	1.38
1/4 to 1/11/00	562.0	1.25
1/11 to 2/3/00	ND	ND

Station 202. Sparrow Spring

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
9/27 to 10/1/99	ND	ND
10/1/99 (water)	ND	ND
10/1 to 10/27/99	564.5	248
10/27/99 (water)	569.6	0.050
10/27 to 11/4/99	562.2	5.38
11/4/99 (water)	ND	ND
11/4 to 12/13/99	562.0	3.38
12/13/99 (water)	ND	ND
12/13/99 to 1/4/00	ND	ND
1/4 to 1/11/00	562.4	0.775
1/11 to 2/3/00	562.8	0.696
2/3 to 2/17/00	ND	ND

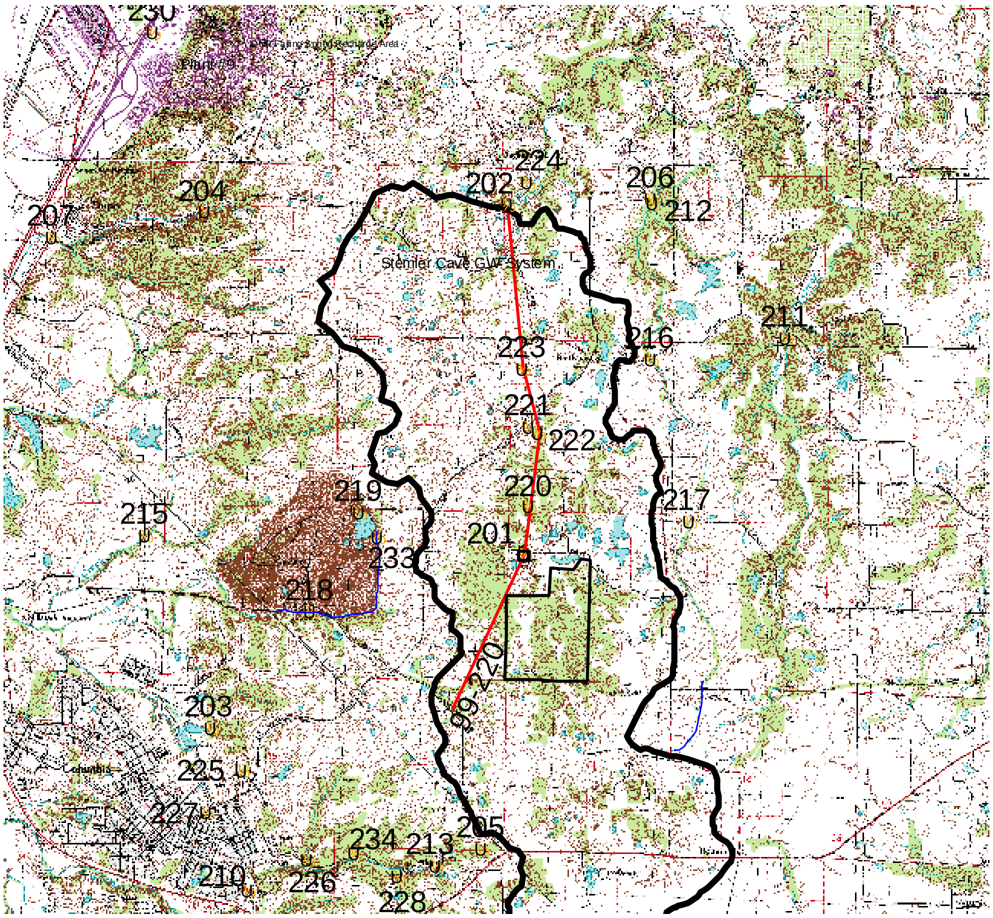
Station 229. Prairie du Pont Creek at Imbs Station Road

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT dye Concentration (ppb)
9/20 to 9/27/99	ND	ND
9/27 to 11/4/99	563.6	6.94
11/4 to 12/13/99	568.7	2.84
12/13/99 to 1/4/00	ND	ND
1/4 to 3/3/00	568.8	2.19

Rhodamine WT dye was recovered from three sampling stations; Stemler Cave, Sparrow Spring, and Prairie du Pont Creek at Imbs Station Road. The stations are listed from upstream to downstream; that is each one derives all its dye from the previous station. This trace demonstrates that the Krause sink and the area along part of Quarry Road drain to the Stemler Cave Nature Preserve and discharges from Sparrow Spring.

The straight-line distance from the Krause sink to the Stemler Cave entrance is approximately 5,200 feet. The elevation loss is approximately 75 feet which represents a mean gradient of about 75 feet per mile. This trace was conducted under very low flow conditions. The dye first arrived at the Stemler Cave entrance between 8 and 15 days after dye introduction. We estimate that the first dye arrival was 14 days after dye introduction, which would represent a mean groundwater velocity for the first dye arrival of about 370 feet per day. This represents a mean groundwater velocity to the Stemler Cave entrance of between 345 and 650 feet per day approximately 372 feet per day.

The dye took at least an additional 4 days to reach Sparrow Spring. This is much slower than previous traces that tended to travel this route in about one day. This indicates that velocity under low flow conditions are appreciably slower than under higher flow conditions.



Legend

- Nature Preserve or Area
- Sampling station
- recharge area boundary
- dye trace

Figure 56
Trace 99-220
Krause Trace

N

0 1 2 Miles

4.3.21 Trace 99-221: Hardin Trace.

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1319 hours on September 12, 1999. Potable water was hauled to the sink in two loads of 1600 gallons each. The water was discharged down the side of the sinkhole. The first load entered the sink from 1317 to 1327 hours, the second load from 1410 to 1420 hours. There was no ponding of water in the sinkhole. The elevation of the dye introduction point is approximately 570 feet msl and is in the NE ¼ SW ¼ of Section 26, T1N, R10W. The location is shown on the Cahokia 7.5-minute quadrangle map. The purpose of this trace was to help define the between the Stemler Cave recharge area and groundwater systems to the north and west. The trace is shown on Figure 57.

The sampling stations for this trace were: 202, 204, 207, 214, 229, and 230.

Data on the dye recovery location for Trace 99-221 are listed below. All data are for charcoal samplers unless otherwise noted.

Station 214. Falling Springs

Sampling period	Peak Emission Wavelength (nm)	Fluorescein dye concentration (ppb)
9/9 to 9/15/99	ND	ND
9/15 to 9/20/99	513.7	15,900
9/20/99 (water)	507.6	16.8
9/20 to 9/27/99	513.8	8,780
9/27/99 (water)	508.4	5.41
9/27 to 10/1/99	514.2	1,500
10/1/99 (water)	507.7	3.67
10/1 to 10/27/99	513.8	1,890
10/27/99 (water)	507.5	0.652
10/27 to 11/4/99	514.1	323
11/4/99 (water)	507.7	0.246
11/4 to 12/13/99	514.3	90.6
12/13/99 (water)	507.4	0.150
12/13/99 to 1/4/00	513.5	22.9
1/4/00 (water)	ND	ND
1/4 to 1/11/00	513.3	12.5
1/11 to 2/3/00	513.6	9.57
2/3 to 2/17/00	513.8	8.40
2/17 to 2/25/00	511.2	1.90
2/25 to 3/3/00	511.6	2.29
3/3 to 3/9/00	512.8	3.83
3/9 to 3/27/00	511.9	5.48

Fluorescein dye from Trace 99-221 was recovered only from Falling Springs. The straight-line distance for this trace is approximately 8,500 feet. The elevation loss is approximately 70 feet with an mean gradient of 43 feet per mile. Dye was first recovered between three and eight days following dye introduction. We estimate that the first dye arrival at Falling Spring was about 5 days after dye introduction. As a result, the mean groundwater velocity for the first dye arrival was about 1,700 feet per day.

The Hardin Trace demonstrates that this dye introduction point is north of the Stemler Cave recharge area. This is the only trace in this study to be recovered at Falling Springs. Falling Springs is probably the most well known of the Southwest Illinois springs and photos of it abound in the literature of the sinkhole plain. Falling Springs is an Illinois Natural Area Inventory site.

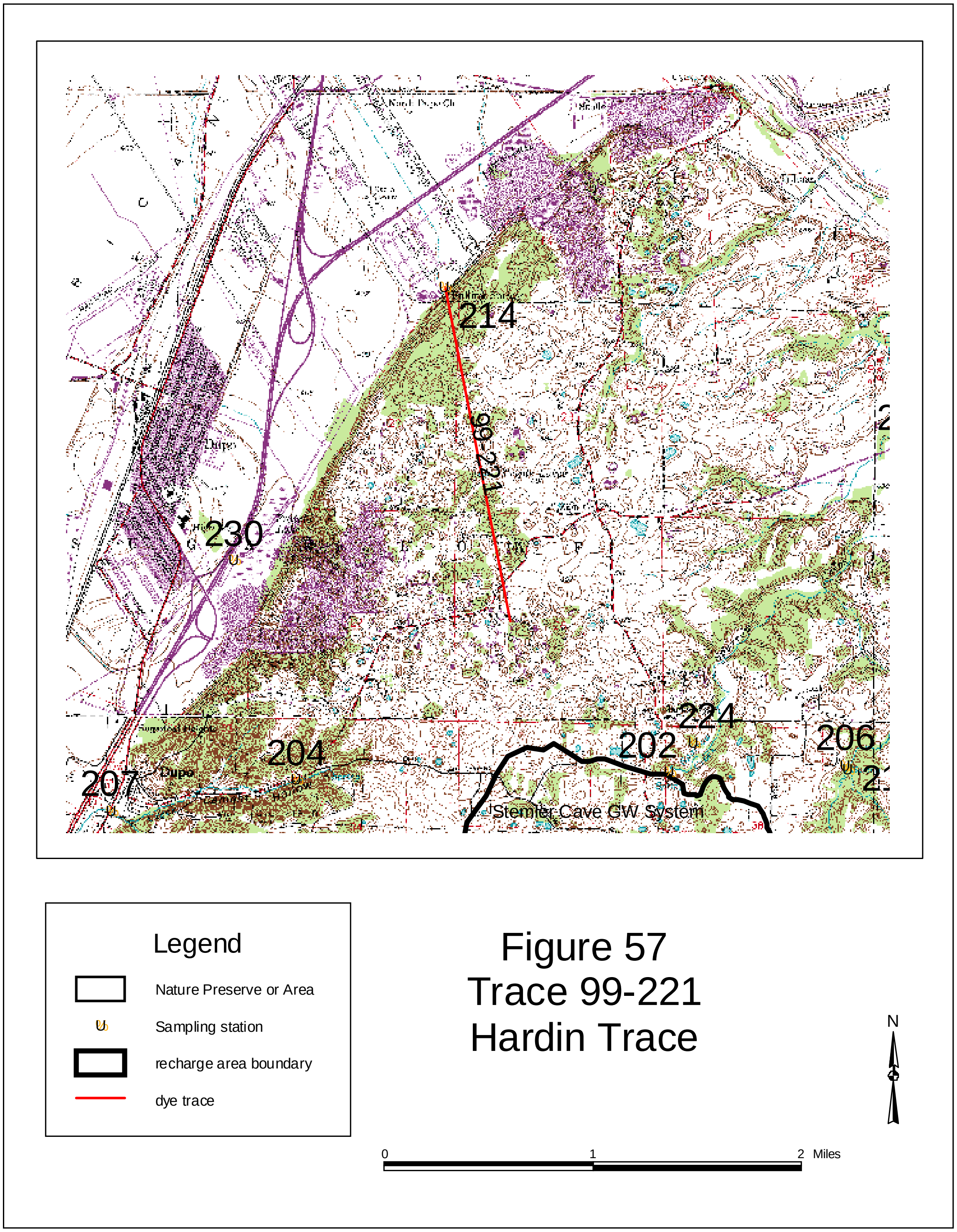


Figure 57
Trace 99-221
Hardin Trace

4.3.22 Trace 00-222: Centreville Road Trace.

One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole at 1048 hours on February 18, 2000. Approximately 3 gpm of storm runoff was entering the groundwater system at the time of dye introduction. The elevation of the dye introduction point is approximately 660 feet msl and is in the SE ¼ NE ¼, of Section 23, T1S, R10W. The location is shown on the Cahokia 7.5-minute quadrangle map. The purpose of this trace was to help recharge area boundaries between the Stemler Cave recharge area and the Haney Spring and County Line Spring recharge areas. The trace is shown on Figure 58. The trace was conducted under low flow conditions.

The sampling stations for this trace were: 201, 202, 203, 205, 210, 213, 229, and 233.

Data on the dye recovery locations for Trace 00-222 are shown below. All data are for charcoal samplers unless otherwise noted.

Station 201. Stemler Cave

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
2/17 to 2/25/00	ND	ND
2/25 to 3/3/00	539.0	869
3/3/00 (water)	532.7	6.45
3/3 to 3/9/00	539.0	224
3/9/00 (water)	532.6	2.06
3/9 to 3/27/00	538.6	94.8
3/27/00 (water)	530.6	0.352
3/9 to 6/8/00	538.6	42.5

Station 202. Sparrow Spring

Sampling Period	Peak Emission Wavelength (nm)	Eosine dye Concentration (ppb)
2/17 to 2/25/00	ND	ND
2/25 to 3/3/00	535.0	1.03
3/3/00 (water)	532.2	1.95
3/3 to 3/9/00	539.3	413
3/9/00 (water)	533.1	6.90
3/9 to 3/27/00	538.8	226

Eosine dye from the Centreville Road Trace was recovered Stemler Cave and Sparrow Spring. The straight-line distance from the dye introduction point to the Stemler Cave entrance is approximately 11,800 feet and the elevation loss is approximately 110 feet. The mean gradient is approximately 49 feet per mile. Comparison of the concentration of dye in water and the concentration of dye in the charcoal sampler suggests that the dye first arrived at Stemler Cave a little more than one day before the samplers were replaced on March 3, 2000. This results in the first arrival of dye about 12 days following dye introduction. The average velocity for this segment of the trace is approximately 1,000 feet per day under these very low flow conditions. Dye first arrived at Sparrow Spring a few minutes before the sample on March 3, 2000 was collected. This is based on the nearly identical values for dye in the charcoal and water samples. The dye took a little more than one day to travel from the Stemler Cave entrance to Sparrow Spring under these flow conditions. The velocity for the latter segment of the trace is approximately 10,000 feet per day.

Station 222 (Stemler Cave-4) and Station 223 (Stemler Cave-5) both sample the main stream in Stemler Cave between the cave entrance and Sparrow Spring. Charcoal packets in place at these stations for nearly a year and a half (from 1/26/99 to 6/8/2000) contained eosine dye derived from Traces 99-216 and 00-222.

This trace demonstrates that the area along Centreville Road and adjacent to the dye introduction point is part of the recharge area for the Stemler Cave Nature Preserve. The proximity of the Centreville Road Trace to Haney Spring and County Line Spring indicates that the dye introduction point is close to the Stemler Cave recharge area boundary.

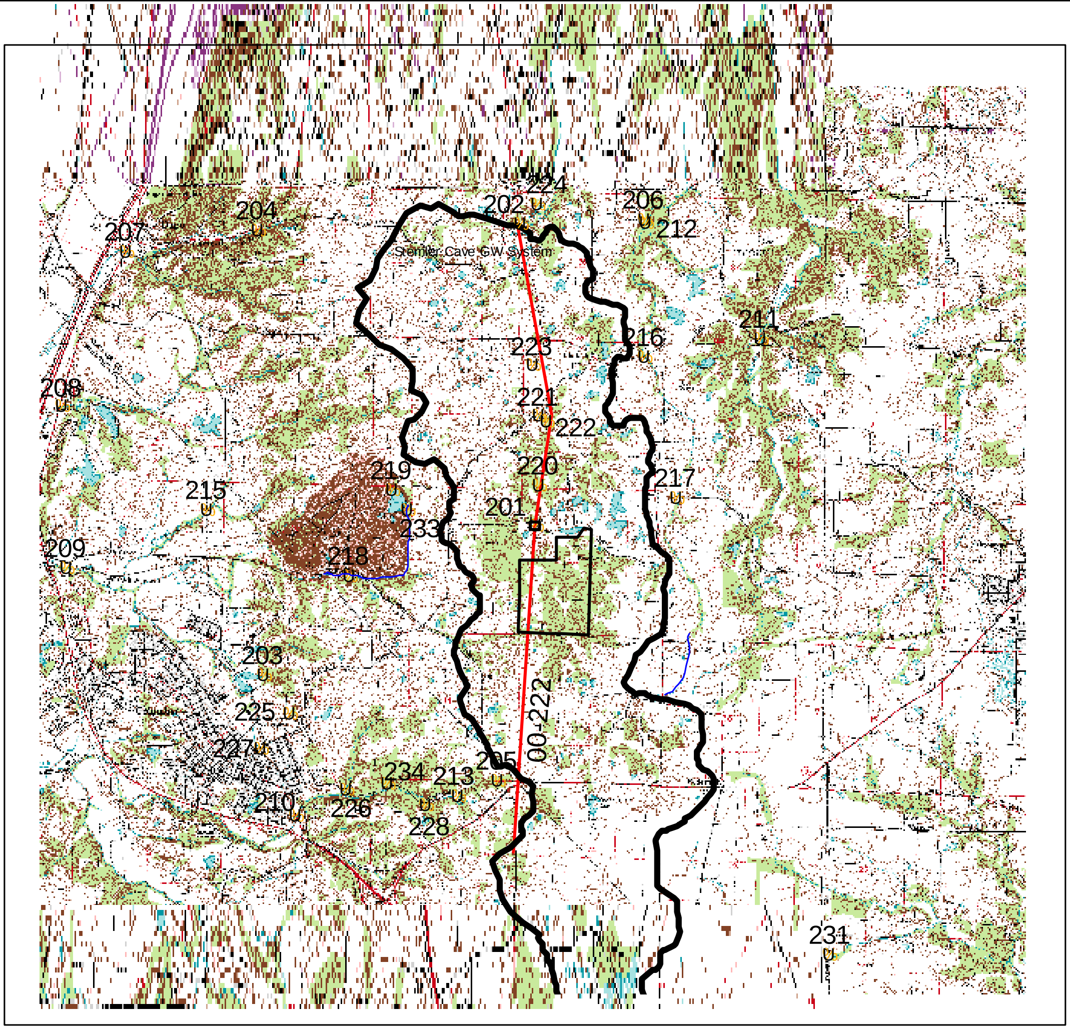


Figure 58
Trace 00-222
Centerville Road Trace

Table 5. Summary of selected CSA dye trace lengths, gradients, and estimated mean velocities for the first arrival of tracer dyes.

From	To	Distance (feet)	Elevation loss (feet)	Mean Gradient (feet/mile)	Est. Mean Velocity (feet/day)	Trace number associated w/velocity
Stemler Cave						
Cossil Fast Pit	Stemler Cave Entrance	3,100	35	60	280	98-201
Stemler Cave Entrance	Sparrow Spring	10,800	55	27	10,800	98-201
Stemler Cave Entrance	Sparrow Spring	10,800	55	27	2,700	99-220
Stemler Cave Entrance	Sparrow Spring	10,800	55	27	10,000	00-222
Charles Sink	Stemler Cave Entrance	8,300	85	54	1,660	98-202
Gilmore Lakes Overflow	Stemler Cave Entrance	16,500	80	26	8,250	98-203
Gilmore Lakes Overflow	Sparrow Spring	27,300	135	26	9,100	98-203
Rodemich Sink	Stemler Cave Entrance	10,200	85	44	2,525	99-211
Rodemich Sink	Sparrow Spring	21,000	140	35	7,000	99-211
Gummerscheimer NE	Sparrow Spring	7,165	150	110	1,790	98-204
Gummerscheimer House Sink	Sparrow Spring	7,750	45	31	2,580	99-209
Gummerscheimer Central Sink	Sparrow Spring	10,700	65	32	5,350	99-210
Harvell Hill Sink	Sparrow Spring	3,300	110	176	1,100	99-214
Stemler Road	Sparrow Spring	10,800	145	71	1,350	99-215
Jost Sinkhole	Sparrow Spring	20,400	140	36	5,100	99-216
Jost Sinkhole	Stemler Cave Entrance	9,600	85	47	7,000	99-216
Wagner Road Sink	Sparrow Spring	4,800	60	66	700	99-217
Krause Sink	Stemler Cave entrance	5,200	75	76	370	99-220
Centreville Road Sink	Stemler Cave Entrance	11,800	110	49	1,000	00-222
Ritter Spring						
Cemetery Sink	Ritter Spring	1,700	60	186	570	98-206
Pioneer Ridge	Ritter Spring	2,750	80	154	920	98-207
Breidecker Sink	Ritter Spring	3,400	50	78	380	99-208
Misc. CSA Traces						
Gummerscheimer South Sink	Columbia Quarry Pond	1,100	147	706	>325	98-205
Stumpf Sink	Haney Spring	6,460	30	25	>3,100	99-213
Bremser Road sink	Plant #1 Spring	2,950	35	63	1,475	99-218
Hardin sink	Falling Springs	8,500	70	43	2,125	99-221

4.4 Recharge Area Delineations

4.4.1 Introduction

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.

There are various Illinois State Nature Preserves and Natural Areas which overlie caves which we have studied in this investigation. To assist in the management of these areas we have routinely delineated the portions of the cave recharge areas which contribute water to individual Nature Preserves or Natural Areas.

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)). This seems particularly appropriate in the case of the four caves since they all contain significant aquatic cave fauna including the Illinois Cave Amphipod. This aquatic troglobitic species has recently been Federally listed as an endangered species.

The OUL has provided two delineations for each of the four studied caves. One delineation is the recharge area for that portion of the cave system which contributes water to a designated Nature Preserves or Natural Area. This delineation will be useful for developing management strategies for the state-managed lands. The second delineation is for the entire cave system, including the spring or springs which ultimately discharge water from the cave system of concern. This type of system delineation has been developed for each of the four biologically significant cave systems identified in the contract as well as for the Lantz Spring and Collier Spring groundwater systems. 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.

Delineation of the Lantz Spring and Collier Spring recharge areas was not required in the contracts. However, enough traces were recovered at these springs incidental to delineation of the adjacent groundwater systems to delineate their recharge areas. We have included these delineations for completeness and potential usefulness. Little is currently known about the cave systems that undoubtedly exist and convey water to these springs. There is further discussion of these additional delineations in Sections 4.4.6 and 4.4.7.

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 which follows the longer flow path.

In many 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.

4.4.2 Fogelpole Cave

Fogelpole Cave currently has approximately 15 miles of mapped passage (Hauck and Addison, 2000) and mapping continues to produce new discoveries in this cave (see Sections 4.2.30 and 4.2.31). The main entrance is on the IDNR-owned Fogelpole Cave Nature Preserve. There are four major streams in Fogelpole Cave; they are located in the following passages: the Northwest Passage, Lemonade Passage, Zebra Passage, and a newly discovered stream in the Sunfish Passage. The streams in the Northwest Passage and the Lemonade Passage join at the Junction Room. The Junction Room is within the Nature Preserve, but the Zebra Passage lies outside of the Preserve. In base flow conditions, over 95% of the water in the Fogelpole groundwater system flows through the Nature Preserve. We believe that the stream in the Sunfish Passage flows to Collier Spring and was the flow route involved in the Brinner Trace (99-127). This stream carries little water at base flow, but is important because of its connection to both groundwater systems. At low flow, Sunfish Passage drains to Collier Spring, but it can overflow into Zebra Passage and discharge at Tierce Spring. Figure 59 shows the flow paths of the Fogelpole Cave streams schematically.

The hydrology of Fogelpole Cave is much more complex than that of the other caves in this study. The main stream in Fogelpole (formed by the confluence of the streams in the Northwest Passage and Lemonade Passage) and the stream in Zebra Passage flow to a pair of springs. One of these is Tierce Spring, an underflow spring, while the physically larger

Indian Hole is an overflow spring. Indian Hole has no flow at base flow conditions. During a storm event on May 7, 2000, P. Moss arrived at the springs shortly after they responded to a storm event. Indian Hole had started to flow but was much less turbid than the water discharging from Tierce Spring. This difference in turbidity is presumably related to the amount of stored water in each conduit that had to be displaced by the floodwaters.

Tierce Spring is proximate to Indian Hole and initial appearances would suggest that it receives water from the Indian Hole pool. However, this is not the case. Dye introduced into the Indian Hole pool under base flow conditions was not recovered from Tierce Spring (Trace 98-104). Tierce Spring has captured the underflow component of the Fogelpole groundwater system at some distance upstream of Indian Hole.

In contrast to all the other known Fogelpole Cave streams, the Sunfish Passage drains to Collier Spring under base flow conditions. It should be noted that no water that flows through the Fogelpole Cave Nature Preserve discharges to Collier Spring.

The recharge area for the Fogelpole Cave Nature Preserve is shown on Map 1 and encompasses approximately 5.13 square miles. This is the recharge area that yields water which appears to qualify as Class III groundwater. The recharge area for the complete Fogelpole Cave groundwater system is also shown on Map 1 and encompasses 7.14 square miles. Approximately 72% of the recharge area for Fogelpole Cave is tributary to the Nature Preserve, yet this area contributes about 95% of the volume of water which discharges from the cave system. The reason for the difference in percentages is that recharge areas for Fogelpole Cave which do not contribute water that passes through the Nature Preserve yield much of their water to surface runoff rather than to groundwater recharge.

The recharge area boundaries for the Fogelpole Cave groundwater system abut parts of the recharge areas for Collier Spring, Illinois Caverns, Krueger Cave, and Lantz Spring. There are some recharge areas which are shared with both Illinois Caverns and Collier Spring (Section 4.2.15 and 4.2.30). Our delineation of shared recharge areas may be too small since our tracing work in areas of potential shared recharge was limited and was not always conducted under high flow conditions when shared recharge is more likely to occur.

Delineation Rationale

The recharge area boundary between the Fogelpole Cave groundwater system and the Krueger System is based on the topographic watershed of Dry Run Creek. On the north side of the boundary is the watershed for Dry Run Creek. Dry Run Creek sinks into the Krueger System. South of this boundary the land is characterized by sinkholes. The St. Joe Trace (99-112) was recovered, in part, in Fogelpole Cave. This trace established a northern limit for recharge to the Fogelpole Cave groundwater system. The Metter Sinking Stream Trace (98-105), its replicate (00-133), and the Rolling Hills Trace (96-02) help define the western boundary of the Fogelpole Cave recharge area as they were all recovered from Collier Spring.

The boundary with the Collier Spring recharge area is delineated in the northwest by four dye traces. They are the Metter Sinking Stream Traces (98-105 and 00-133) and the Rolling Hills Trace (96-02) (all of which were detected at Collier Spring), and the nearby Gotto Trace (99-125), which was detected in the Fogelpole Cave Nature Preserve. The boundary is drawn approximately halfway between the Gotto and Rolling Hills Traces. These latter two traces are the traces that are most proximate to one another yet contributed water and tracer dyes to different groundwater systems.

The Brinner Trace (99-127) demonstrated the existence of a shared recharge area between Fogelpole Cave and Collier Spring. We have included the Garner Trace (99-126) in that shared recharge area based on cave mapping. We believe that, if samplers had been present in the Sunfish Passage in Fogelpole Cave, they would have detected dye from the Garner Trace. The Garner Trace was conducted during flow conditions that were too low to permit water to overflow into Zebra Passage and yield a dye recovery at Tierce Spring.

The St. Joe Trace (99-112) identified a shared recharge area contributing water to both the Fogelpole Cave and the Illinois Caverns groundwater systems. That section of the recharge area boundary is drawn based upon the topographic watershed for the St. Joe sink. We have no data to indicate that there is more recharge area shared between Fogelpole Cave and Illinois Caverns, yet such additional areas might be discovered by more intensive dye tracing, especially if this work was conducted under high flow conditions.

The remainder of the boundary with the Illinois Caverns groundwater system recharge area is based on topographic boundaries that separate sinking streams that recharge each system. The Schultheis Sinking Stream Trace (99-115) was recovered in the Fogelpole Cave system while the Kruse Trace (00-130) was recovered in the Illinois Caverns groundwater system. These traces are used to delineate the topographic divide between the Fogelpole Cave and Illinois Caverns recharge areas.

The boundary with the Lantz Spring recharge area is based both on topographic divides and dye traces recovered in each system. The LL Road Corner Trace (99-111) and the MM Road Trace (99-120) demonstrate that surface watersheds are providing recharge to Lantz

Spring. The topographic boundaries of the watersheds for the dye introduction points were used as the recharge area boundaries. Another part of the boundary was defined by the Polka Trace (99-121) and the Barchet Trace (99-122), recovered from Fogelpole Cave and Lantz Spring, respectively. The recharge area boundary was placed approximately halfway between these dye introduction points.

The northeast boundary of the Fogelpole Cave recharge area is based on the topographic watershed of an unnamed tributary of the South Fork of Horse Creek. It was on this tributary that Station 129 was established. The karst features in this area are included in the Fogelpole Cave groundwater system recharge area and the surface watershed is excluded.

The divide between the recharge area for the Fogelpole Cave Nature Preserve and the entire Fogelpole Cave recharge area is based primarily on cave mapping. However, the Kaskaskia Road Trace (00-131) helps define this boundary as well.

4.4.3 Illinois Caverns

Illinois Caverns has 5.37 miles of mapped passage (Galandak, undated). Most of this lies downstream of the Illinois Caverns Natural Area boundary. About 40% of the groundwater system's base flow passes through the Natural Area.

There is only one major stream in Illinois Caverns. The main stream leaves the cave through an unenterable side passage downstream of the Sand Crawl. Two minor tributary streams enter the cave beyond this point and flow down the main passage. These two minor tributaries have not been dye traced. During high flows the main stream flows down the main passage as well as through the small, unenterable side passage.

The recharge area for the Illinois Caverns Natural Area is approximately 0.65 square miles. Water from this area would appear to qualify as Class III groundwater. The recharge area for the Illinois Caverns Natural Area is shown on Map 1. The recharge area of the entire Illinois Caverns groundwater system is approximately 2.10 square miles; this recharge area is also shown on Map 1. The recharge area for the Natural Area represents about 31% of the total recharge area for Illinois Caverns; as indicated earlier, this area accounts for about 40% of the base flow discharge from the system. As is the case with some of the other groundwater systems studied in the area, some of the portions of the recharge area which do not contribute water to the Natural Area yield part of their flow to surface runoff.

The recharge area boundaries for the Illinois Caverns groundwater system abut parts of the boundaries of the Fogelpole Cave, Krueger Cave, and Lantz Spring recharge areas. The Illinois Caverns recharge area also joins the Curran Spring recharge area. There is recharge area which is shared with the Fogelpole Cave groundwater system (Section 4.2.15).

Delineation Rationale

An area along the recharge area boundary is contributing water to both the Fogelpole Cave and the Illinois Caverns groundwater systems. That section of the boundary is drawn based on the topographic watershed for the St. Joe sink. While we have no data indicating that there is more shared recharge area with Fogelpole Cave than the St. Joe Sink, more intensive dye tracing (especially under high flow conditions) might enlarge the shared recharge area.

The remainder of the boundary with the Fogelpole Cave groundwater system recharge area is based on topographic boundaries that separate sinking streams that recharge each system. The Schultheis Sinking Stream Trace (99-115) was recovered in the Fogelpole Cave groundwater system while the Kruse Trace (00-130) was recovered in the Illinois Caverns groundwater system. These traces adequately characterize the topographic divide between the Fogelpole Cave and Illinois Caverns recharge areas.

The recharge area boundary between the Krueger System and Illinois Caverns is based primarily on topographic divides that have been confirmed by dye tracing. The Nobbe Trace (98-103) confirms that the sinking streams to the north are draining into the Krueger System. There is an area that we have shown as shared recharge between the Krueger System and Illinois Caverns. In this case, it is apparent from the topography and relevant cave maps that runoff from this area is recharging Kelly Spring. However, the main passage of Illinois Caverns runs under this area and infiltrating water provides some recharge to Illinois Caverns.

The recharge area boundary between the Krueger System and the Illinois Caverns groundwater system in and around the Illinois Caverns Natural Area (ICNA) is complex and may inter-finger. Part of the ICNA contributes water to the Krueger Cave System. In fact, the overlay of the Krueger Cave system presented by Frasz (1983) shows that part of the Krueger Cave System underlies the ICNA. The recharge area delineation is guided by the Walsh Trace (99-116), which was recovered in the Krueger Cave System; the Illinois Caverns Trace (98-101); the ICNA Trace (99-123); and maps of the respective caves. A high density of sinkholes characterizes this area and the boundary might well be adjusted around some of these sinkholes by more intensive dye tracing. Distinguishing among the three RSA biologically significant cave recharge areas was not deemed to be as important as defining areas which provided recharge waters to at least one of these biologically significant caves.

To the southeast, the recharge area abuts that of Lantz Spring. The LL Road Corner Trace (99-111) demonstrated that the topographic watershed of this branch of Horse Creek is outside of the Illinois Caverns recharge area. The Illinois Caverns groundwater system recharge area is shown on Map 1.

4.4.4 Krueger Cave System

The Krueger Cave System has between five and six miles of mapped cave passage. The system includes Krueger Cave, Dry Run Cave, Spider Cave, Half-Mile Cave, and Kelly Spring Cave. Krueger, Half-Mile, and Dry Run Caves have all been physically connected (ISS, 2000). The vast majority of the system lies upstream of the Nature Preserve. There are no significant tributary streams between the Armin Krueger Speleological Nature Preserve and Kelly Spring. This spring is about 800 feet from the closest Preserve boundary. Kelly Spring is the sole discharge point for the Krueger System. It should be noted that not all of the water passes directly under the natural bridge near the spring. Flow measurements made at the natural bridge were consistently lower than those measurements made about 150 feet downstream.

The tributary passage from Dual Pit (located within the Nature Preserve) to the main stream of Kelly Spring Cave is the only tributary that enters the system between Big Sink and Kelly Spring. It has little flow and appears to derive its recharge from the overlying parts of the Armin Krueger Speleological Nature Preserve. Water quality is likely to be statistically identical at Big Sink and at Kelly Spring.

The recharge area for the cave stream at the Armin Krueger Speleological Nature Preserve is approximately 5.38 square miles. The Armin Krueger Speleological Nature Preserve recharge area yields which appears to qualify as Class III groundwater. An additional 0.02 square miles of land recharges the Kruger Cave system but lies downstream of the designated preserve. Including this land, the recharge area for the Kruger Cave System is 5.40 square miles. The size of this area is similar to the size of the recharge area of the Fogelpole Cave Nature Preserve.

The Krueger groundwater system abuts the Illinois Caverns, Collier Spring, Fogelpole Cave, and Curran Spring recharge areas, as well as the surface watersheds for Fountain and Rockhouse Creeks. The recharge areas for the Krueger System are shown on Map 1.

Delineation Rationale

The recharge area boundary between the Fogelpole Cave groundwater system and the Krueger System is based on the topographic watershed of Dry Run Creek. On the north side of the boundary is the watershed for Dry Run Creek, which sinks into the Krueger System and lends its name to the Dry Run part of Krueger – Dry Run Cave. The St. Joe Trace (99-112) was recovered, in part, in Fogelpole Cave. This trace established a northern limit for recharge to the Fogelpole Cave groundwater system. The Metter Sinking Stream Trace (98-105), its replicate (00-133), and the Rolling Hills Trace (96-02) help define the western boundary as they were all detected at Collier Spring.

The Fountain Creek Trace (99-117) and the Rockhouse Creek Trace (99-114) demonstrated that these creeks do not recharge the Krueger System. The topographic divide between these watersheds and the Dry Run Creek watershed is the Krueger System recharge area boundary. There is an unnamed branch of Horse Creek whose watershed divide defines the northeast boundary of the Krueger System recharge area. This branch runs through the Armin Krueger Speleological Nature Preserve. Similarly, the watershed divide of a tributary of the above-mentioned branch of Horse Creek forms the recharge area boundary to the east.

The recharge area boundary between the Krueger System and the Illinois Caverns groundwater system in and around the Illinois Caverns Natural Area (ICNA) is complex and may inter-finger. Part of the ICNA contributes water to the Krueger Cave System. In fact, the overlay of the Krueger Cave system presented by Frasz (1983) shows that part of the Krueger Cave System underlies the ICNA. The recharge area delineation is guided by the Walsh Trace (99-116), which was recovered in the Krueger Cave System; the Illinois Caverns Trace (98-101); the ICNA Trace (99-123); and maps of the respective caves. A high density of sinkholes characterizes this area and the boundary might well be adjusted around some of these sinkholes by more intensive dye tracing. Distinguishing among the three RSA biologically significant cave recharge areas was not deemed to be as important as defining areas which provided recharge waters to at least one of these biologically significant caves.

4.4.5 Stemler Cave

Stemler Cave has approximately one mile of mapped passage. About 125 feet of cave passage lies under the Stemler Cave Nature Preserve. The majority of the cave is downstream of the Nature Preserve. The cave discharges its water at Sparrow Spring, which is the sole discharge point for the system. Approximately 85% of the base flow of this stream passes through the Nature Preserve. The Stemler Cave discharge measurements were provided by Dr. Steven Taylor of the Illinois Natural History Survey (Taylor et al., in press).

The recharge area delineation around the dye introduction sink for the Stemler Road Trace (Trace 99-215) was influenced by the report by Jim Sherrell (personal communication, 1998) that he had introduced dye to a sinkhole across Bluffside Road from the 99-215 trace sink and that his dye was recovered at Columbia Quarry Plant No.1.

The recharge area for the Stemler Cave Nature Preserve includes most of the other nearby state-managed or state-owned lands. The recharge area comprises approximately four square miles. It is this area that yields water which may qualify for designation as Class III groundwater. The recharge area is shown on Map 2. The entire Stemler Cave recharge area is also shown on Map 2 and includes approximately 7.14 square miles.

The Nature Preserve recharge area comprises approximately 55% of the entire system's recharge area. The difference between having 85% of the flow and only 55% of the recharge area is attributed to appreciable surface runoff from areas tributary to the cave system but not tributary to the Nature Preserve portion of that system. The presence of the Gilmore Lakes in the recharge area for the Nature Preserve may provide for higher base flow recharge per unit area because this watershed would be expected to have a subdued response to runoff events because of lake storage.

Delineation Rationale

The topographic watershed of Prairie du Long Creek defines the southern boundary of the Stemler Cave recharge area. The Prairie du Long Trace (99-219) demonstrated that Prairie du Long Creek does not recharge Stemler Cave. The Gilmore Lakes Sink Trace (98-203) demonstrated that the sinkholes north of the Prairie du Long Creek watershed do in fact recharge Stemler Cave. Thus, the recharge area has been delineated along the edge of the Prairie du Long Creek watershed.

The eastern boundary of the Stemler Cave recharge area is also a topographic watershed boundary. However, there is a stream, Spring Valley, whose watershed defines the recharge area boundary. The Spring Valley Trace (99-212) demonstrated that this stream does not recharge Stemler Cave. However, four traces were initiated from karst features along the eastern side of the Stemler Cave recharge area. All were recovered within the Stemler Cave groundwater system. These traces were: Cossil Fast (98-201); Charles Sink (98-202); Rodemich (99-211); and Wagner Road (99-217). These dye traces demonstrate that the karst features west of the Spring Valley watershed recharge the Stemler Cave groundwater system.

The western boundary of the Stemler Cave recharge area abuts the Haney and County Line Springs recharge areas. It is not clear from the existing data what the relationship is between the Haney and County Line Springs. However, the Stumpf Trace (99-213) is within the Haney Spring recharge area, while the Gilmore Lakes Sink Trace (98-203), the Jost Trace (99-216), the Krause Trace (99-220), and the Centreville Road Trace (00-222) all are in the Stemler Cave recharge area. In drawing the delineation boundary we have considered the fact that the flow rates of Sparrow Spring (which drains Stemler Cave) is about five times greater than the flow rate of Haney Spring. As a result, the recharge area for Stemler Cave should be about five times larger than the recharge area for Haney Spring.

We have excluded a small area near County Line Spring from the Stemler Cave recharge area to account for recharge to County Line Spring. No dye traces were recovered from County Line Spring. This may be related, in part, to the spring having only intermittent flow. We have no direct data indicating whether this is an overflow spring or a spring that has such a small recharge area that it does not have perennial flow. However, examination of the cave feeding this spring (Oliver and Graham, 1988) reveals that the cave is relatively extensive and presumably has had its base flow captured by another spring.

Also relevant to the western boundary delineation are the Krause Trace (99-220) and the Bremser Road Trace (99-218). The Krause Trace was detected at Stemler Cave, and the Bremser Road Trace was detected at Plant No.1 Spring. Plant No.1 Spring discharges from a west-facing slope, and the conduit feeding the spring probably curves significantly to the east to flow around the valley into which the spring discharges. The land overlying this implied flow path is part of the recharge area of Plant No.1 Spring. As a result, the Stemler

Cave recharge area boundary is drawn considerably closer to the Krause sink than to the Bremser Road sink.

The Stemler Road Trace (99-215) also helps define the western edge of the Stemler Cave recharge area. In this area, the delineation was drawn approximately halfway between Trace 99-215 and Sherrell's nearby trace, which he reportedly detected at Plant No.1. Our data indicate that the Stemler Road sink may recharge both Plant No.1 Spring and the Stemler Cave groundwater system.

Four dye traces define the western recharge area boundary northeast of Plant No.1 Spring. They are the various Gummerscheimer Traces (98-205, 98-206, 99-209, and 99-210). Trace 98-205 was the only one of these recovered outside the Stemler Cave groundwater system. The delineation is shown approximately halfway between the introduction point for the nearest trace recovered in the Stemler Cave groundwater system and the sink where dye for Trace 98-205 was introduced. The topographic watershed of a tributary of Palmer Creek also defines a portion of the western boundary of the Stemler Cave recharge area.

The remainder of the western boundary of the Stemler Cave recharge area is defined primarily by surface watersheds and the Harvell Hill Trace (99-214). There are three springs in Cement Hollow and probably others in valleys draining towards the Mississippi River. Some small areas of sinkholes have been excluded from the Stemler Cave recharge area due to these small discharge springs.

The northern boundary of the Stemler Cave recharge area is defined by two dye traces and Sparrow Spring. The relevant traces are the Hardin Trace (99-221), which was recovered at Falling Springs, and the Harvell Hill Trace (99-214), which was recovered at Sparrow Spring. The delineation was also influenced by the presence of WH Spring (Station 224). Its presumed recharge area is likely to be between these two traces. This results in the boundary being drawn much closer to the Harvell Hill sink than to the Hardin sink.

The divide between the recharge area for the Nature Preserve and that of the entire Stemler Cave groundwater system is based primarily on two dye traces. These were the Stemler Road Trace (99-215), which did not pass through the Nature Preserve, and the Cossil Fast Trace (98-201), which did pass through the Nature Preserve.

4.4.6 Collier Spring

Delineation of the Collier Spring recharge area was not an identified task in the contracts for this study. However, we developed considerable data on this groundwater system in the course of the study. It is likely that the Illinois Cave Amphipod is present in this groundwater system since there is a hydrologic connection with Fogelpole Cave (where the amphipod is known to exist). As a result, we have developed a recharge area delineation for Collier Spring.

As noted in Section 4.2.8, water is discharged downstream of Collier that was sampled by the station Collier Downstream. Our data do not show a distinct dye signature for the smaller discharge point. However, only in the case where most of the dye was discharged downstream would there be a distinct dye signature.

The Collier Spring recharge area forms a crescent around the southwestern side of the Fogelpole Cave recharge area. It abuts the Krueger Cave recharge area as well as the recharge area for Illinois Caverns. The Brinner Trace (99-127) demonstrated an inter-system hydrologic connection since dye was recovered in both Fogelpole Cave and at Collier Spring. The recharge area for Collier Spring is shown on Map 1 and includes approximately 7.90 square miles.

There are no significant caves currently known within the boundaries of the Collier Spring recharge area. Lewis et al. (1999) bio-inventoried two small caves within the Collier Spring drainage, as well as Collier Spring. No rare or endangered species were collected. It is likely that a major cave remains to be discovered feeding this spring, and that it will contain important fauna.

Delineation Rationale

The boundary between the Fogelpole Cave recharge area and the Collier Spring recharge area is drawn approximately halfway between dye introductions recovered from each system. To the northwest are the Metter Traces (98-105 and 00-133) and the Rolling Hills Trace (96-02); all three of these traces were detected at Collier Spring. Nearby is the Gotto Trace (99-125) which was detected in the Fogelpole Cave Nature Preserve. The boundary is drawn approximately halfway between the Gotto and Rolling Hills Traces. The Brinner Trace (99-127) demonstrated the existence of a shared recharge area between the Fogelpole Cave and Collier Spring groundwater systems. We have included the Garner Trace (99-126) in that shared recharge area based on cave mapping. We believe that, if samplers had been present in the Sunfish Passage in Fogelpole Cave, they would have detected dye from the Garner Trace. The Garner Trace was conducted during flow conditions that were too low to permit water overflow into Zebra Passage and resulting dye recovery at Tierce Spring.

The recharge area boundary between the Collier Spring recharge area and the Krueger Cave System recharge area is based on the topographic watershed of Dry Run Creek. On the north side of the boundary is the watershed for Dry Run Creek, which sinks into the Krueger System and lends its name to Dry Run part of Krueger – Dry Run Cave. The Metter Sinking Stream Trace (98-105); its replicate (00-133); and the Rolling Hills Trace (96-02) demonstrate that the karst features south of the Dry Run Watershed recharge Collier Spring.

The Horse Creek topographic watershed defines most of the southeast section of the Collier Spring recharge area. The Wittenauer Trace (98-106) demonstrated that karst features northeast of this watershed recharge Collier Spring. To the southeast of Collier spring is a small area containing sinkholes and some karst windows. We have included these karst features within the Collier Spring recharge area due to their proximity, as well as a lack of other known discharge points.

To the south of the Collier Spring recharge area are two relatively large springs: Couch's Spring and Spring #1. Their flow rates plus results from the Church Trace (99-118) and Jacob's Trace (98-107) guided the delineation in this area. A relatively large area was excluded from the Collier Spring recharge area to accommodate the necessary recharge areas for these other two springs. Couch's Spring (also known as Spring #2) and Spring #1 were lumped together as part of the INAI's "Renault Cave System". However, no hydrological connection is known to exist between these groundwater systems.

The southwestern portion of the Collier Spring recharge area was defined primarily by three dye traces: the Nottmeier Trace (98-109), which was recovered from Steam Thresher Spring; the Steingrubey Trace (98-108), which was recovered in Morrison Hollow; and the Fults Road Trace (99-113), which was recovered from Collier Spring.

The northwest recharge area boundary is defined primarily by two traces: the Metter sinking stream Trace (98-105), which was recovered at Collier Spring; and the Brushy Prairie Trace (00-129), which was recovered from Maeystown Creek. The watershed for the Metter sinking stream defines the northwestern boundary of the Collier Spring recharge area.

4.4.7 Lantz Spring

Lantz Spring was not one of the cave systems included in the contracts. However, in the course of this study, sufficient dye traces were conducted to permit an effective delineation of the Lantz Spring recharge area. The Lantz Spring recharge area delineation is shown on Map 1 and encompasses approximately 1.86 square miles.

Lantz Spring is a small rise-pool spring. We measured its flow on October 9, 1998 at 44 gpm. There are no known caves in the Lantz Spring recharge area. The geologic setting for the Lantz Spring recharge area is distinctly different in one respect from that of the other recharge areas. A thin layer of sandstone (probably Aux Vases) overlies much of the limestone. The presence of a sandstone cap can greatly affect storm response as well as the amount of water contributed to a spring per unit area of land. Numerous sinkholes have collapsed upwards through the sandstone and provide discrete recharge to the spring. These collapse features also reveal the thinness of the sandstone.

Delineation Rationale

The boundary with the Fogelpole Cave groundwater system recharge area is based upon topographic divides and dye tracing results. The LL Road Corner Trace (99-111) and the MM Road Trace (99-120) demonstrated that a surface watershed is providing recharge to

Lantz Spring. The topographic boundaries of the watersheds for the dye introduction points were used as the recharge area boundary. Another part of the boundary is defined by the Polka Trace (99-121) and the Barchet Trace (99-122), recovered from Fogelpole Cave and Lantz Spring, respectively. The recharge area boundary was drawn approximately halfway between these dye introduction points.

The watershed for LL Road Corner Trace dye introduction stream also defines the boundary to the north that divides the Illinois Caverns recharge area and Lantz Spring recharge area.

A topographic boundary was used to delineate the southeastern part of the Lantz Spring recharge area. This topographic boundary is along the same unnamed tributary of Horse Creek that was used to define the northeastern part of the Fogelpole Cave recharge area.

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. Many more traces were initiated for this project than were required by the contract. However, some details were not resolved. Some of these may have little impact, but are intriguing nonetheless. 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.

Illinois Caverns Sump

It is unclear from the current traces in Illinois Caverns (Traces 98-101, 98-112, 99-123, and 00-130) whether the terminal sump discharges to all the known springs for the system or if it discharges to a subset of them. This trace would have no impact on Class III groundwater designation since it is downstream of the Illinois Caverns Natural Area. The caves upstream of the springs are likely to be presumed *G. acherondytes* habitat because of their hydrologic connection with Illinois Caverns. However, a brief examination and a small collection of amphipods in Walsh Cave by C. Paine (Webb et al., 1993) and J. Lewis (Lewis et al., 1999) did not demonstrate the presence of the Illinois Cave Amphipod.

Gotto Karst Window to Junction Room, Fogelpole Cave

Trace 99-125 data suggest that there are two base level flow paths from the Gotto Karst Window to the Junction Room in Fogelpole Cave. The path through the Northwest Entrance has largely been mapped (Hauck and Addison, 2000), but additional exploration and possibly more dye tracing with several in-cave sampling stations might provide illumination into the possibility of undiscovered cave passage along this implied additional flow path.

Zebra Passage

It is not known at this time whether or not the downstream sump in Zebra Passage contributes water to mapped parts of Fogelpole Cave. It is known from the Fogelpole Cave map (Hauck and Addison, 2000) that no part of Zebra Passage contributes to the Fogelpole Cave Nature Preserve. A trace of this stream with in-cave sampling stations near the downstream end of the main stream of Fogelpole Cave would resolve this detail of the flow route of the Zebra Passage stream. It would also help resolve the relationship of Myron's Misery Cave and Bat Sump to Fogelpole Cave. These two small caves lie between Zebra Passage and the main stream in Fogelpole Cave (Southeast Passage).

Spring Search

It has been demonstrated by this study and suggested by common sense that there are significant springs that are unknown to science. The data indicate that there are springs in Morrison Hollow and feeding Maeystown Creek that are as yet unidentified and unlocated. It is likely that there are many other springs in the karst that are not presently known. A much better understanding of the karst region could be gained if all the creeks were examined for springs. Searching for springs that do not derive their water from the four biologically significant caves studied in the present contracts is outside the scope of the present study.

Dye Tracing Surface Streams

Studies conducted by the OUL in the Southwest Illinois Karst demonstrate that many of the surface streams lose some or all of their flow to the karst groundwater system. These include Fountain Creek (Aley and Aley, 1998), Trout Hollow (Moss, 1998), two tributaries of Horse Creek, and possibly Spring Valley. Tracer dyes were introduced into the latter three streams during this study. It is important both for a better understanding of the karst and for management purposes to know which sections of which streams are losing surface flow into the karst groundwater system. This is very important for siting of industrial or waste-handling facilities, including public and private sewage treatment systems. The implications for the protection of public health and the groundwater fauna of the karst suggest that this is a very necessary study as there are numerous surface streams in the Southwest Illinois Karst that have potential to be losing streams. In particular, Spring Valley in St. Clair County between Kropp and Saeger Roads seems to have both surface and subsurface flow routes (see Section 4.3.12).

Cave Mapping and Bio-Inventory

Cooperators of the Illinois Speleological Survey are discovering many new caves (Schmitt, 2000). Some of these newly discovered caves have already proven to be biologically significant (Lewis et al., 1999). A greater understanding of the karst biota and groundwater behavior can be gained with more cave mapping, discovery, and bio-inventory of the newly discovered caves. Many important groundwater systems have no known cave entrances. One of the longest caves in Illinois could lie within the Collier Spring recharge area and be supplying water to this spring

5.0 SUMMARY AND CONCLUSIONS

5.1 Contract Requirements

In the Technical Proposal to the INPC, dated March 9, 1998, the OUL proposed conducting five to six traces in the CSA using about 10 sampling stations. The OUL also proposed 10 to 12 traces in the RSA using about 25 sampling stations. After the INPC awarded this work to the OUL, additional funds for this project were made available through the IDNR C2000 program. The C2000 contract is with the MCSWCD. There was sufficient funding from C2000 to roughly double the level of field effort. Reporting efforts were only slightly increased. Similarly, the City of Columbia, Illinois contracted with the OUL to do work that resulted in three dye traces that are relevant to the delineation of the Stemler Cave recharge area The Columbia Quarry Company funded four additional dye traces. Three dye traces were previously conducted in the RSA with funding through the Mississippi Karst Resource Planning Committee from the USEPA.

Considering this as one project with multiple funding sources (INPC, C2000, the City of Columbia, and the Columbia Quarry Company), the OUL expected that 17 to 19 traces would be conducted in the CSA. The OUL further expected that 23 to 25 dye traces would be used to delineate recharge areas in the RSA, including the three traces previously conducted under a USEPA grant. In fact, 22 dye traces were conducted in the CSA and 36 dye traces were used in the RSA.

The INPC contract had a June 1, 1998 start date. Work was to be completed by July 31, 1999. The C2000 contract was signed with SWCD on August 10, 1998 and had a completion date of June 30, 2000. The INPC gave a contract extension to the OUL to permit all work to be completed by the later date. The work for the Columbia Quarry Company and the City of Columbia was completed within this same time frame. The combined project had a June 1, 1998 to June 30, 2000 duration.

The INPC research permit required that all sampling materials be removed from the Nature Preserves and that the original permit be returned to the INPC. All sampling materials have been removed from the Nature Preserves and from Illinois Caverns, as well. The original INPC research permit accompanied their draft copy of this report.

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 Info compatible files were specified as one of the contract deliverables. Arc View 3.2 themes accompany this report. These themes show all the dye traces as diagrammatic lines, the recharge areas of six groundwater systems, and the recharge areas of the relevant, dedicated Illinois Nature Preserves and the Illinois Caverns Natural Area. This report completes the delineation study and satisfies the requirements of the contracts with the INPC and the SWCD.

5.2 Character and Purpose of the Delineations

The Illinois Nature Preserves Commission (INPC) published a Request for Proposal for delineation of groundwater recharge areas for four biologically significant cave systems in Monroe and St. Clair Counties, Illinois. The cave systems were Fogelpole Cave, Illinois Caverns, Dry Run Cave (Krueger System), and Stemler Cave. Within these cave systems lie the Armin Krueger Speleological Nature Preserve, Stemler Cave Woods Nature Preserve, Stemler Cave Nature Preserve, Fogelpole Cave Nature Preserve, and the Illinois Caverns Natural Area. In the future, additional Nature Preserves may be dedicated within these cave and groundwater systems. Subsequently, C2000 funds were made available for a greater level of effort. The additional work was done under contract to the MCSWCD.

The four cave systems are part of an important karst ecosystem and provide habitat for the Federally listed endangered Illinois Cave Amphipod. The State of Illinois, through the INPC and the IDNR has a management role in these particular caves. In order to best manage the caves, 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 the 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. The 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. The example from Columbia Quarry's expansion at Plant No.1 is especially relevant. The OUL found subtleties in the groundwater flow that were quite relevant to the IDNR Consultation process that would not have been known at the level of effort we were initially contracted to provide. Similarly, the Brinner Trace (99-127) suggested that there can be appreciable water movement within the epikarst. Most of the traces under this contract did not have in-cave sampling points that would shed light on the extent of epikarstic water movement. That level of investigation was beyond the scope of the present study.

Dye can be considered a surrogate for contaminants which 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 frequent samples collected 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 55 new dye introductions that were recovered at 53 sampling stations. A total of 87 sampling stations were established.

We delineated the recharge areas primarily through dye tracing, but also drew upon our knowledge of the caves involved, flow rate measurements of springs, and hydrogeological considerations. All four of these biologically significant caves are in the Southwest Illinois Karst, which is an intensely karstified sinkhole plain area.

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

1) There are hydrologic connections between some of the groundwater systems. At least one sinkhole contributes water to both the Illinois Caverns and the Fogelpole Cave groundwater systems (Section 4.2.15). While most of Fogelpole Cave discharges its water to Indian Hole and Tierce Spring, a newly discovered section of the cave discharges at Collier Spring and can overflow to Tierce Spring (Section 4.2.30).

2) Stemler Cave has a much larger recharge area than previously delineated by IDNR and includes the Illinois Route 158 highway corridor. As a result, we now know highway runoff and spills have the potential to degrade water quality in the Stemler Cave Nature Preserve.

3) Fogelpole Cave and Illinois Caverns have significantly smaller recharge areas than previously delineated by IDNR.

4) Groundwater in the Southwest Illinois Karst can travel great distances. Two traces went over five miles straight-line distance (Sections 4.2.8 and 4.3.3).

5) Mean groundwater gradients in this study range from 26 to 411 feet per mile. The four systems studied have 26 to 176 feet per mile gradients. Typical gradients in the four caves range from 26 to 65 feet per mile. Groundwater gradients towards the Mississippi River tend to be much greater than the groundwater gradients to its tributaries, such as Horse Creek.

6) Mean groundwater velocity ranged from 200 to 10,000 feet per day under base flow conditions. About one mile per day was typical in the study area.

7) There can be appreciable horizontal movement of water within the epikarst (Section 4.2.30). The epikarst is the highly weathered upper portion of the limestone bedrock.

8) The persistence of dye pulses ranges from less than one day to more than one year. 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 at least daily.

9) Surface streams as shown on the USGS topographic maps may lose some or all of their flow into the karst groundwater system.

10) Watersheds of sinking streams on the margins of recharge areas tend to define the margins of the those recharge areas.

11) There is little correlation between sinkhole density and recharge area boundaries found in the study area. In some areas the recharge area boundaries correlate well with topographic divides characterized by few to no surface karst features. However, almost as frequently, the recharge area boundaries pass through areas of high sinkhole density. The recharge area boundary between the Krueger System and the Illinois Caverns groundwater system presents examples of both. This study indicates little reliability in recharge area delineations that do not rely primarily on dye tracing.

5.4 Identification of Recharge Areas and Associated Springs

Fogelpole Cave Recharge Area

The total size of this recharge area is 7.14 square miles. The portion of the recharge area which is located in or tributary to the Fogelpole Cave Nature Preserve is 5.13 square miles. These values include lands which function as shared recharge areas and yield waters to other delineated groundwater systems. The Fogelpole Cave Recharge Area includes some lands where the recharge water is shared with the Illinois Caverns groundwater system and with the Collier Spring groundwater system. The Fogelpole Cave Recharge Area borders recharge areas for Collier Spring, Illinois Caverns, the Krueger Cave System, Lantz Spring, and probably some other small springs.

Aside from shared recharge areas, the Fogelpole Cave Recharge Area discharges groundwater only at Tierce Spring under low flow conditions. Under moderate flow conditions the recharge area discharges groundwater at Tierce Spring and at Indian Hole (also called Indian Hole Spring). In contrast, the shared recharge area discharges at Collier Spring under low flow. At high flows, the shared recharge area overflows to Tierce Spring and Indian Hole. All three of these springs are located in relatively close proximity to one another. Figure 59 shows the flow paths in Fogelpole Cave schematically under various flow conditions. On Figure 59, it should be noted that at higher flows, the normal flow routes are also followed. The high and extremely high flow routes are overflow routes.

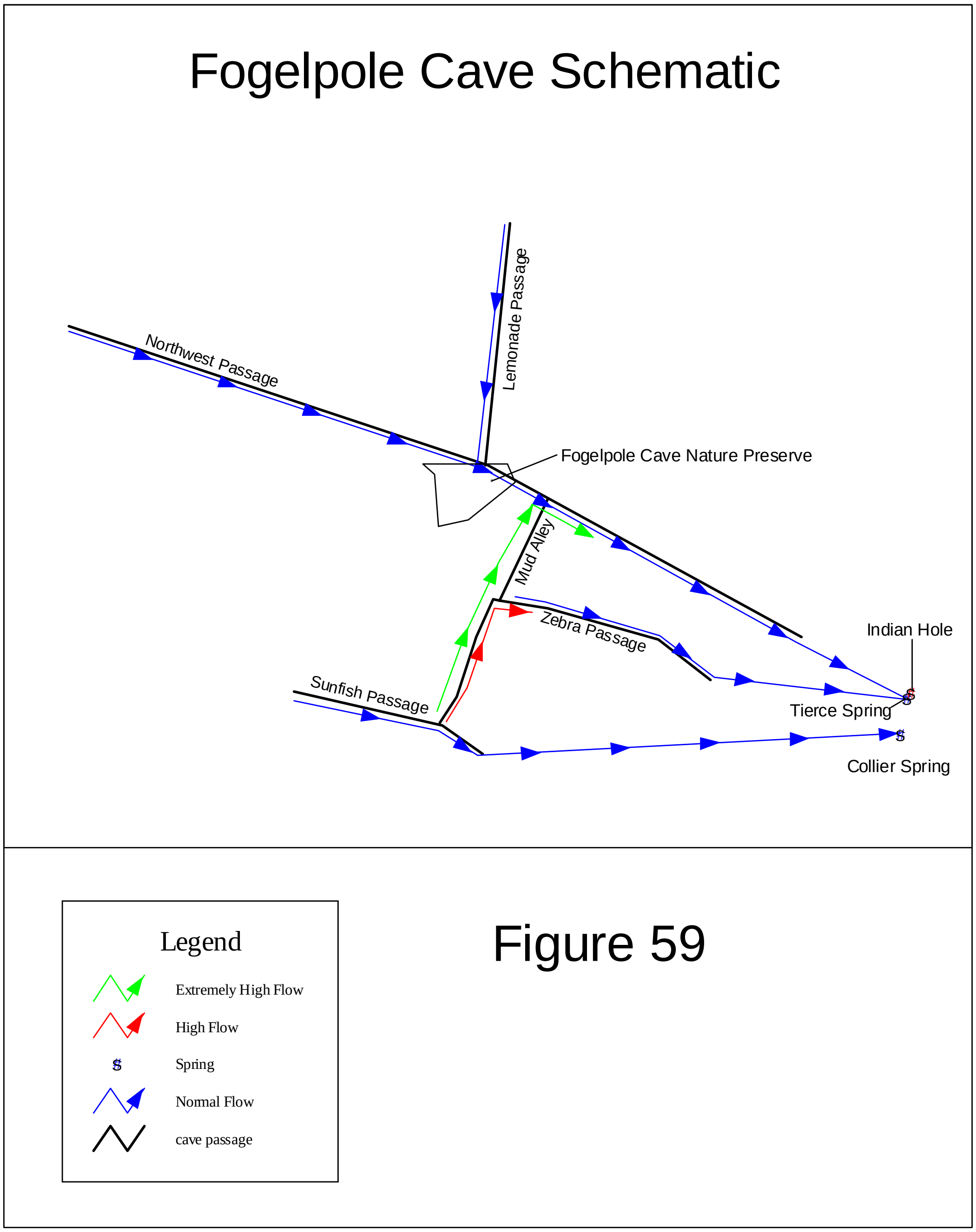


Figure 59

Collier Spring Recharge Area

The total size of this recharge area is 7.90 square miles. There are no currently established nature preserves which are associated with Collier Spring. The recharge area size includes lands which function as shared recharge areas and yield waters to other delineated groundwater systems. The Collier Spring Recharge Area includes some lands where the recharge water is shared with the Fogelpole Cave groundwater system. Further, the Sunfish Passage of Fogelpole Cave drains to Collier Spring. The flow paths of Fogelpole Cave, including the Sunfish Passage, at various flow conditions are shown schematically on Figure 59. On Figure 59, it should be noted that at higher flows, the normal flow routes are also followed. The high and extremely high flow routes are overflow routes.

Under high flow conditions, the Collier Spring groundwater system overflows into the Fogelpole Cave system and discharges at Tierce Spring and Indian Hole as well as Collier Spring.

Under low flow conditions the Collier Spring Recharge Area borders recharge areas for Fogelpole Cave, the Krueger Cave System, the Renault Cave System and probably some smaller springs.

Illinois Caverns Recharge Area

The total size of this recharge area is 2.10 square miles. The portion of the recharge area which is located in or tributary to the designated Illinois Caverns Natural Area is 0.65 square miles. These values include lands which function as shared recharge areas and yield waters to other delineated groundwater systems. The Illinois Caverns Recharge Area includes some lands where the recharge water is shared with the Fogelpole Cave Recharge Area and other areas where the recharge water is shared with the Krueger Cave System. The Illinois Caverns Recharge Area borders recharge areas for Fogelpole Cave, the Krueger Cave System, Lantz Spring, Curran Spring, and probably some other small springs.

Aside from shared recharge areas, the Illinois Caverns Recharge Area discharges groundwater at Dye Spring, Walsh Spring, and Walsh Cave. Walsh Cave and Walsh Spring are located about 250 feet apart; both of these features are about 3,000 feet from Dye Spring. Dye Spring is an underflow spring and receives most of the flow from Illinois Caverns under low flow conditions. Walsh Cave is an overflow spring and receives most of the flow from Illinois Caverns under high flow conditions. Walsh Spring and Walsh Cave are closely connected hydrologically.

Krueger Cave System Recharge Area

This cave system includes Krueger Cave, Dry Run Cave, Spider Cave, Half-Mile Cave, and Kelly Spring Cave. Krueger Cave, Half Mile, and Dry Run Caves have all be physically connected by cavers. The total size of this recharge area is 5.40 square miles. The portion of the recharge area which is located in or tributary to the Armin Krueger Speleological Nature Preserve is 5.38 square miles. These values include lands which function as shared recharge areas and yield waters to other delineated groundwater system. The Krueger Cave System Recharge Area includes some lands where the recharge water is shared with the Illinois Caverns, Collier Spring, Fogelpole Cave, and Curran Spring groundwater systems and probably some other small springs.

Aside from shared recharge areas, the Krueger Cave System Recharge Area discharges all of its groundwater at Kelly Spring.

Lantz Spring Recharge Area

The total size of this recharge area is 1.86 square miles. There is no Nature Preserve associated with this spring or its recharge area. Our groundwater tracing studies did not identify an areas which function as shared recharge areas and yield waters to other delineated groundwater system. Lantz Spring appears to be the only discharge point for groundwater from the Lantz Spring Recharge Area. The Lantz Spring Recharge Area borders recharge areas for Fogelpole Cave, Illinois Caverns, and probably some other small springs.

Stemler Cave Recharge Area

The total size of this recharge area is 7.14 square miles. The portion of the recharge area which is located in or tributary to the Stemler Cave Nature Preserve is 3.93 square miles. There are no identified lands which we have determined function as shared recharge areas and yield waters to other delineated groundwater system. The Stemler Cave Recharge Area borders recharge areas for Falling Spring, Ritter Spring, Haney Spring, and a number of other small springs. The Stemler Cave Recharge Area discharges groundwater only at Sparrow Spring.

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 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 (such as that conducted along the western border of the Stemler Cave Recharge Area) should be conducted in areas which 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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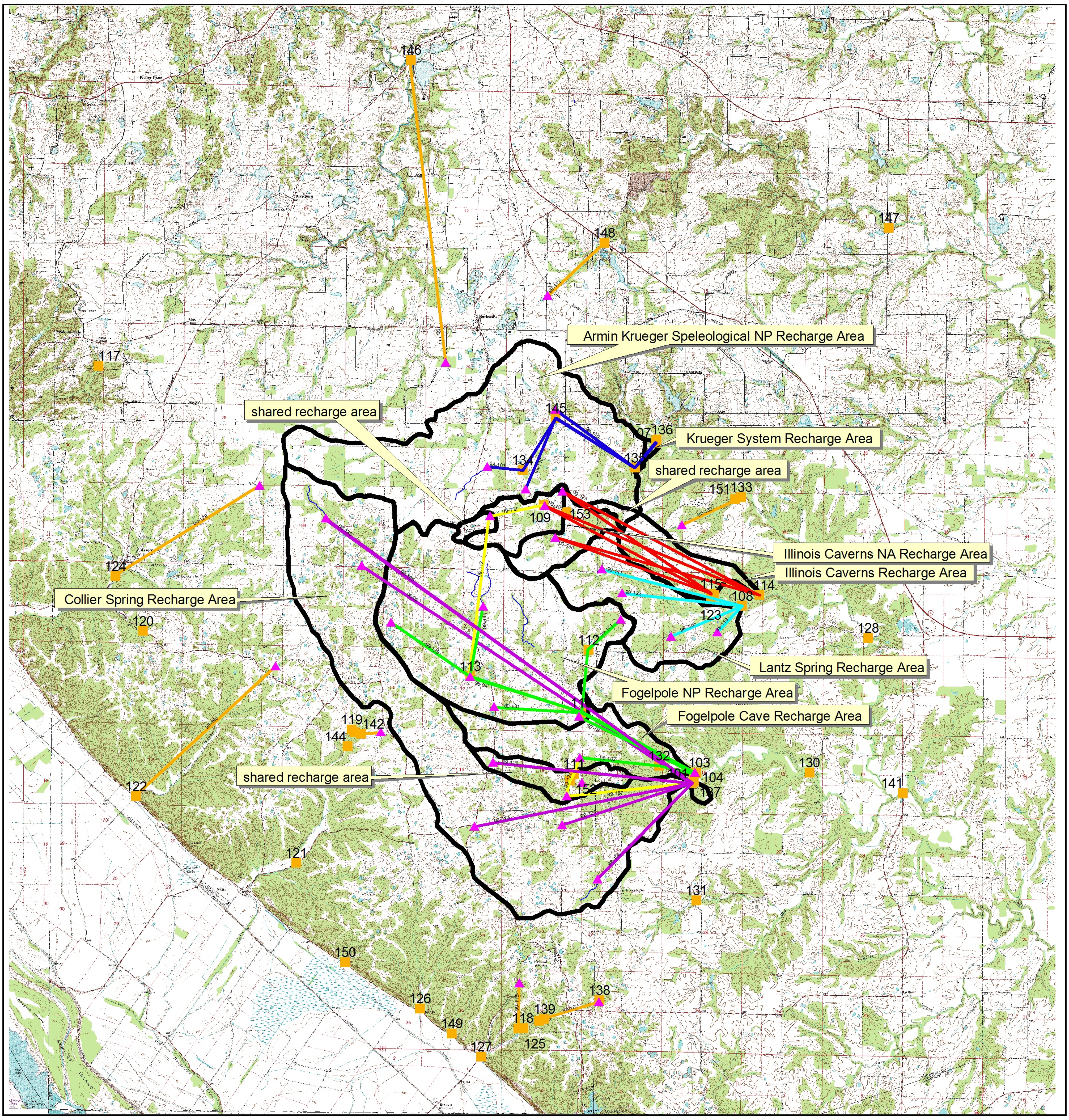
APPENDIX A

TABULAR RESULTS FOR CHARCOAL AND WATER SAMPLES

APPENDIX B

OZARK UNDERGROUND LABORATORY

PROCEDURES AND CRITERIA



Map 1
Renault Study Area

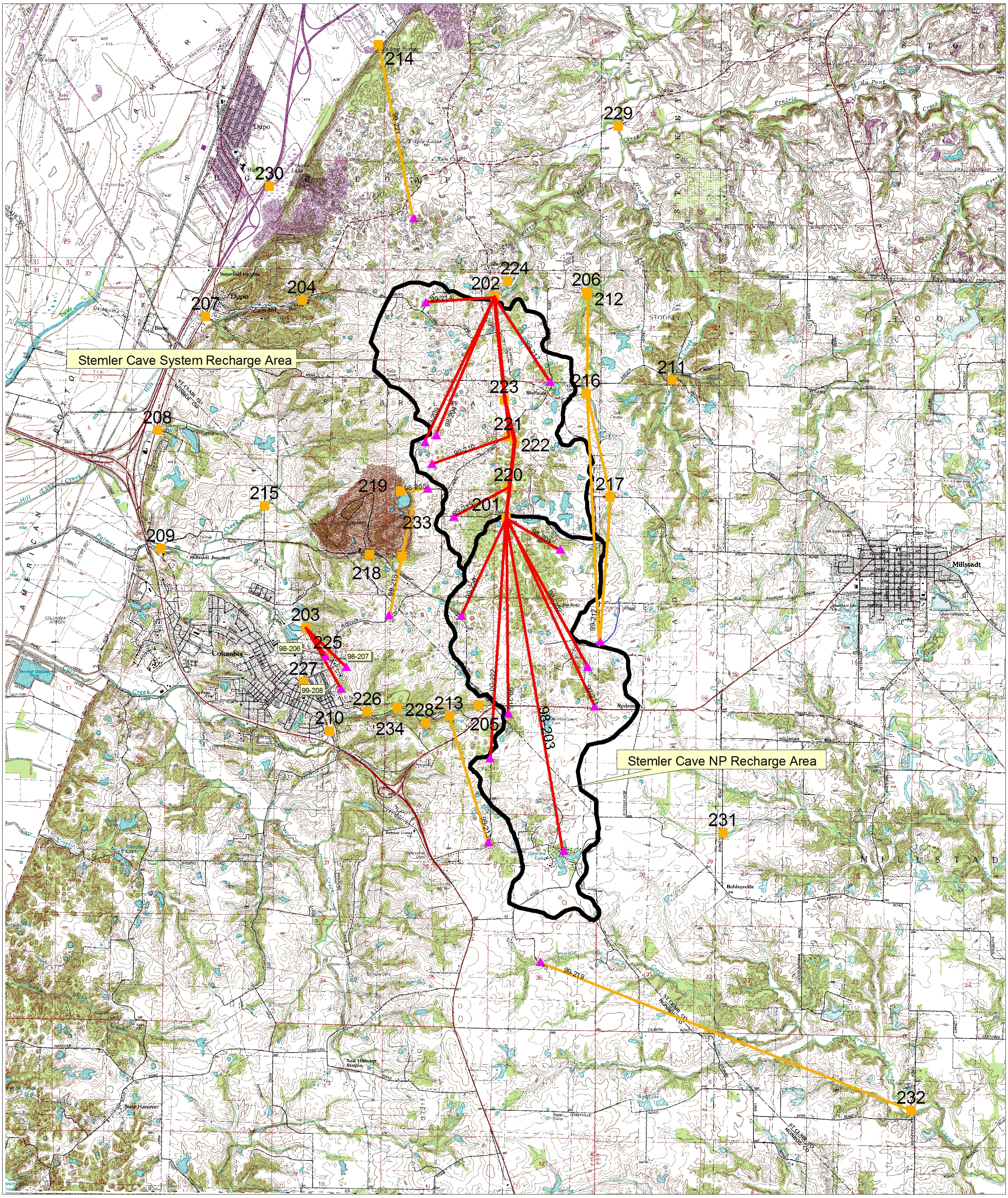
Legend

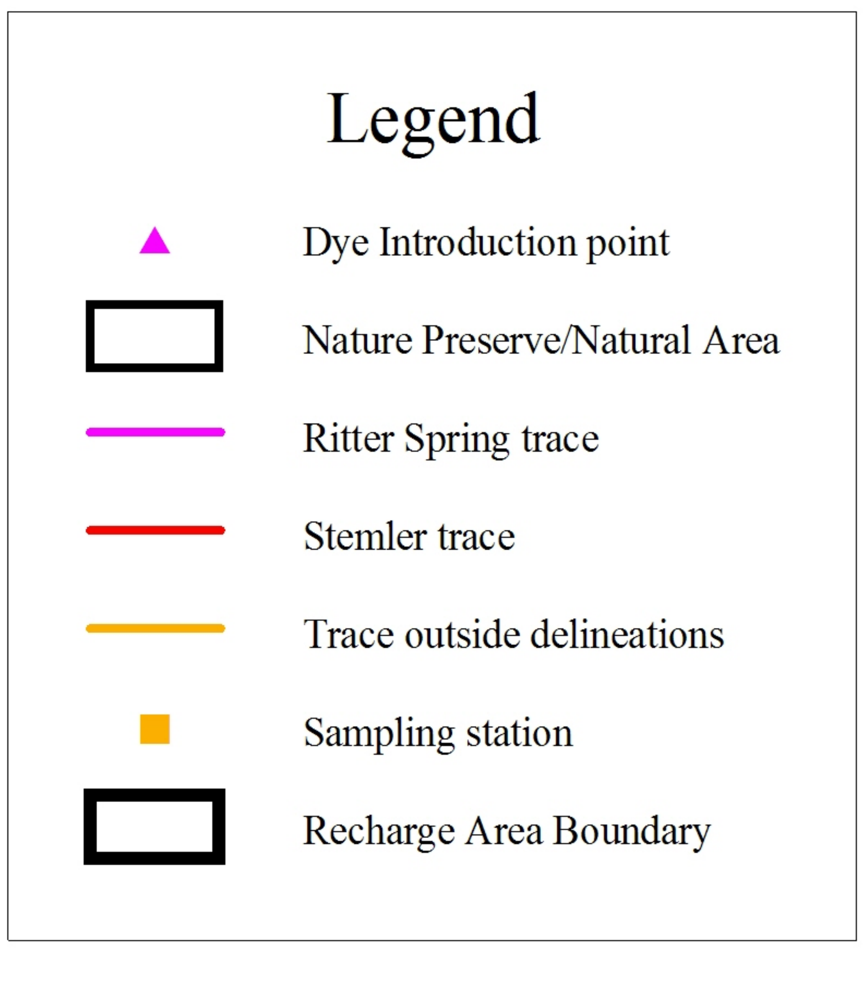
- Dye Introduction point
- Nature Preserve/Natural Area
- Trace outside delineations
- Collier Spring trace
- Krueger trace
- Fogelpole trace
- Illinois Caverns trace
- Recharge Area linking trace
- Sampling station
- Recharge Area Boundary

0 7000 14000 21000 Feet

N

Ozark Underground Laboratory, 2000





Map 2
Columbia Study Area