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MONROE COUNTY RECHARGE AREA DELINEATIONS

FINAL REPORT

June 2009

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A contract study for the Southwest Illinois Resource Conservation and Development, Inc. with funding from the Illinois Department of Natural Resources and a grant from the Illinois Environmental Protection Agency (FAA agreement number 3190523).

1.0 EXECUTIVE SUMMARY

The karst terrane of Southwest Illinois complicates analysis of potential groundwater contamination. The vulnerability of a karst groundwater system to contamination is not equal for all parcels of land within a given recharge area. Unlike surface water systems, in which a topographic map analysis can quickly define the lands that contribute water to a given sampling point, karst areas require recharge area delineations to show lands that are potential may contribute point source or nonpoint source pollution.

The study area is within an area of intense karstification known as the Waterloo subkarst (Aley *et al*., 2000). Sinkholes, caves, and springs are characteristic of the area. The area is underlain by St. Louis Limestone and covered with a thick mantle of loess (wind-deposited silt). The study area is characterized by a high density of sinkholes that permit rapid movement of surface water into the groundwater system. This creates many opportunities for rapid transport of contaminants to a groundwater system used for residential water supplies and that provides habitat for cave dwelling species. The area has been undergoing a conversion from agriculture to residential use since the mid-1980s. As many rural residents draw water from wells completed in the same (or cave-containing rock formations) rock formation as those of caves, land use conversion has the potential to cause decreased water quality.

The study area is bounded by Andys Run to the north, the Pautler Cave System recharge area to the east (Aley and Moss, 2001), the headwaters of Fountain Creek to the south, and by Bond Creek to the west.

Our proposal estimated that 15 new dye introductions would be needed. In fact, 19 new dye introductions were made which demonstrated 21 groundwater flow paths. These groundwater traces, 15 previous groundwater traces, topography, and proprietary cave map overlays were used as the basis for the recharge area delineation of Frog Spring, Luhr Spring, Dual Spring, and to complete and revise the Antler-Annbriar Springs System. Two other recharge areas not required by our contract were also completed. The additional recharge areas are of Schnellbecher Spring and Andys Run Spring. This makes a total of seven recharge areas delineations completed (including the previously delineated Pautler Cave) in the Waterloo subkarst and these are all shown on Figure 29. In addition to the utility of these recharge areas for land use decision making generally, all of the groundwater systems known to provide habitat for the Illinois cave amphipod now have delineated recharge areas. The Illinois cave amphipod (*Gammarus acherondytes*) is listed as a Federal and State endangered species and is a globally-rare species.

Antler-Annbriar Springs

One of the characteristics that make the Antler-Annbriar Springs groundwater system important is that it provides habitat for the Illinois cave amphipod. Aley and Moss (2001) provided a partial delineation of the Annbriar Spring recharge area. The size of the area was estimated to be approximately 6.0 square miles at low flow and approximately 12.1 square miles at high flow. The difference arises because most of the Pautler Cave Recharge Area to the east of the Antler-Annbriar Springs low flow recharge area can overflow to the Antler-Annbriar groundwater system under high flow conditions (Aley and Moss, 2001). The current investigation revised the low flow recharge area down to approximately 5.6 square miles and the high flow recharge area to 11.6 square miles.

There is some significance to the geographic setting of both Antler and Annbriar Springs. Annbriar Spring is actually a complex of ever-changing discharge points, almost all of which are in the bed of Fountain Creek. After major flood events, the channel gravels are rearranged and often old outlets clog and new outlets open up. Antler Spring, however, is a single orifice spring on the north side of the Fountain Creek floodplain. It is more intuitive to recognize that a spring rising in a creek bed might be recharged from both sides of the creek in which it is located, as is the case with Annbriar Spring. However, it is not particularly intuitive that a spring, such as Antler Spring, at one edge of a valley whose floor is about 700 feet wide would be recharged by lands on both sides of the creek and has in fact, much longer flow paths from the south than from the north side where Antler Spring discharges.

Dual Spring Recharge Area

Dual Spring gets its name from a pair of rise pools that are about 30 feet apart. Dual Spring West has perennial flow, while Dual Spring East discharges only under relatively high flow conditions. One of the characteristics that make the Dual Spring groundwater system important is that it provides habitat for the Illinois cave amphipod. Previous tracing, in particular Trace 97-11 shown on the inset on Figure 3, (Aley *et al*., 1998) demonstrated that Fountain Creek loses some of its water which is then discharged from Dual Spring. This finding requires inclusion of the entire topographic watershed of Fountain Creek upstream of the losing point. This extends the recharge area into areas that are not mapped as karst and do not appear to function as karst. This area includes about half of the City of Waterloo.

Since Pautler Cave discharges into Fountain Creek upstream of the losing point that recharges Dual Spring, the Pautler Cave recharge area is entirely shared with Dual Spring (as well most of it being shared with Antler-Annbriar Springs at very high flows).

Like the Antler-Annbriar Springs recharge, Dual Spring also has different recharge areas under normal and very high flow conditions. Figure 24 shows both the high and low flow recharge areas and are labeled as such. The low flow recharge area encompasses approximately 27.7 square miles. However, under high flow conditions when the part of the Antler-Annbriar Springs recharge area south of Fountain Creek overflows from Reverse Stream, the recharge area includes approximately 31.7 square miles.

Luhr Spring

The Luhr Spring recharge area lies adjacent to and generally east of the Dual Spring recharge area. One of the characteristics that make the Luhr Spring groundwater system important is that it provides habitat for the Illinois cave amphipod. The recharge area includes approximately 1.3 square miles, all of which lies on the south side of Fountain Creek. The Luhr Spring recharge area has a cave system whose main axis is to the northeast and converges on the axis of the Columbia Syncline, essentially parallel to Snow White Cave in the Dual Spring recharge area. Figure 25 shows the Luhr Spring recharge area. Luhr Spring has the same recharge area under all flow conditions and no part of its recharge area has been shown to be shared with any other groundwater system.

Frog Spring

Frog Spring is the only groundwater system known to provide habitat for the Illinois cave amphipod that discharges on Bond Creek. Bond Creek is a major tributary of Fountain Creek, it flows north roughly parallel to the Mississippi River valley bluff line and generally about one mile east of the bluff line.

Frog Spring's recharge area appears to be the same under all flow conditions and no recharge areas have been identified as shared with any other groundwater system. Figure 26 shows the Frog Spring recharge area. The Frog Spring recharge area encompasses approximately 2.2 square miles.

Schnellbecher Spring

The recharge area of Schnellbecher Spring is not one that was listed in our contract to delineate. However, we believe that sufficient data now exists to do so and its recharge area delineation is included for completeness and potential utility for land use decisions. The Schnellbecher Spring groundwater system is not known to have particular biological significance (Lewis *et al*., 2003).

Schnellbecher Spring's recharge area does not change boundaries with changing flow conditions. Schnellbecher Spring, like Frog Spring to the south, discharges on Bond Creek. There is no evidence of Schnellbecher Spring sharing recharge with any other groundwater systems. The recharge area encompasses approximately 0.6 square miles and is shown on Figure 27.

Andys Run Spring

The recharge area of Andys Run Spring is not one that was listed in our contract to delineate. However, we believe that sufficient data now exists to do so and its recharge area delineation is included for completeness and potential utility for land use decisions. The Andys Run Spring groundwater system is not known to have particular biological significance (Lewis *et al*., 2003).

Andys Run Spring's recharge area does not change boundaries with changing flow conditions. Andys Run Spring discharges on Andys Run and is the only groundwater system delineated that discharges on Andys Run. There is no evidence of Andys Run Spring sharing recharge with any other groundwater systems. The recharge area encompasses approximately 0.3 square miles and is shown on Figure 28. It should be noted that the western boundary is not well defined at this time.

Significant Findings

Of particular note is that this investigation resulted in a revision of the Annbriar Spring Recharge Area on the south side of Fountain Creek. The Reverse Stream Overflow Trace demonstrated that land that almost certainly overlies conduits which discharge at Annbriar Spring actually recharges Dual Spring. However, that should not affect any IDNR consultation or other endangered species affected decision-making since both groundwater systems provide habitat for the Illinois cave amphipod.

It has also been illuminating to witness and document the evolution of the Annbriar Spring groundwater system, which over the last ten years or so has changed from most of the water being discharged from the Annbriar Spring Complex to now being primarily discharged from Antler Spring. Antler Spring has been shown in this study to be connected directly to the same groundwater flow paths which discharge or formerly discharged at Annbriar Spring.

For planning purposes we believe that it is important to understand that the Fountain Creek watershed part of the Dual Spring recharge area generally presents less of a threat to groundwater quality than the rest of the recharge area for three reasons:

- Only a small percentage of the water in Fountain Creek recharges Dual Spring, thus not all contamination moving down Fountain Creek enters the groundwater system.

- The groundwater path to the spring seems relatively short and is unlikely to pass through much Illinois cave amphipod habitat. The flow path's straight-line length is less than 850 feet. Undoubtedly, the actual flow path has some sinuosity and is somewhat longer than 850 feet. By not traveling far through the groundwater system, there is less potential habitat impacted and fewer individual Illinois cave amphipods dependent on the water quality along that flow path. It is also likely that this flow path is completely filled with water, which is not thought to be ideal cave amphipod habitat.

- Since most of the flow path for this water is on the surface, there is much more opportunity for natural cleansing of the water than there is along underground flow paths.

The investigation revealed a great deal of complexity in the groundwater systems of Antler-Annbriar Springs and Dual Spring. The major complexities are listed below:

1) The Pautler Cave recharge area all contributes some water to Dual Spring since Pautler Cave discharges upstream of the losing point in Fountain Creek and that water is, in turn, discharged from Dual Spring.

2) The majority of the Dual Spring recharge area is from land that is not karst, but happens to be in the Fountain Creek watershed upstream of the losing point in Fountain Creek that recharges Dual Spring.

3) Dual Spring also is recharged by water that overflows out of Reverse Stream (karst window and overflow spring in the Antler-Annbriar Springs system) under high flow conditions. First, by water that is lost through the overflow channel and then through the

losing point in Fountain Creek when conditions in which overflow is high enough to reach Fountain Creek.

4) Most of the Pautler Cave recharge area is shared with the Antler-Annbriar Springs groundwater system under high flow conditions. At high flows, Pautler Cave overflows into the Antler-Annbriar Springs groundwater system.

5) Part of the Antler-Annbriar Springs groundwater system underlies land which recharges Dual Spring.

6) The Antler-Annbriar Springs recharge area is in two, discontinuous parts; one north of Fountain Creek and the other south of Fountain Creek, which are separated by about 3,500 feet.

7) There is flow crossing under Fountain Creek which discharges at Antler Spring.

Other findings of note and generalizations from the complexities noted above:

8) There are hydrologic connections between some of the groundwater systems. Since selected sinkholes were used as dye introduction points and dye tracing was not conducted under all possible flow conditions, not all of the existing hydrological connections may have been identified.

9) The lands overlying a groundwater system may not recharge that system via discrete recharge features.

10) The sources of spring water in the southwest Illinois karst can come from great distances from the spring and may originate well off the karst area.

11) Groundwater velocities through karst conduits are fast, typically on the order of thousands of feet per day.

12) The persistence of dye pulses is highly variable. If we consider tracer dye as a surrogate for groundwater contamination, it is clear that grab samples of water can easily miss contaminant pulses unless they are very high frequency samples, such as a daily collection.

13) Streams mapped as surface streams may be losing or sinking streams.

14) There is no substitute for comprehensive dye tracing in understanding groundwater movement in karst. It is also reasonable to consider that more complexity in karst groundwater movement is recognizable with more detailed investigations of groundwater movement.

The recharge areas are generally interpolations between dye introduction points. The recharge area boundaries are often zones having appreciable width instead of a finite line, except when a topographic divide is the boundary. When a change of land use is being considered which could significantly impact water resources is proposed or planned near a recharge area boundary and if there is not already site-specific groundwater tracing data, site-specific dye tracing should be done prior to significant investment in or approval of the proposed change. The site-specific tracing would provide direct, empirical evidence of which groundwater system or systems have the potential to be impacted.

In the southwest Illinois karst, a great deal of effort has gone into the groundwater tracing work to delineate recharge. 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 and plans in the region. Data left on the shelf do not help to enhance or protect public health or natural resources. It is important that the recharge area delineation rationales be read and understood, instead of placing sole reliance on paper or digital maps.

Vulnerability mapping should be conducted for the delineated recharge areas. As briefly mentioned in this report, the vulnerability of a karst 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 its fauna. 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

2.1 Background and Purpose

In karst, it is not possible to tie water quality to particular land uses without recharge area delineations. With surface waters, a topographic map can be used to quickly define the lands that contribute water to a given sampling point. However in karst identifying the lands contributing water is not obvious and often there is transfer of water across topographic basin boundaries. So, recharge area delineations are a necessary additional step in tying water quality to both point source and nonpoint source pollution.

Protection and recovery efforts on behalf of the Illinois cave amphipod and groundwater quality are quite limited if the lands to be protected are not defined. This project is designed to provide the land identifications necessary to implement appropriate protection strategies including Illinois Department of Natural Resources (IDNR) Consultation, listing on the Illinois Natural Area Inventory (INAI), potential designation as Class III groundwater, US Fish and Wildlife Service (USFWS) and US Department of Agriculture (USDA) conservation policies. The Ozark Underground Laboratory (OUL) has previously delineated nine groundwater systems within Monroe County. Groundwater systems whose recharge areas have not been delineated that are included in this project are Frog Spring, Luhr Spring, and Dual Spring, as well as the recharge area of Annbriar Spring that lies north of Fountain Creek. All of these springs are in Monroe County, Illinois.

2.2 Study Area

The study area is within an area of intense karstification known as the Waterloo subkarst (Aley *et al*., 2000) and is bounded by Andys Run to the north, the Pautler Cave System recharge area to the east (Aley and Moss, 2001), the headwaters of Fountain Creek to the south, and by Bond Creek to the west. The study area is shown on Figure 1 and Figure 2.

The area is underlain by St. Louis Limestone and covered with a relatively thick mantle of loess (wind-deposited silt). The study area is characterized by a relatively high density of sinkholes that permit rapid movement of surface water into the groundwater system. Water also enters the groundwater system through sinking and losing streams. In much of the southwest Illinois karst, all runoff enters the groundwater system. Contaminant and sediment transport is primarily through discrete openings into the bedrock and the groundwater system that are frequently large enough to permit turbulent flow into and through the groundwater system.

The area has been undergoing a conversion from agriculture to residential use since the mid-1980s. This change in land use has been a source of concern as a cause for decreased water quality in the karst area. It is especially a concern because many rural residents draw water from wells completed in the same rock formation that the caves occur. This creates many opportunities for rapid transport of contaminants to residential water supplies and to the cave streams which support important biological communities.

Figure 1
Location of the Study Area

3.0 METHODS

3.1 Groundwater Tracing Methods

Groundwater tracing with fluorescent dyes is a very valuable investigative technique in karst aquifers (Aley, 2000). Fieldwork was conducted to identify locations where waters sink from the surface into the groundwater system. Sampling stations were established in relevant springs, surface streams, and any other potentially relevant locations to be continuously sampled for the subsequent presence of the dye. Next, tracer dyes were selected and introduced into the sinking water. Sampling was conducted on a continuous basis until the end of the project.

3.2 Tracer Dye Nomenclature

Four fluorescent dyes were used in this groundwater tracing study. Fluorescein's Color Index (C.I.) name is Acid Yellow 73, C.I. Number 45350. Rhodamine WT's C.I. name is Acid Red 388; there is no assigned Color Index Number for this dye. Eosine's (sometimes called eosin) C.I. name is Acid Red 87, C.I. Number 45380. Sulforhodamine B's C.I. name is Acid Red 52, C.I. Number 45100. All four of the dyes used are harmless in the typical concentrations used in professionally directed groundwater tracing (Smart, 1984; Field *et al.*, 1995). All four of these dyes are typically and routinely used for groundwater tracing studies, and the OUL has successfully used all four in numerous studies in the region and elsewhere (*e.g.* Aley and Moss, 2001; Aley *et al.*, 2000).

3.3 Dye Introductions

The results of 19 dye introductions are included in this report and were initiated for this investigation. Fifteen additional groundwater flow paths are included that were conducted in previous investigations by OUL. The current traces are numbered sequentially with the first two digits indicating the year, the third digit represents the study area (in this case the Waterloo study area), and the last pair of digits indicates the serial number of the trace. For example, Trace 08-320 was initiated in 2008, it is located in the Waterloo subkarst, and is the 20th trace initiated in the Waterloo subkarst and the first new dye trace for this study. Sampling station numbers use a similar scheme. A three-digit number is assigned to each sampling station. The first digit is a "3" indicating that it is in the Waterloo study area. The final two digits are the serial number within the study area. We retained the numbers for stations that were used by Aley and Moss (2001) and have continued the sequence for stations that were added for this investigation.

The "Results" section of this report contains the details of the individual dye introductions, including the locations and elevations of the dye introduction points.

3.4 Sampling Stations Used

The sampling stations are located on the Waterloo or Valmeyer 7.5-minute quadrangle maps. The locations of the sampling stations were obtained with a Trimble Juno ST GPS (global positioning system), which is capable of resolution to as little as seven feet. The locations of the sampling stations are shown on Figure 2. An index to dye sampling locations is presented in Table 1.

Table 1. Index to dye sampling stations.

Sta. No.	Station Name	North Latitude	West Longitude	Map	Elevation (ft)
307	Dual Spring East	38.34522	90.20972	Waterloo	435
308	Dual Spring West	38.34534	90.20992	Waterloo	435
309	Annbriar Spring	38.34715	90.20737	Waterloo	435
310	Fountain Creek upstream Annbriar Spring	38.34670	90.20654	Waterloo	436
311	Fountain Creek at HH Road	38.36476	90.23295	Waterloo	415
318	Fountain Creek upstream of sink point	38.34321	90.20795	Waterloo	438
319	Fountain Cr. downstream Annbriar Spring	38.34706	90.20891	Waterloo	433
321	Floodplain Estavelle	38.34393	90.20834	Waterloo	436
326	small spring downstream of Dual Spring	38.34558	90.21107	Waterloo	433
327	Reverse Stream	38.33010	90.22035	Waterloo	520
329	Frog Spring	38.32239	90.24481	Valmeyer	550
330	Schnellbecher Spring	38.34744	90.25592	Waterloo	470
331	Bond Creek at HH Road	38.36542	90.24075	Waterloo	410
332	Antler Spring	38.35284	90.21442	Waterloo	432
333	Luhr Spring	38.35303	90.21754	Waterloo	431
334	Barker Spring	38.35291	90.22266	Waterloo	425
335	Bond Creek upstream of Schnellbecher Spring	38.34697	90.25663	Valmeyer	475
337	Bond Creek upstream Frog Spring	38.32227	90.24527	Waterloo	551
338	Bond Creek at D Road	38.31250	90.25982	Valmeyer	790
339	Sore Knee	38.35519	90.22005	Waterloo	440
340	Fountain Creek upstream Luhr Spring	38.35316	90.21717	Waterloo	430
341	Fountain Creek upstream Barker Spring	38.35327	90.22138	Waterloo	426
342	Andys Run at Andy Road	38.37055	90.21055	Waterloo	435
343	Andys Run Spring	38.36896	90.21692	Waterloo	450
344	Downstream Andys Run	38.37040	90.23012	Waterloo	415
345	Metzger Spring	38.36565	90.23204	Waterloo	412
346	White Oak Spring	38.35317	90.22162	Waterloo	438

Surface sampling stations were established to identify potential groundwater discharges from unsampled or unknown springs. The remaining sampling stations sample groundwater discharges from springs directly and provide detail on the groundwater flow paths.

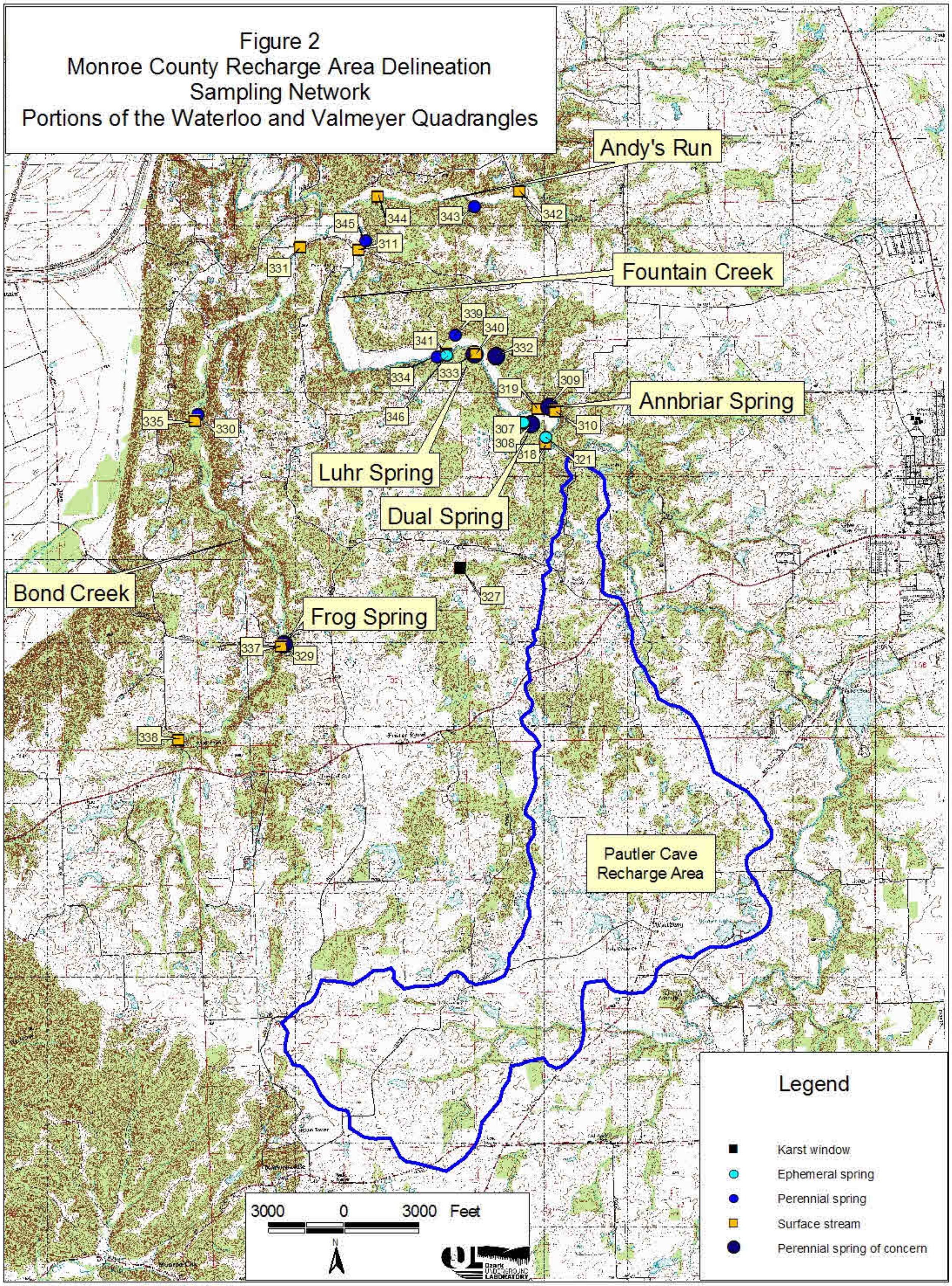


Figure 2
Monroe County Recharge Area Delineation
Sampling Network
Portions of the Waterloo and Valmeyer Quadrangles
Andy's Run
Fountain Creek
Annbriar Spring
Luhr Spring
Dual Spring
Bond Creek
Frog Spring
Pautler Cave
Recharge Area
344
343
342
345
311
331
339
341
340
332
334
333
319
309
346
335
330
307
308
310
318
321
327
337
329
338
Legend
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
3000
0
3000
Feet
N

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 analyses were conducted using a Shimadzu RF-5301 spectrofluorophotometer operated under a synchronous scan protocol. A brief description is included in the Sections 3.5.1 and 3.5.2 for the reader's convenience. OUL's Procedures and Criteria document is provided in Appendix B.

3.5.1 Activated Carbon Samplers

All four of the dyes used (fluorescein, eosine, rhodamine WT, and sulforhodamine B) can be adsorbed onto laboratory grade coconut shell charcoal samplers. The samplers are placed in the water to be sampled and typically are left for periods of about one to two weeks.

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

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

Samples collected in the field were immediately refrigerated and maintained under refrigeration until delivery to the laboratory. Upon arrival at OUL, samplers were immediately refrigerated at 4^{o} C until analysis. All sampler placement, collection, and analysis work was conducted by OUL personnel. Philip Moss, who is licensed as a Professional Geologist by the State of Illinois, conducted all of the fieldwork.

3.5.2 Water Samples

Water samples were analyzed during the study for background fluorescence, if dye were detected in the associated carbon sample, or if activated carbon samplers had been lost. Water collections were made in disposable 50 ml capped vials and are immediately refrigerated and maintained under refrigeration until delivery to the laboratory. Upon arrival at OUL, samples were immediately refrigerated at 4^{o} C until analysis. Approximately 2.5 ml of the water sample is withdrawn with a disposable pipette and placed in a disposable cuvette. This sample was then analyzed using OUL's spectrofluorophotometer. All water samples were collected and analyzed by OUL personnel. Philip Moss, who is licensed as a Professional Geologist by the State of Illinois, conducted all of the fieldwork. These samples provide data on the quantities of dyes present at the time of collection.

4.0 RESULTS

4.1 Introduction

Our proposal estimated that 23 sampling stations would be used for detecting dye. Twenty-seven sampling stations were established for this investigation. OUL made 19 dye introductions specifically for this study to date and is including the results in this report of 13 additional dye introductions that demonstrated 15 different flow paths. These dye traces were conducted by OUL prior to this study. These previous traces are briefly discussed in Section 4.2.

4.2 Previous Groundwater Tracing Results

Thirteen groundwater traces were conducted prior to this investigation that are relevant to the delineation of the springs of concern to this study. They have the following numeric designations: 96-01, 97-03, 97-04, 97-09, and 97-11, which are discussed in detail by Aley and Aley (1998); 98-03, which is discussed by Moss (1998); and 00-301, 00-304, 00-308, 00-314, 00-316, 00-317, and 01-318, which are discussed in detail by Aley and Moss (2001). Figure 3 shows the diagrammatic flow paths of these traces.

The traces are listed below first by groundwater system and then by chronology.
Antler-Annbriar Springs: 96-01, 97-04, 97-09, 98-03, 00-301, 00-304, 00-308, 00-316, and 00-316

Dual Spring: 97-11 and 01-318

Frog Spring: 00-314

Luhr Spring: 00-317

Vandeventer Spring (Pautler Cave): 96-03. 96-03, 97-10, 00-302, 00-303, 00-305, 00-306, 00-307, 00-310, and 00-315

Schnellbecher Spring: 97-01 and 97-03

Trace 97-11 is especially important because it demonstrated that Fountain Creek loses some of its flow into the Dual Spring groundwater system. The straight-line flow path is about 825 long and the elevation loss is about three feet. The losing point has been observed to reverse flow under high flow conditions and discharge water into Fountain Creek. This is a complex response that is dependant on both the height of the flow or pressure (stage and head, respectively) in the Dual Spring groundwater system and the stage of Fountain Creek. To reverse flow, there must be appreciably more head in the Dual Spring groundwater system near the losing point than there is in Fountain Creek. Since the systems have different response times, the relationship can change quickly and the direction of flow can change just as quickly.

The importance of Fountain Creek providing recharge to Dual Spring is that the entire Fountain Creek watershed upstream of the losing point is part of the Dual Spring recharge area.

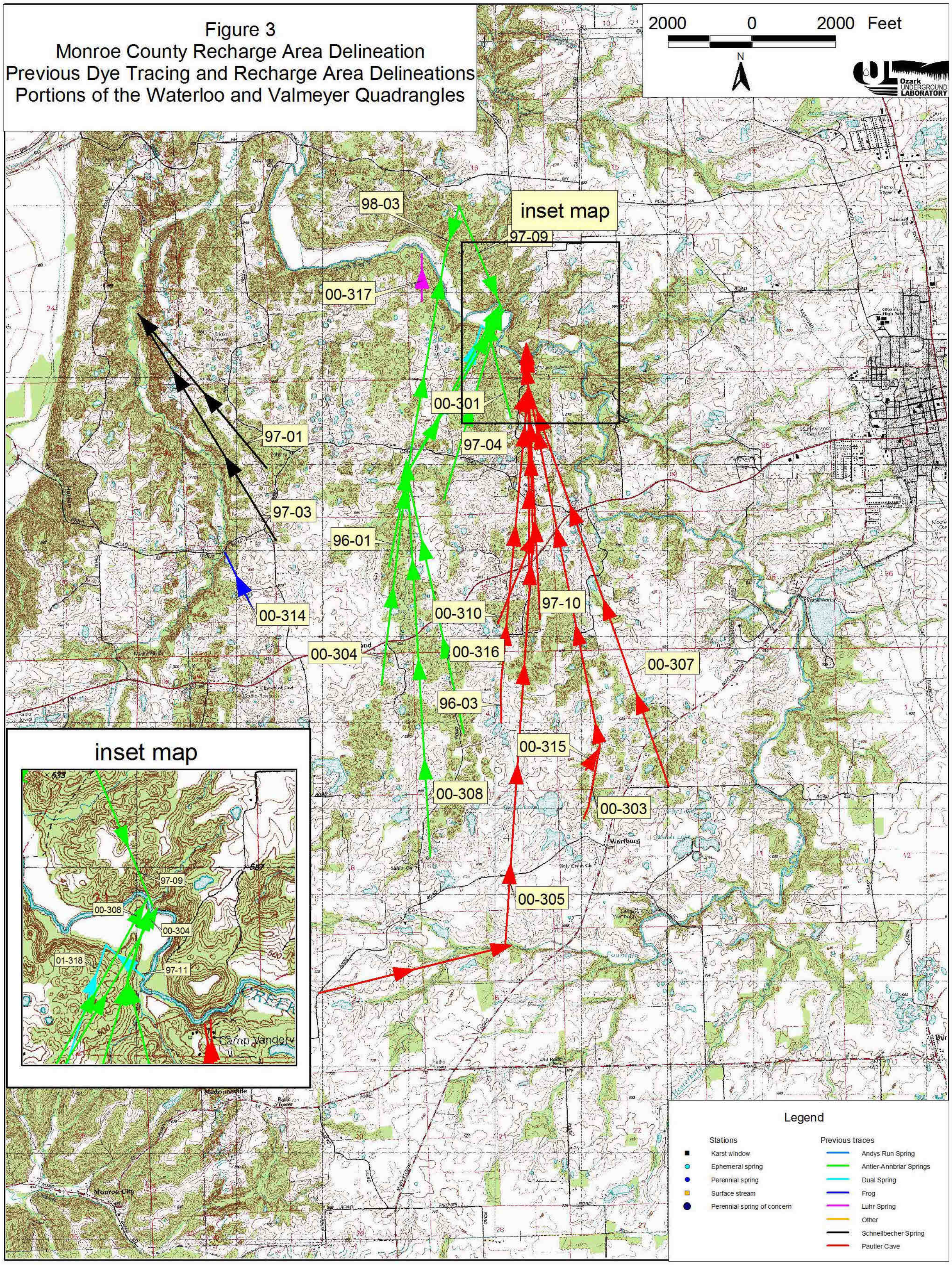


Figure 3
Monroe County Recharge Area Delineation
Previous Dye Tracing and Recharge Area Delineations
Portions of the Waterloo and Valmeyer Quadrangles
2000 0 2000 Feet
N
Ozark Underground Laboratory
inset map
98-03
97-09
00-317
00-301
97-01
97-04
97-03
96-01
00-314
00-310
97-10
00-304
00-316
00-307
96-03
00-315
00-308
00-303
00-305
Wartburg
inset map
97-09
00-308
00-304
01-318
97-11
Camp Vandeventer
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Previous traces
Andys Run Spring
Antler-Annbriar Springs
Dual Spring
Frog
Luhr Spring
Other
Schnellbecher Spring
Pautler Cave

4.3 New Groundwater Tracing Results by Individual Traces

The dye tracing results initiated under contract with Southwestern Illinois Resource Conservation and Development, Inc. are discussed in the following sections. The serial number assigned to the traces conducted for this investigation continue from those assigned by Aley and Moss (2001), which were also done in the Waterloo subkarst. We believe that this convention will minimize confusion among users of both sets of data. For each dye introduction the following information (where applicable) 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) the locations where dye was detected,
5) tables showing dye detections, and
6) relevance to the project.

In the tables showing dye detections in the individual trace discussions, footnotes are sometimes used to qualify the results. Table 2 explains the footnotes that are used in the dye detection tables. Complete reporting of the results of all analyzed samples are provided in Appendix A.

Table 2. Explanation of Footnotes.

Footnote	Explanation
ND	No dye detected
*	A fluorescence peak is present which does not meet all the criteria for a positive dye result. However, it has been calculated as though it were the tracer dye for background purposes.
**	A fluorescence peak is present which does not meet all the criteria for a positive dye result. However, it has been calculated as though it were the tracer dye.
(1)	The charcoal packets were out of the water when they were recovered.
(2)	A fluorescence peak is present that does not meet all the criteria for a positive dye result. However it has been calculated as a positive dye result because dye was found in the corresponding charcoal sampler.
(3)	Only a water sample was collected during this sampling period.
(4)	A fluorescence peak is present that doesn't meet all the criteria for this dye. However, since this dye is present in previous samples, the concentration has been calculated as this dye.
(5)	There was no flow at this site when the charcoal was collected.
(6)	No samples were collected because there was no flow and the water was frozen.
(7)	The site was dry when the charcoal was collected.
(8)	The packets were buried in mud when the charcoal was collected.
(9)	No charcoal or water was collected during this sampling period.

4.3.1 Trace 08-320: Bond Creek Trace

On January 1, 2008 at 1600 hours, three pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into Bond Creek. The dye introduction point was at 38.29449^{o} North Latitude (N) and 90.25713^{o} West Longitude (W) at an elevation of approximately 650 feet above mean seal level (msl). Flow was estimated to be approximately 15 gallons per minute (gpm) at the time of dye introduction. The purpose of the trace was two-fold; to determine whether or not Bond Creek loses water through its channel that recharges Frog Spring and also to determine whether or not groundwater is likely to flow under Bond Creek. If no losing reaches were found, then it would almost be certain that there is no shallow groundwater flow under Bond Creek. Previous investigations have shown that groundwater does flow under Fountain Creek in the study area and therefore the possibility of similar hydrologic patterns in and under Bond Creek warranted investigation.

Dye from Trace 08-320 was detected at the following sampling stations (from upstream to downstream):

Dye Detection from Trace 08-320: Station 338 – Bond Creek at D Road.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
12/4 to 12/18/07	ND	ND
12/18/07 to 1/7/08	541.5	2,460
1/7 to 1/11/08	541.7	847
1/11 to 1/22/08	541.0	254
1/22 to 2/8/08	540.9	222
2/8 to 3/3/08	540.7	61.5
3/3 to 3/7/08	540.5	5.15
3/7 to 3/14/08	540.5	20.5
3/14 to 3/21/08	540.6	6.98
3/21 to 4/2/08	540.4	6.74
4/2 to 4/14/08	541.0	1.50
4/14 to 4/24/08	539.9	3.54
4/24 to 5/27/08	540.0	1.92
5/27 to 6/9/08	538.7	1.75
6/9 to 6/18/08	539.4	3.01
6/18 to 6/25/08	538.7 (4)	1.23
6/25 to 7/10/08	540.8	1.34
7/10 to 8/12/08	539.2	1.27
8/12 to 10/2/08	ND	ND

Dye Detection from Trace 08-320: Station 337 – Bond Creek upstream of Frog Spring.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
12/4 to 12/18/07	ND	ND
12/18/07 to 1/7/08	541.1	305
1/7 to 1/11/08	541.4	62.1
1/11 to 1/22/08	540.9	27.9
1/22 to 2/8/08	540.7	24.6
2/8 to 3/3/08	540.7	15.6
3/3 to 3/7/08	541.1	2.34
3/7 to 3/14/08	540.6	3.67
3/14 to 3/21/08	541.5	1.08
3/21 to 4/2/08	541.3	1.62
4/2 to 4/14/08	ND	ND

Dye Detection from Trace 08-320: Station 335 – Bond Creek upstream of Schnellbecher Spring.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
12/12 to 12/18/07	ND	ND
12/18/07 to 1/7/08	540.5	4.29
1/7 to 1/11/08	541.3	149
1/11 to 1/22/08	541.1	26.1
1/22 to 2/8/08	541.1	11.4
2/8 to 3/3/08	541.3	5.55
3/3 to 3/7/08	543.6 (4)	0.689
3/7 to 3/14/08	541.6	0.571
3/14/08 (water)	ND	ND
3/21 to 4/2/08	ND	ND

Dye Detection from Trace 08-320: Station 331 – Bond Creek at HH Road.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
12/18/07 to 1/7/08	ND	ND
1/7 to 1/11/08	541.1	14.9
1/11 to 1/22/08	541.1	13.0
1/22 to 2/8/08	540.4	3.21
2/8 to 3/3/08	540.7	2.41
3/3 to 3/7/08	ND	ND

No dye was detected at either of the sampled springs along Bond Creek; Frog Spring and Schnellbecher Spring. We conclude from these data that Bond Creek is not a losing creek, that shallow groundwater almost certainly does not flow under it, and most importantly, that Bond Creek does not recharge Frog Spring. Figure 4 shows the diagrammatic flow path of the Bond Creek Trace.

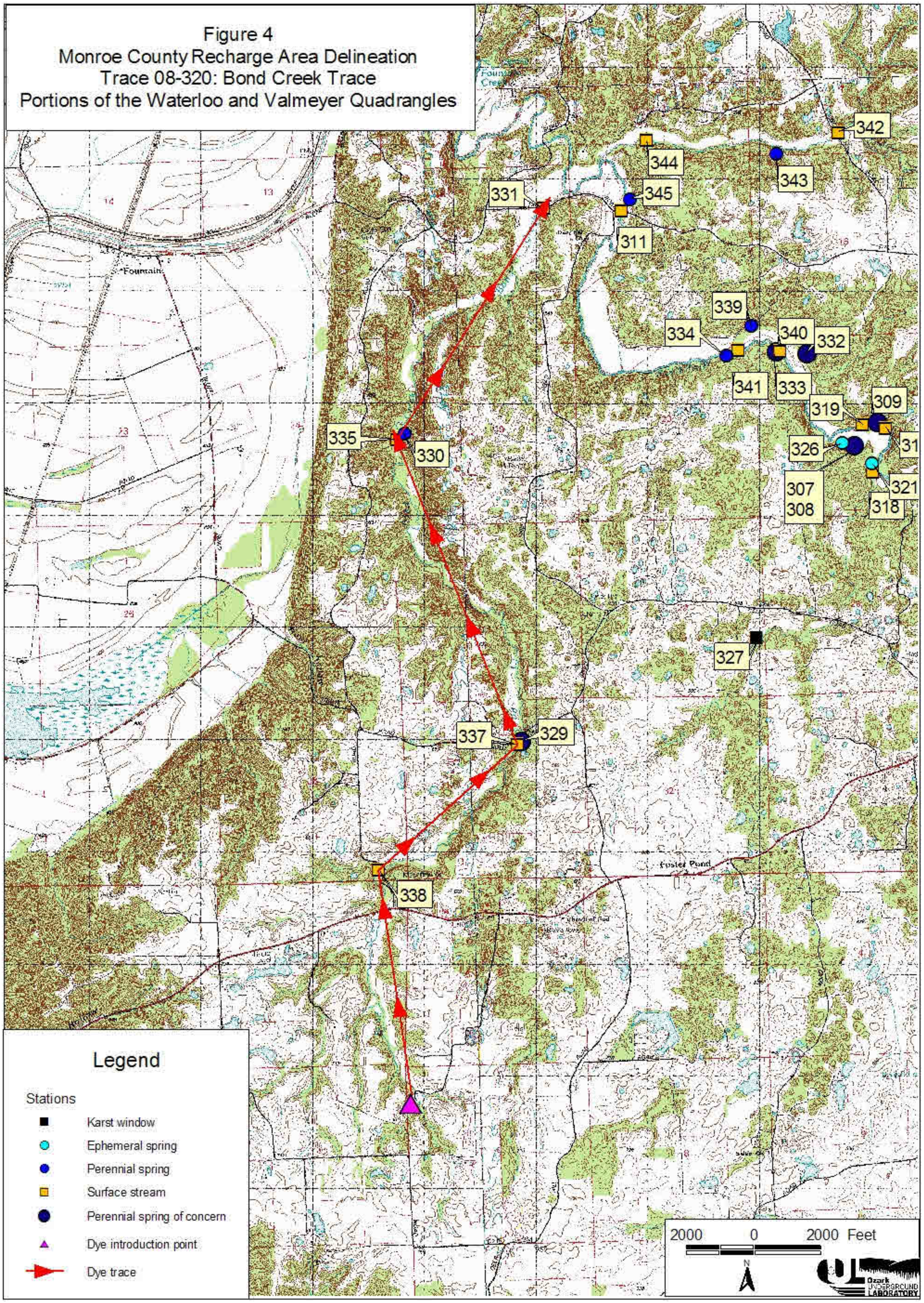


Figure 4
Monroe County Recharge Area Delineation
Trace 08-320: Bond Creek Trace
Portions of the Waterloo and Valmeyer Quadrangles
342
344
343
345
331
311
339
334
340
332
341
333
319
309
335
330
326
307
308
321
318
327
337
329
338
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
2000 0 2000 Feet
N

4.3.2 Trace 08-321: Antler Trace

On January 1, 2008 at 1700 hours, one-quarter pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into pooled water in a wet-weather sinking stream. The dye introduction point is located at 38.35670^{o} N and 90.21510^{o} W at an elevation of approximately 480 feet msl. There was no apparent flow at the time of dye introduction.

Dye from Trace 08-321 was detected at the one sampling station:

Dye Detection from Trace 08-321: Station 332 – Antler Spring.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
12/5 to 12/18/07	ND	ND
12/18/07 to 1/7/08	516.4 **	0.923
1/7 to 1/11/08	515.4	9.42
1/11 to 1/22/08	513.6 **	1.12
1/11 to 1/22/08 duplicate	514.8 **	0.801
1/22 to 2/8/08	515.4	2.94
2/8 to 2/27/08	518.2 **	0.715
2/27 to 3/3/08	ND	ND

There were also irregular peaks in the range of fluorescein dye in samples collected in Fountain Creek (on which Antler Spring is located), the timing of which was consistent with the detections being derived from Antler Spring discharge. The concentrations indicate that most of the dye was discharged from Antler Spring, but that a small quantity of dye may have been discharged from the Annbriar Spring Complex. The hydrological relationship between the Annbriar Spring Complex and Antler Spring is discussed in more detail in Section 4.3.3. The definite detection of dye at Antler Spring along with the results from Trace 08-322, discussed in the next section, shows that this dye introduction point is within the Annbriar Spring recharge area. Figure 5 shows the diagrammatic flow path of the Antler Trace.

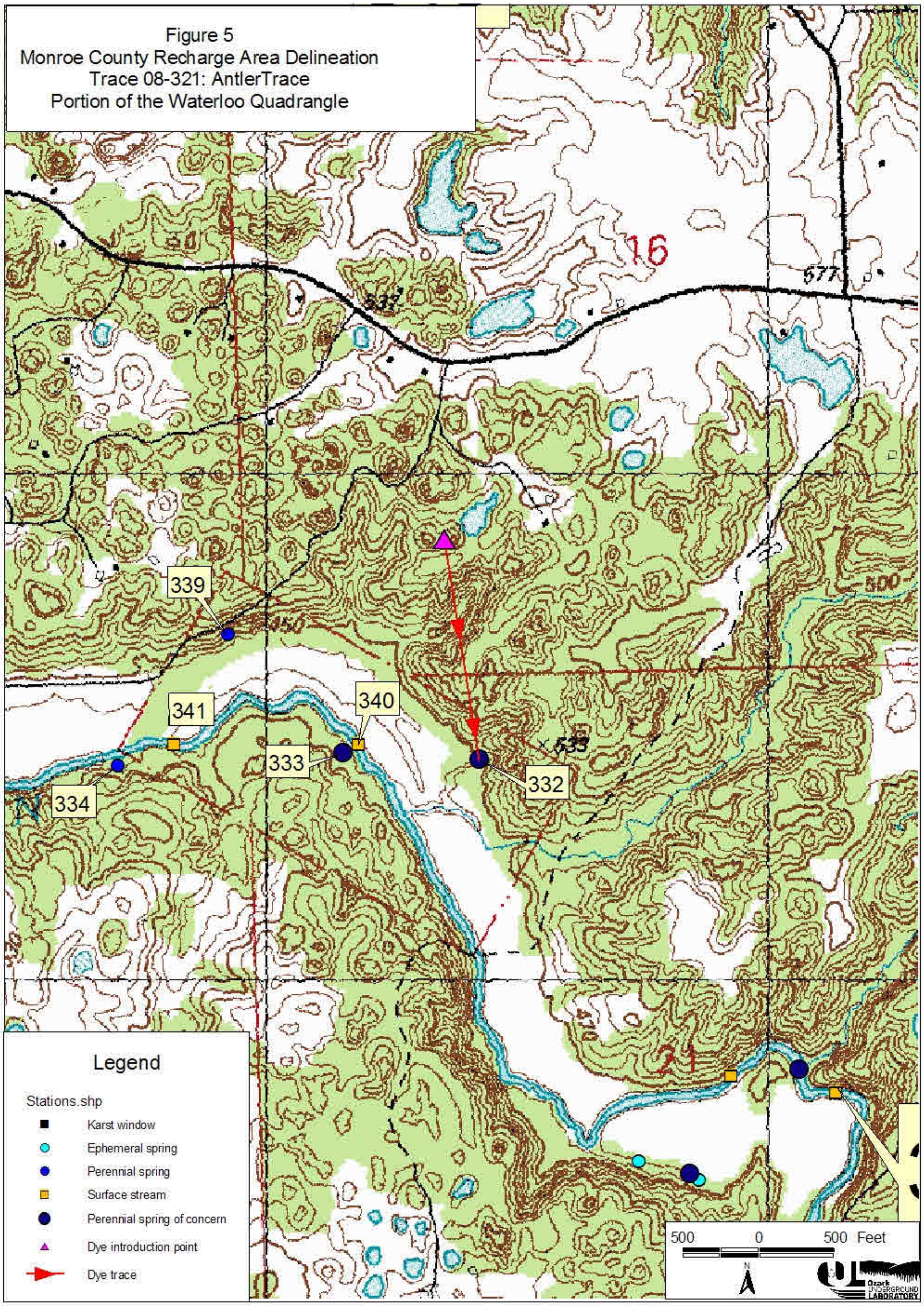


Figure 5
Monroe County Recharge Area Delineation
Trace 08-321: AntlerTrace
Portion of the Waterloo Quadrangle
16
339
341
340
333
332
334
21
Legend
Stations.shp
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
500
0
500 Feet

4.3.3 Trace 08-322: Hoffman Trace

On January 6, 2008 at 1530 hours, one pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into the downstream end of a large karst window. The location of the dye introduction point was 38.29757° N and 90.22849° W at an elevation of approximately 660 feet msl. Approximately eight gpm were sinking into the groundwater system at the time of dye introduction.

Dye from Trace 08-322 was detected at the following sampling stations:

Dye Detection from Trace 08-322: Station 309 – Annbriar Spring.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
12/18/07 to 1/7/08	ND	ND
1/7 to 1/11/08	569.5 **	3.08
1/11 to 1/22/08	ND	ND

Dye Detection from Trace 08-322: Station 311 – Fountain Creek at HH Road.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
1/7 to 1/11/08	ND	ND
1/11 to 1/22/08	567.0 **	4.59
1/22 to 2/8/08	568.8	11.0
2/8 to 2/27/08	ND	ND

Dye Detection from Trace 08-322: Station 319 – Fountain Creek Downstream of Annbriar Spring.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
12/18/07 to 1/7/08	ND	ND
1/7 to 1/11/08	571.3 **	5.95
1/11 to 1/22/08	569.0 **	4.47
1/22 to 2/8/08	569.5	11.6
2/8 to 2/27/08	ND	ND

Dye Detection from Trace 08-322: Station 327 – Reverse Stream.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
12/18/07 to 1/7/08	ND	ND
1/7 to 1/11/08	569.2	54.4
1/11 to 1/22/08	569.1	73.9
1/22 to 2/8/08	568.9	51.3
1/22 to 2/8/08	568.6	58.3
2/8 to 3/3/08	571.4 (4)	3.46
3/3 to 3/7/08	ND	ND

Dye Detection from Trace 08-322: Station 332 – Antler Spring.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
12/18/07 to 1/7/08	ND	ND
1/7 to 1/11/08	569.7	22.5
1/11 to 1/22/08	569.0	6.66
1/11 to 1/22/08 duplicate	568.5	7.49
1/22 to 2/8/08	569.9	25.8
2/8 to 2/27/08	ND	ND

Dye Detection from Trace 08-322: Station 340 – Fountain Creek upstream Luhr Spring.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
12/18/07 to 1/7/08	ND	ND
1/7 to 1/11/08	571.5	3.98
1/7 to 1/11/08 duplicate	570.4 **	3.04
1/7 to 1/11/08 verification	570.3	4.50
1/11 to 1/22/08	569.4 **	3.56
1/22 to 2/8/08	569.3	9.87
2/8 to 2/27/08	ND	ND

Dye Detection from Trace 08-322: Station 341 – Fountain Creek upstream Barker Spring.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
12/18/07 to 1/7/08	ND	ND
1/7 to 1/11/08	569.5	6.16
1/7 to 1/11/08 duplicate	570.0	6.42
1/7 to 1/11/08 verification	568.9	7.25
1/11 to 1/22/08	567.0 **	2.94
1/22 to 2/8/08	569.5	9.72
2/8 to 2/27/08	ND	ND

Annbriar Spring has multiple outlets within the channel of Fountain Creek. The number and locations of these outlets changes over time especially after significant storms. Station 309 is slightly downstream of the main outlet of Annbriar Spring. Station 310 is upstream in Fountain Creek of any known outlets of Annbriar Spring. Station 319 is essentially a backup station for Station 309. It is downstream in Fountain Creek of all the outlets of Annbriar Spring. Figure 6 show the locations of these sampling stations and the diagrammatic flow paths demonstrated by the Hoffman Trace.

Antler Spring is a rise pool spring at the intersection of the valley wall with the Fountain Creek floodplain and is located approximately 575 feet northwest of the Fountain Creek channel. Previous tracing had resulted in detections from the same traces at both Annbriar Spring and at Antler Spring (Aley and Moss, 2001). Those traces showed higher concentrations of dye at Annbriar Spring than at Antler Spring, which is located farther downstream along Fountain Creek. One hypothesis for the paired detections was that all of the dye was being discharged from Annbriar Spring and then some of that discharge leaked back into the groundwater system out of the Fountain Creek channel and was discharged again from Antler Spring. The previous results supported that hypothesis in that the Annbriar Spring dye detections were all higher than those of the same time period collected from Antler Spring. If this hypothesis were true, then groundwater fauna that avoid the surface environment could not be presumed to be present in the Antler Spring groundwater system, since their hydrologic linkage would have a surface connection.

However, the results of Trace 08-322 shed new light on the relationship between Annbriar Spring and Antler Spring. Antler Spring had consistently higher concentrations from this trace than Annbriar Spring did as measured at both Stations 309 and 319. This dye did not flow from Annbriar Spring to Antler Spring, but followed two groundwater paths from the dye introduction point to pair of springs. Concentration data for rhodamine WT dye from Trace 08-322 was higher at Reverse Stream (a karst window in the Annbriar Spring groundwater system) than at either Antler or Annbriar Springs. This suggests that the split in flow paths is downstream of Reverse Stream. It also indicates a change in the proportion of water discharged by Antler and Annbriar Springs since previous tracing studies.

The fact that both springs are recharged by groundwater flow paths from a shared recharge area suggests that this is a distributary system and that aquatic cave fauna associated with either spring should be presumed to inhabit the combined groundwater system (Moss and Aley, 2003). Henceforth, we are using the name Antler-Annbriar Springs to better identify the groundwater system formerly only known as Annbriar Spring.

Since the system is now generally discharging most of the water from Antler Spring instead of Annbriar Spring, we believe that Antler Spring should be part of the name. We also believe that Annbriar Spring should be retained for two reasons; historical continuity and recognition that it may someday recapture more water from the groundwater system.

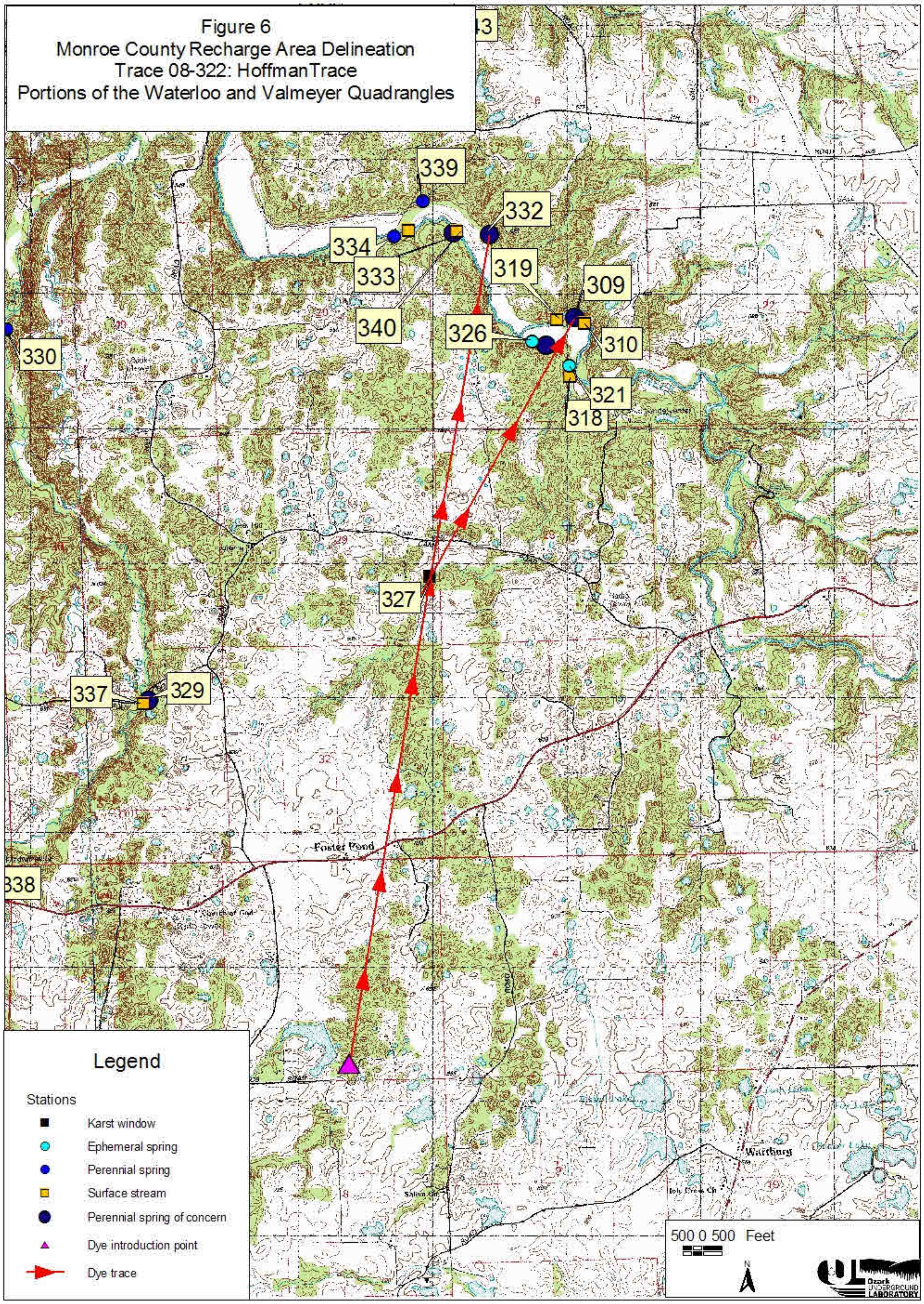


Figure 6
Monroe County Recharge Area Delineation
Trace 08-322: HoffmanTrace
Portions of the Waterloo and Valmeyer Quadrangles
339
332
334
333
319
309
340
326
310
330
321
318
327
337
329
338
Foster Pond
Waitburg
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
500 0 500 Feet
Ozark Underground Laboratory

4.3.4 Trace 08-323: Schmatt Trace

On February 5, 2008 at 2000 hours, one-half pound of eosine was introduced into a sinkhole. The location of the dye introduction point was 38.6048° N and 90.21915° W at an elevation of approximately 510 feet msl. Approximately four gpm of storm water runoff were sinking into the groundwater system at the time of dye introduction. The purpose of the trace was to help define the northwestern boundary of the Antler-Annbriar Springs recharge area. Figure 7 shows the diagrammatic flow path of the Schmatt Trace.

Dye from Trace 08-323 was detected at one sampling station:

Dye Detection from Trace 08-323: Station 343 – Andys Run Spring.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
12/18/07 to 1/7/08	ND	ND
1/7 to 2/27/08	541.0	13.2
2/27 to 3/7/08	540.9	1.44
3/7 to 3/14/08	541.1	1.31
3/14 to 3/21/08	542.0 (4)	0.770
3/21 to 4/2/08	ND	ND

This trace demonstrates that the dye introduction point recharges Andys Run Spring and is outside the Antler-Annbriar Springs recharge area. This is also the first trace detection reported from Andys Run Spring.

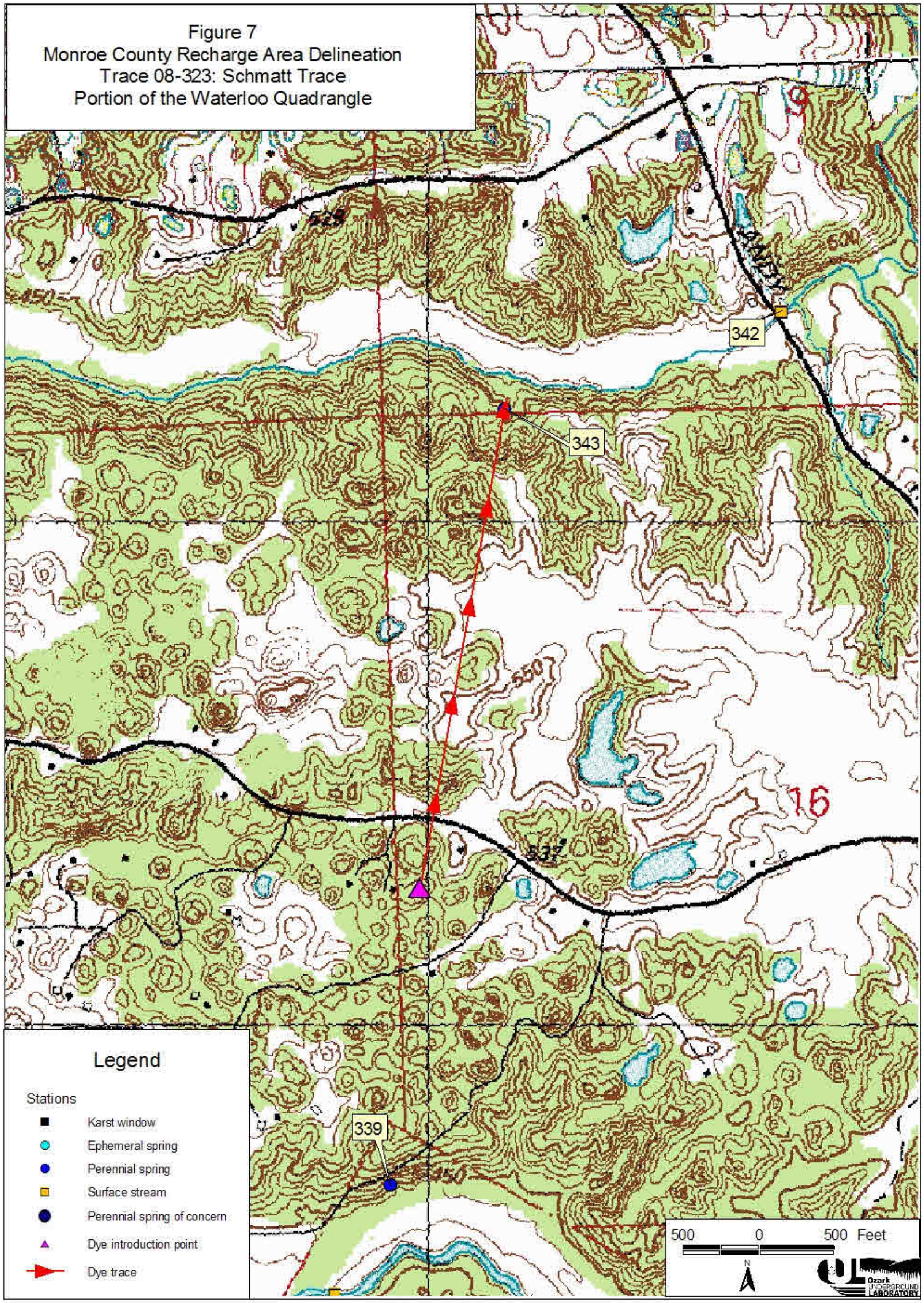


Figure 7
Monroe County Recharge Area Delineation
Trace 08-323: Schmatt Trace
Portion of the Waterloo Quadrangle
342
343
339
16
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
500
0
500 Feet
N

4.3.5 Trace 08-324: Frank Trace

On March 2, 2008 at 1430 hours, one-half pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinking stream. The location of the dye introduction point was 38.34733^{o} N and 90.20092^{o} W at an elevation of approximately 480 feet msl. Approximately ten gpm were sinking into the groundwater system at the time of dye introduction. The purpose of the trace was to help define the eastern boundary of the Antler-Annbriar Springs recharge area. Figure 8 shows the diagrammatic flow path of the Frank Trace.

Dye from Trace 08-324 was detected at one sampling station:

Dye Detection from Trace 08-324: Station 332 – Antler Spring.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
2/27 to 3/3/08	ND	ND
3/3 to 3/7/08	568.9	35.0
3/7 to 3/14/08	ND	ND

Trace 08-324 demonstrates that the Frank sinking stream and its topographic watershed recharge the Antler-Annbriar Springs groundwater system. It also indicates that the two sinking streams and adjacent sinkholes between the Frank Trace dye introduction point and the Antler dye introduction point all recharge the Antler-Annbriar Springs groundwater system.

It is noteworthy that no dye from Trace 08-324 was detected at either Stations 309 or 319 (Annbriar Spring) even though Annbriar Spring is much closer to the dye introduction point than Antler Spring and is part of the same groundwater system.

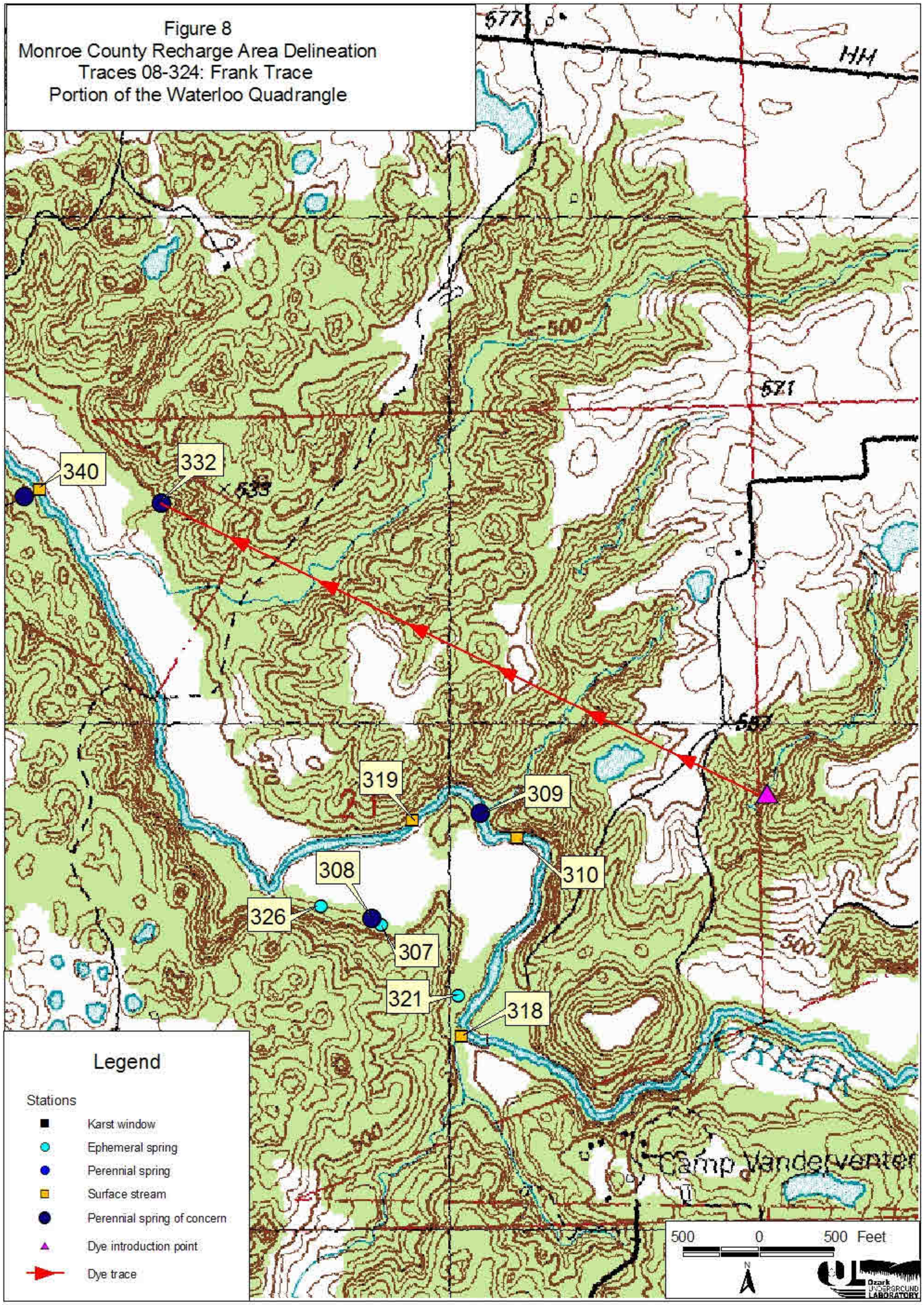


Figure 8
Monroe County Recharge Area Delineation
Traces 08-324: Frank Trace
Portion of the Waterloo Quadrangle
340
332
319
309
310
308
326
307
321
318
CREEK
Camp Vandeventer
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
500
0
500 Feet

4.3.6 Trace 08-325: Flag Trace

On March 3, 2008 at 1610 hours, one-half pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole. The location of the dye introduction point was 38.33568^{o} N and 90.22068^{o} W at an elevation of approximately 555 feet msl. Approximately six gpm of storm runoff were sinking into the groundwater system at the time of dye introduction. The purpose of the trace was to determine in which recharge area the dye introduction point lies. The dye introduction point is near the recharge areas for Antler-Annbriar Springs, Dual Spring, and Luhr Spring. Figure 9 shows the diagrammatic flow path of the Flag Trace.

Dye from Trace 08-325 was detected at the following sampling stations (from upstream to downstream):

Dye Detection from Trace 08-325: Station 333 – Luhr Spring.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
1/11 to 2/27/08	ND	ND
2/27 to 3/7/08	515.8	319
3/7 to 3/14/08	515.6	6.82
3/14 to 3/21/08	517.0	1.12
3/21 to 4/2/08	ND	ND

Dye Detection from Trace 08-325: Station 341 – Fountain Creek upstream Barker Spring.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
1/11 to 2/27/08	ND	ND
2/27 to 3/7/08	516.1	3.76
3/7 to 3/14/08	517.2 **	0.417
3/14 to 3/21/08	ND	ND

Dye Detection from Trace 08-325: Station 311 – Fountain Creek at HH Road.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
1/11 to 2/27/08	ND	ND
2/27 to 3/7/08	516.0	3.23
3/7 to 3/14/08	ND	ND

Trace 08-325 demonstrates that its dye introduction point recharges Luhr Spring. The dye introduction point lies within an approximately 80-acre property that has been subdivided into 20 lots and had a realtor's "For Sale" sign along Trout Camp Road.

Figure 9
Monroe County Recharge Area Delineation
Traces 08-325: Flag Trace
Portion of the Waterloo Quadrangle

4.3.7 Trace 08-326: Andys Run Tributary Trace

On March 18, 2008 at 0635 hours, two pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a tributary of Andys Run. The location of the dye introduction point was 38.36041° N and 90.19985° W at an elevation of approximately 570 feet msl. Approximately 50 gpm of storm runoff was flowing in a wet-weather stream channel at the time of dye introduction. The purpose of the trace was to determine if parts of the Andys Run watershed leak into the Annbriar-Antler Spring groundwater system. Figure 10 shows the diagrammatic flow path of the Andys Run Tributary Trace.

Dye from Trace 08-326 was detected at the following sampling stations (from upstream to downstream):

Dye Detection from Trace 08-326: Station 342 – Andys Run at Andy Road.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
1/7 to 2/27/08	ND	ND
2/27 to 3/21/08	543.2	1.72
2/27 to 3/21/08 duplicate	541.5	2.37
3/21 to 4/2/08	ND	ND

Dye Detection from Trace 08-326: Station 344 – Downstream Andys Run ad.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
1/7 to 2/27/08	ND	ND
2/27 to 3/21/08	542.1	1.65
3/21 to 4/2/08	ND	ND

The section of Andys Run tested by Trace 08-326 does not leak into the Fountain Creek topographic basin and therefore lies outside the Antler-Annbriar Springs recharge area. The tested reach of Andys Run does not recharge any sampled springs.

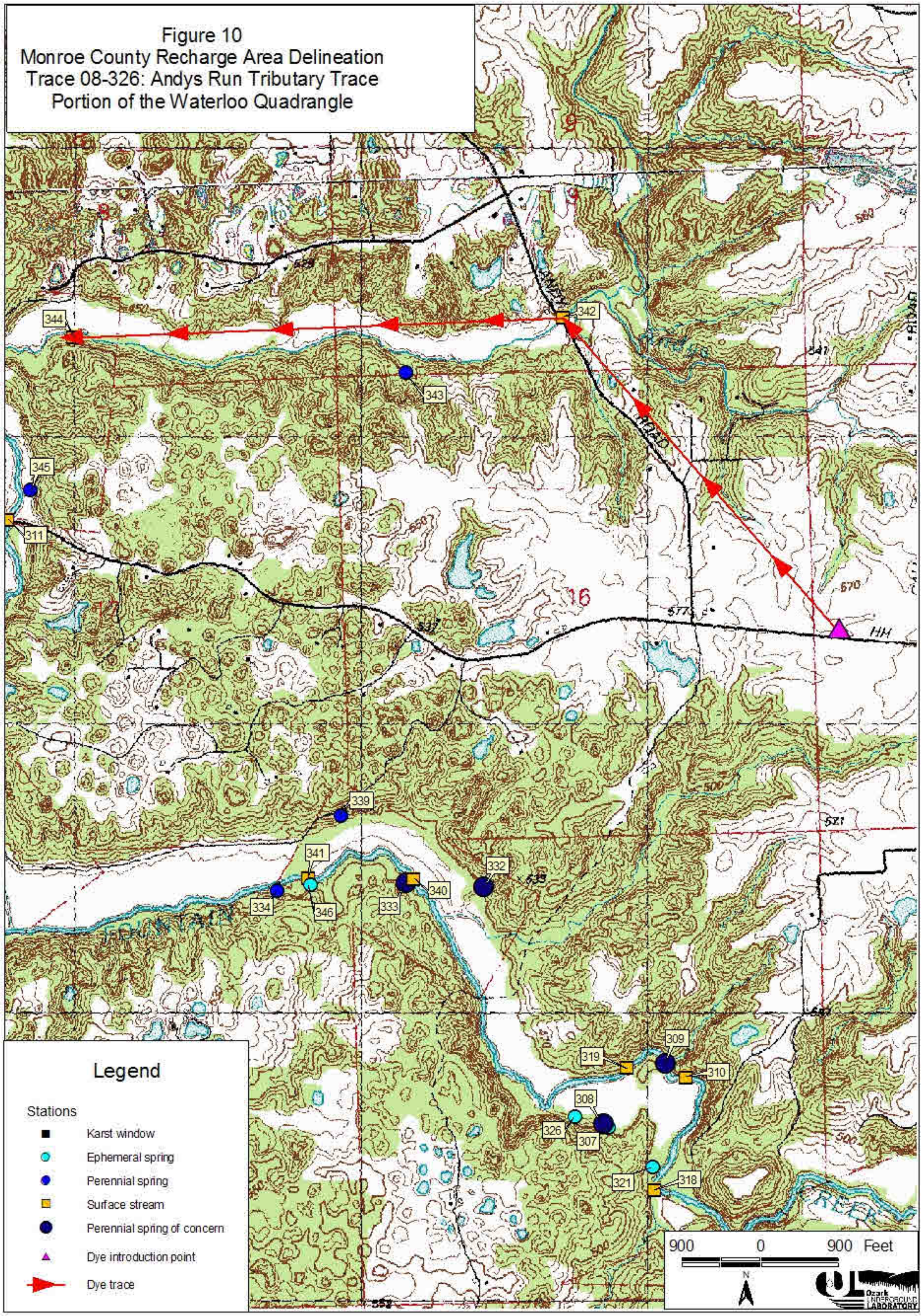


Figure 10
Monroe County Recharge Area Delineation
Trace 08-326: Andys Run Tributary Trace
Portion of the Waterloo Quadrangle
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
900 0 900 Feet
N
Ozark Underground Laboratory
342
344
343
345
311
339
341
332
340
333
334
346
309
319
310
308
326
307
321
318
16
HH

4.3.8 Trace 08-327: Deer Hill Road Trace

On April 10, 2008 at 0436 hours, two pounds of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced into the headwaters of a sinking stream. The location of the dye introduction point was 38.28238° N and 90.24704° W at an elevation of approximately 740 feet msl. Approximately 10 gpm of storm runoff was flowing at the dye introduction point at the time of dye introduction. The purpose of the trace was to determine if the sinking stream recharged the Frog Spring or Antler-Annbriar Springs groundwater system. Figure 11 shows the diagrammatic flow path of the Deer Hill Road Trace.

Dye from Trace 08-327 was only detected at two sampling stations:

Dye Detection from Trace 08-327: Station 329 – Frog Spring.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
3/21 to 4/2/08	ND	ND
4/2 to 4/14/08	578.5	13.1
4/14 to 4/24/08	579.2 (4)	7.77
4/24 to 5/12/08	ND	ND

Dye Detection from Trace 08-327: Station 331 – Bond Creek at HH Road.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
3/21 to 4/14/08	ND	ND
4/14 to 5/27/08	579.0	3.00
5/27 to 6/18/08	ND	ND

Trace 08-327 demonstrates that the sinking stream tested and its topographic basin recharges Frog Spring. It also makes it almost certain that the sinking stream to the west of the tested sinking stream also recharges Frog Spring. We were unable to obtain permission to test the western sinking stream and no public roads cross it (we can introduce dye from public right-of-way).

The failure to detect sulforhodamine dye from Trace 08-327 at Station 335, Bond Creek upstream of Schnellbecher Spring, which is located between Frog Spring and Station 331, was due to the samplers being washed away during the period in which the dye would have passed the sampling station.


Figure 11
Monroe County Recharge Area Delineation
Trace 08-327: Deer Hill Road Trace
Portions of the Waterloo and Valmeyer Quadrangles
339
340
341
332
334
333
319
309
346
335
330
310
307
308
318
321
327
337
329
338
Foster Pond
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
2000
0
2000 Feet
N

4.3.9 Trace 08-328: Gall Road Trace

On April 10, 2008 at 0502 hours, 1.25 pounds of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a tributary of Fountain Creek. The location of the dye introduction point was 38.35059^{o} N and 90.17946^{o} W at an elevation of approximately 575 feet msl. Approximately 250 gpm of storm runoff was flowing at the dye introduction point at the time of dye introduction. The purpose of the trace was to determine if the tributary or the tested portions of Fountain Creek recharge the Antler-Annbriar Springs groundwater system. Figure 12 shows the diagrammatic flow path of the Gall Road Trace. Of course, the dye did not travel in straight-line segments, but followed the stream channel.

Dye from Trace 08-328 was detected at all of the sampling stations located in Fountain Creek and at Dual Spring. The trace did not reveal any new groundwater flow paths. The fact that Fountain Creek recharges Dual Spring was first learned from Trace 97-11 (Aley *et al*., 1998).

Dye from Trace 08-328 was detected at the following sampling stations (from upstream to downstream):

Dye Detection from Trace 08-328: Station 318 – Fountain Creek upstream of sink point.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/21 to 4/2/08	ND	ND
4/2 to 4/14/08	515.9	2.23
4/14 to 4/24/08	ND	ND

Dye Detection from Trace 08-328: Station 308 – Dual Spring West.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/21 to 4/2/08	ND	ND
4/2 to 4/14/08	516.4	2.22
4/14 to 4/24/08	ND	ND

Dye Detection from Trace 08-328: Station 310 – Fountain Creek upstream of Annbriar.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/21 to 4/2/08	ND	ND
4/2 to 4/14/08	515.8	2.46
4/14 to 4/24/08	ND	ND

Dye Detection from Trace 08-328: Station 309 –Annbriar Spring.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/21 to 4/2/08	ND	ND
4/2 to 4/14/08	516.4	2.22
4/14 to 4/24/08	ND	ND

Dye Detection from Trace 08-328: Station 319 – Fountain Creek downstream of Annbriar.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/21 to 4/2/08	ND	ND
4/2 to 4/14/08	516.0	3.39
4/14 to 4/24/08	ND	ND

Dye Detection from Trace 08-328: Station 340 – Fountain Creek upstream of Luhr Spring.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/21 to 4/2/08	ND	ND
4/2 to 4/14/08	516.0	2.07
4/14 to 4/24/08	ND	ND

Dye Detection from Trace 08-328: Station 341 – Fountain Creek upstream of Barker Spring.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/14 to 3/2108	ND	ND
3/21 to 4/14/08	516.2	1.91
4/14 to 6/18/08	516.8 **	0.841
6/18 to 6/25/08	ND	ND

Dye Detection from Trace 08-328: Station 311 – Fountain Creek at HH Road.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
3/21 to 4/2/08	ND	ND
4/2 to 4/14/08	515.7 (1)	4.00
4/14 to 5/27/08	ND	ND

All of these dye detections have values that vary within sampling and analysis error. Based on these results along with those of Trace 97-01 (Aley *et al*., 1998), it is our interpretation that all of the dye stayed in the Fountain Creek channel to Station 318. Just downstream of Station 318 is the dye introduction point for Trace 97-01 all of which dye went to Dual Spring by use of a funnel to introduce the dye into the losing point and to prevent dye being dispersed into the creek. Some of the dye from Trace 08-328 was lost from the creek channel through the losing point and was detected at Dual Spring. Some of the dye stayed in the Fountain Creek channel and was detected at Stations 310, 309 (Annbriar Spring is located within the flow of Fountain Creek), and Station 319. Stations 340, 314, and 311 received dye from both the dye that stayed in Fountain Creek and dye discharged back into Fountain Creek from Dual Spring.

We specifically interpret these data to mean that no dye from Trace 08-328 was discharged from Annbriar Spring. To be a credible detection of dye discharged from Annbriar Spring there would need to have been at least an order of magnitude higher concentration of dye at Annbriar Spring or immediately downstream of Annbriar Spring (Station 319) than was detected upstream of Annbriar Spring (Station 310) and that was clearly not the case.

In 1997 when Trace 97-11 was conducted, a whirlpool was observed at the losing point. It has been several years since the loss of water from Fountain Creek was that obvious. However, Trace 08-328 demonstrates that Fountain Creek is still recharging Dual Spring, in spite of a lack of such a noticeable feature as a whirlpool in the creek.


Figure 12
Monroe County Recharge Area Delineation
Trace 08-328: Gall Road Trace
Portion of the Waterloo Quadrangle
344
343
342
345
311
339
340
341
332
334
333
319
309
346
307
308
310
318
321
327
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
1000 0 1000 2000 Feet
N
Ozark Underground Laboratory

4.3.10 Trace 08-329: Reverse Stream Overflow Trace

On May 7, 2008 at 1352 hours, one pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into the overflow channel of Reverse Stream. This particular stream is dry under low to moderate flow, a sinking stream under high flow conditions, and a losing stream some of whose flow discharges through the surface channel into Fountain Creek under very high flow conditions. The location of the dye introduction point was 38.33248^o N and 90.21156^o W at an elevation of approximately 495 feet msl. Approximately 400 gpm of storm water runoff was flowing at the time of dye introduction, all of which was sinking into the groundwater system. Thus, this trace was conducted under very high flow conditions. The purpose of the Reverse Stream Overflow Trace was to help define the boundary between the Dual Spring and Antler-Annbriar Springs recharge areas. Figure 13 shows the diagrammatic flow path of the Reverse Stream Overflow Trace.

Dye from Trace 08-329 was detected at the following sampling stations:

Dye Detection from Trace 08-329: Station 307 – Dual Spring East.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
4/2 to 4/14/08	ND	ND
4/14 to 5/12/08	569.2	29.6
5/12 to 5/27/08	569.0	15.4
5/27 to 6/18/08	570.1	5.11
6/18 to 6/25/08	572.0 (4)	3.88
6/25 to 10/14/08	568.6	4.84
10/14 to 11/25/08	ND	ND

Dye Detection from Trace 08-329: Station 308 – Dual Spring West.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
4/14 to 4/24/08	ND	ND
4/24 to 5/12/08	569.0	36.2
5/12 to 5/27/08	ND	ND

Dye Detection from Trace 08-329: Station 321 – Floodplain Estavelle.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
4/14 to 5/12/08	ND	ND
5/12 to 6/18/08	569.9	12.7
6/18 to 7/10/08	ND	ND

Trace 08-329 demonstrates that the dye introduction point lies within the Dual Spring recharge area. The dye introduction point had previously been thought to recharge Antler-Annbriar Springs based on the fact that it almost certainly overlies a groundwater conduit which discharges at Annbriar Spring. Trace 08-329 is also the first trace ever detected at Dual Spring East or Floodplain Estavelle. An estavelle is a karst feature that functions as a sinkhole (recharge feature) under low flow conditions and as a spring (discharge feature) under high flow conditions. These two features seldom discharge water and Trace 08-329 has confirmed that both are part of the Dual Spring groundwater system.

The notably longer detection of dye at Dual Spring East than at Dual Spring West is due to Dual Spring West having perennial flow and Dual Spring East does not frequently discharge. Dual Spring East certainly flowed briefly during Trace 08-329, but only long enough to get dye to the rise pool, not enough to flush it out of the spring pool. The longer detection is a product of residence time in the rise pool of Dual Spring East between discharge events.

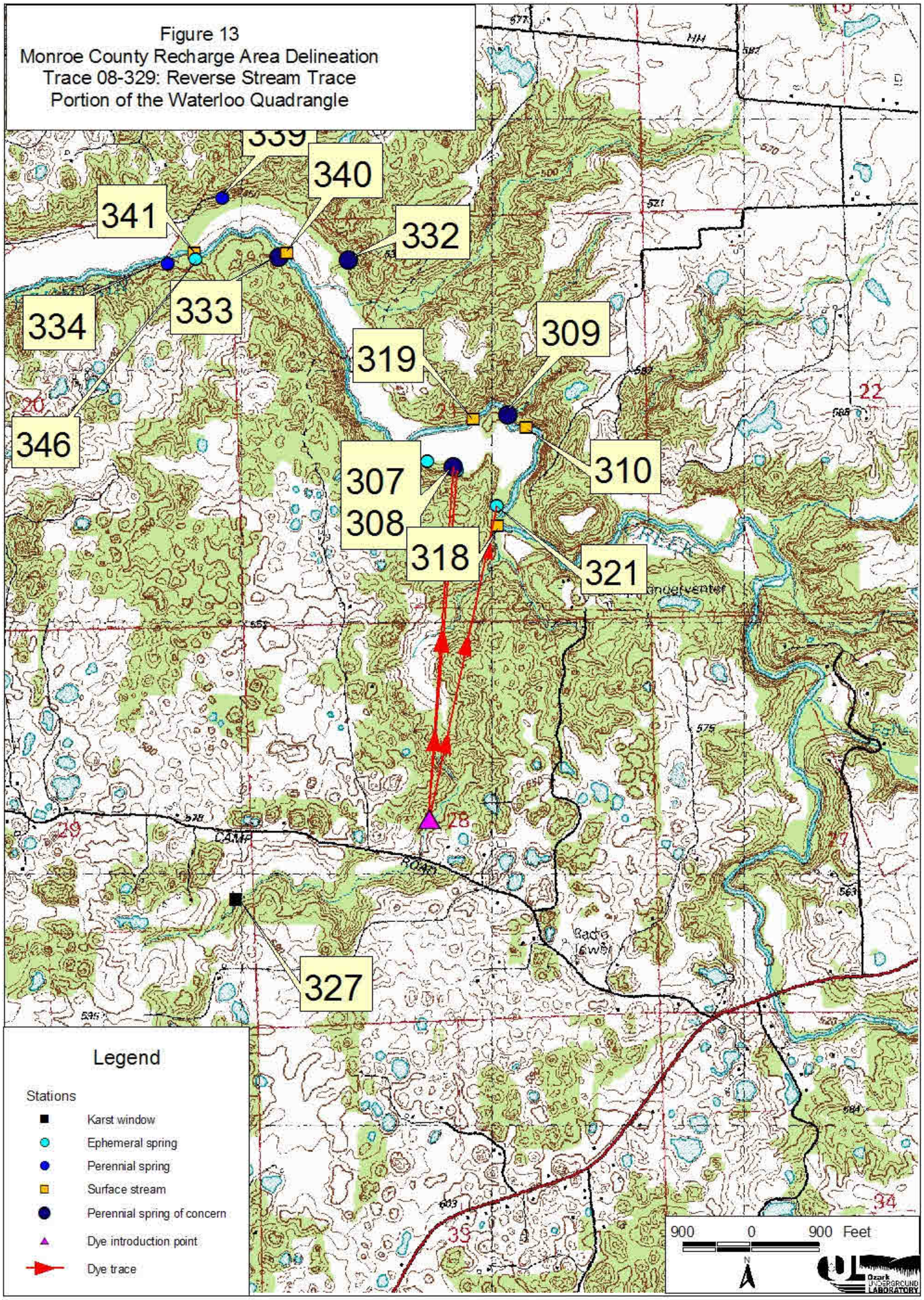


Figure 13
Monroe County Recharge Area Delineation
Trace 08-329: Reverse Stream Trace
Portion of the Waterloo Quadrangle
339
340
341
332
334
333
309
319
346
310
307
308
318
321
327
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
900 0 900 Feet

4.3.11 Trace 08-330: Glaenzer Trace

On June 6, 2008 at 1808 hours, one pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole during a runoff-producing storm. The location of the dye introduction point was 38.30491^{o} N and 90.23930^{o} W at an elevation of approximately 630 feet msl. The purpose of the Glaenzer Trace was to help define the boundary between the Frog Spring and the Antler-Annbriar Springs recharge areas. Approximately 25 gpm of storm water runoff was entering the groundwater system at the time of dye introduction. Figure 14 shows the diagrammatic flow path of the Glaenzer Trace.

Dye from Trace 08-330 was detected at the following sampling stations (from upstream to downstream):

Dye Detection from Trace 08-330: Station 329 – Frog Spring.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
5/12 to 5/27/08	ND	ND
5/27 to 6/9/08	541.1	176
6/9 to 6/18/08	541.0	17.3
6/18 to 6/25/08	540.9	6.99
6/25 to 7/10/08	541.1	5.14
7/10 to 8/12/08	540.7	6.94
8/12 to 10/2/08	538.8	0.798
10/2 to 10/14/08	ND	ND

Dye Detection from Trace 08-330: Station 335 – Bond Creek upstream of Schnellbecher.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
3/21 to 4/14/08	ND	ND
4/14 to 6/9/08	541.3	29.8
6/9 to 6/18/08	541.0	4.50
6/18 to 6/25/08	540.4	0.681
6/25 to 10/14/08	ND	ND

Dye Detection from Trace 08-330: Station 331 – Bond Creek at HH Road.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
4/14 to 5/27/08	ND	ND
5/27 to 6/18/08	541.1	60.9
6/18 to 6/25/08	ND	ND

The dye concentrations from samples collected at the above-listed locations indicate that all of the dye detected was discharged from Frog Spring. The other two detections were downstream of Frog Spring and derived their dye from Frog Spring's discharge. Trace 08-330 demonstrates that the Glaenzer sinkhole lies within the Frog Spring recharge area.

Figure 14
Monroe County Recharge Area Delineation
Trace 08-330: Glaenzer Trace
Portions of the Waterloo and Valmeyer Quadrangles
339
340
341
332
334
333
319
346
330
307
308
318
327
337
329
Foster Pond
Church of God
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
1000 0 1000 Feet

4.3.12 Trace 08-331: Dairy Farm Trace

On December 27, 2008 at 1503 hours, one pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole. At the time of dye introduction, flow into the groundwater system through this sinkhole was estimated to be approximately 10 gpm. The location of the dye introduction point was 38.30930^o N and 90.25072^o W at an elevation of approximately 675 feet msl. A dry set was placed at this location on June 12, 2008 using 0.5 pound of fluorescein. However, no dye was detected from this dry set and an inspection on June 23, 2008 showed signs of disturbance other than from water flow. A dry set involves dye being placed at a location with flow only during runoff conditions and placed in a manner that permits the dye to be automatically introduced into water when it begins to flow. The purpose of the Dairy Farm Trace was to help delineate the western boundary of the Frog Spring recharge area. Figure 15 shows the diagrammatic flow path demonstrated by the Dairy Farm Trace.

Dye from Trace 08-331 was detected at the following sampling stations (from upstream to downstream):

Dye Detection from Trace 08-331: Station 329 – Frog Spring.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
11/25 to 12/31/08	ND	ND
12/31/08 to 1/7/09	577.5	7.39
1/7 to 1/20/09	575.6 (4)	2.70

Dye Detection from Trace 08-331: Station 335 – Bond Creek upstream of Schnellbecher.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
11/25 to 12/31/08	ND	ND
12/31/08 to 1/7/09	577.4 *	1.81

The dye concentrations from samples collected at the above-listed locations indicate that all of the dye detected was discharged from Frog Spring. The other detection was downstream of Frog Spring and derived its dye from the discharge from Frog Spring. Trace 08-331 demonstrates that the Dairy Farm sinkhole lies within the Frog Spring recharge area.


Figure 15
Monroe County Recharge Area Delineation
Trace 08-331: Dairy Farm Trace
Portions of the Waterloo and Valmeyer Quadrangles
339
340
341
332
334
333
309
319
346
335
330
307
308
318
321
327
337
329
338
Foster Pond
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
1000 0 1000 Feet

<u>4.3.13 Trace 08-332: TNC Trace</u>

On June 12, 2008 at 1318 hours, one pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was placed in a sinkhole as a dry set. The location of the dye introduction point was 38.32878° N and 90.22670° W at an elevation of approximately 565 feet msl. The purpose of the TNC Trace was to help delineate the boundaries of the Antler-Annbriar Springs, Dual Spring, and Luhr Spring recharge areas. Figure 16 shows the diagrammatic flow path of the TNC Trace.

Dye from Trace 08-332 was detected at the following sampling stations (from upstream to downstream:

Dye Detection from Trace 08-332: Station 308 – Dual Spring West.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Concentration (ppb)
5/27 to 6/18/08	ND	ND
6/18 to 6/25/08	(3)	
6/25/08 (water)	580.9	4.78
6/25 to 7/10/08	578.3	38.1
7/10 to 10/14/08	577.8	10.9

Dye Detection from Trace 08-332: Station 340 – Fountain Creek upstream of Luhr Spring.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Concentration (ppb)
5/27 to 6/18/08	ND	ND
6/18 to 6/25/08	578.9	13.9
6/25 to 7/10/08	578.5	10.2
7/10 to 10/14/08	575.6	3.97

Dye Detection from Trace 08-332: Station 341 – Fountain Creek upstream of Barker Spring.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Concentration (ppb)
5/27 to 6/18/08	ND	ND
6/18 to 6/25/08	578.9	13.9
6/25 to 7/10/08	578.5	10.2
7/10 to 10/14/08	575.6	3.97

Dye Detection from Trace 08-332: Station 311 – Fountain Creek at HH Road.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Concentration (ppb)
5/27 to 6/18/08	ND	ND
6/18 to 6/25/08	578.7	9.88
6/25 to 10/14/08	576.6	3.90
10/14 to 10/22/08	ND	ND

The dye concentrations from samples collected at the above-listed locations indicate that all of the dye detected was discharged from Dual Spring West. Trace 08-332 demonstrates that the TNC sinkhole recharges Dual Spring.

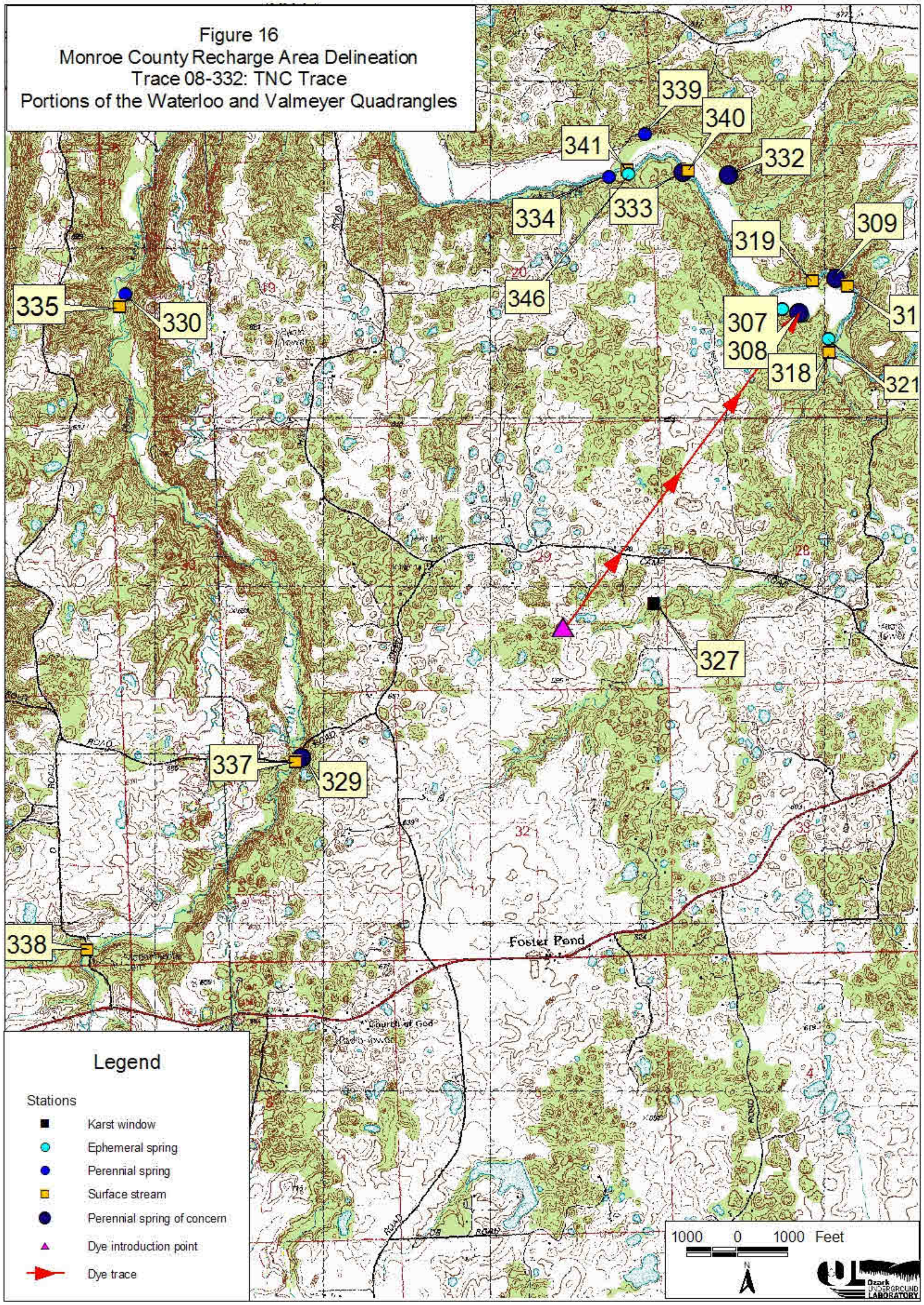


Figure 16
Monroe County Recharge Area Delineation
Trace 08-332: TNC Trace
Portions of the Waterloo and Valmeyer Quadrangles
339
340
341
332
334
333
309
319
346
335
330
307
308
318
321
327
337
329
338
Foster Pond
Church of God
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
1000 0 1000 Feet

4.3.14 Trace 08-333: Cemetery Trace

On October 15, 2008 at 1508 hours, one pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole receiving storm water runoff. The location of the dye introduction point was 38.33393° N and 90.23357° W at an elevation of approximately 610 feet msl. Flow was estimated to be approximately two gpm. The purpose of the trace was to help define the recharge area boundary near the boundaries of the Luhr, Dual, and Schnellbecher Springs recharge areas. Figure 17 shows the diagrammatic flow path demonstrated by Cemetery Trace.

Dye from Trace 08-333 was detected at the following sampling stations (from upstream to downstream):

Dye Detection from Trace 08-333: Station 333 – Luhr Spring.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Concentration (ppb)
7/10 to 10/14/08	ND	ND
10/14 to 10/28/08	568.3	573
10/28 to 11/6/08	567.2	5,000
11/6 to 11/25/08	568.5	1,310
11/25 to 12/31/08	568.9	1,010
12/31/08 to 1/7/09	568.5	233

Dye Detection from Trace 08-333: Station 341 – Fountain Creek upstream of Barker Spring.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Concentration (ppb)
6/25 to 10/14/08	ND	ND
10/14 to 10/22/08	568.1	3.75
10/22 to 10/28/08	568.1	66.2
10/28 to 11/6/08	569.0	11.6
11/6 to 11/25/08	568.9	8.88
11/25 to 12/31/08	571.2	3.55
11/25 to 12/31/08 duplicate	571.0	2.85
12/31/08 to 1/7/09	568.1	3.75

Dye Detection from Trace 08-333: Station 311 – Fountain Creek at HH Road.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Concentration (ppb)
6/25 to 10/14/08	ND	ND
10/14 to 10/22/08	570.8 *	2.32
10/22 to 10/28/08	568.0	38.2
10/28 to 11/6/08	568.8	14.8
11/6 to 11/25/08	568.8	7.18
11/25 to 12/31/08	ND	ND

Trace 08-333 shows that the Cemetery sinkhole recharges Luhr Spring. The dye concentrations decreasing downstream from Luhr Spring are consistent with all the dye being discharged from Luhr Spring.


Figure 17
Monroe County Recharge Area Delineation
Trace 08-333: Cemetery Trace
Portions of the Waterloo and Valmeyer Quadrangles
339
340
341
332
334
333
309
319
346
335
330
307
308
318
31
321
327
337
329
338
Foster Pond
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
1000 0 1000 Feet
N
Ozark Underground Laboratory

4.3.15 Trace 08-334: Steinmann Trace

On October 15, 2008 at 1557 hours, 0.5 pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole receiving storm water runoff. The location of the dye introduction point was 38.33844° N and 90.24379° W at an elevation of approximately 635 feet msl. Flow was estimated to be approximately 20 gpm at the time of dye introduction. The purpose of the trace was to help define the boundary between the Schnellbecher and Dual Springs recharge areas. Figure 18 shows the diagrammatic flow path demonstrated by the Steinmann Trace.

Dye from Trace 08-334 was detected at the following sampling stations (from upstream to downstream):

Dye Detection from Trace 08-334: Station 330 – Schnellbecher Spring.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Concentration (ppb)
6/25 to 10/14/08	ND	ND
10/14 to 10/22/08	516.5	5,360
10/22 to 10/28/08	516.0	158
10/28 to 11/6/08	515.8	99.4
11/6 to 11/25/08	515.8	34.0
11/25 to 12/31/08	515.9	19.4
12/31/08 to 1/7/09	515.9	1.62

Dye Detection from Trace 08-334: Station 331 – Bond Creek at HH Road.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Concentration (ppb)
6/25 to 10/14/08	ND	ND
10/14 to 10/22/08	515.9	246
10/22 to 10/28/08	515.6	22.5
10/28 to 11/6/08	516.1	7.39
11/6 to 11/25/08	515.9	2.77
11/25 to 12/31/08	516.1	2.40
12/31/08 to 1/7/09	516.1 (4)	0.750

Trace 08-334 demonstrates that the Steinmann sinkhole recharges only Schnellbecher Spring and therefore lies outside the recharge area of Dual Spring. The lower dye concentrations in each sampling period at Station 331 when compared to the concentrations for the same periods at Schnellbecher Spring (Station 330) are consistent with all of the dye having been discharged from Schnellbecher Spring.

Figure 18
Monroe County Recharge Area Delineation
Trace 08-334: Steinmann Trace
Portions of the Waterloo and Valmeyer Quadrangles
339
340
341
332
334
333
319
309
346
335
330
307
308
31
318
321
327
337
329
338
Foster Pond
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
1000 0 1000 Feet

4.3.16 Trace 08-335: Heck Trace

On October 17, 2008 at 0951 hours, 0.5 pound of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced into sinkhole. The location of the dye introduction point was 38.36108^{o} N and 90.21562^{o} W at an elevation of approximately 610 feet msl. Flow in the sinkhole was estimated to be approximately 10 gpm at the time of dye introduction. The purpose of the trace was to help delineate the boundary between the Andys Run Spring and the Antler-Annbriar Springs recharge areas. Figure 19 shows the diagrammatic flow path demonstrated by the Heck Trace.

Dye from Trace 08-335 was detected at the following sampling stations (from upstream to downstream):

Dye Detection from Trace 08-335: Station 343 – Andys Run Spring.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Concentration (ppb)
6/18 to 10/14/08	ND	ND
10/14 to 10/22/08	577.3	2,000
10/22 to 10/28/08	577.0	5,010
10/28 to 11/6/08	577.9	566
11/6 to 11/25/08	577.8	395
11/25 to 12/31/08	577.7	111
12/31/08 to 1/7/09	577.7	14.1
1/7 to 1/20/09	577.5	15.4
1/7 to 1/20/09 duplicate	577.5	16.8

Dye Detection from Trace 08-335: Station 344 – Downstream Andys Run.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Concentration (ppb)
4/2 to 6/18/08	ND	ND
6/18 to 10/14/08	(3)	
10/14 to 10/22/08	578.2	5.62
10/22 to 10/28/08	577.8	68.6
10/28 to 11/6/08	578.7	8.82
11/6 to 11/25/08	577.9	12.3
11/25 to 1/7/09	574.2 (4)	1.54

Trace 08-335 demonstrated that the Heck sinkhole recharges Andys Run Spring and lies outside the recharge area for Antler-Annbriar Springs. The lower dye concentrations in each sampling period at Station 344 when compared to the concentrations for the same periods at Andys Run Spring (Station 343) are consistent with all of the dye having been discharged from Andys Run Spring.


Figure 19
Monroe County Recharge Area Delineation
Trace 08-335: Heck Trace
Portion of the Waterloo Quadrangle
345
344
343
342
311
339
340
341
332
334
333
319
309
346
310
307
308
318
321
327
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
1000 0 1000 Feet

4.3.17 Trace 08-336: Bicklein Trace

On December 27, 2008 at 1520 hours, 0.5 pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into storm water runoff flowing in a sinkhole. The location of the dye introduction point was 38.34374^{o} N and 90.23287^{o} W at an elevation of approximately 610 feet msl. Flow in the sinkhole was estimated to be approximately 30 gpm at the time of dye introduction. The purpose of the trace was to delineate the boundary between Schnellbecher Spring, Barker Spring, and Luhr Spring recharge areas. Figure 20 shows the diagrammatic flow path demonstrated by the Bicklein Trace.

Dye from Trace 08-336 was detected at the following sampling station:

Dye Detection from Trace 08-336: Station 334 – Barker Spring.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Concentration (ppb)
11/25 to 12/31/08	ND	ND
12/31/08 to 1/7/09	540.5	5.73
1/7 to 1/20/09	540.0	2.06

Dye from Trace 08-336 was detected only at Barker Spring. This result demonstrates that the Bicklein sinkhole recharges Barker Spring and lies outside the recharge area of Luhr Spring. Trace08-336 is the first trace ever reported to be detected at Barker Spring.


Figure 20
Monroe County Recharge Area Delineation
Trace 08-336: Bicklein Trace
Portions of the Waterloo and Valmeyer Quadrangles
339
340
341
332
334
333
309
319
346
335
330
307
308
318
321
327
337
329
338
Foster Pond
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
1000 0 1000 Feet

4.3.18 Trace 08-337: McBride Road Trace

On December 27, 2008 at 1536 hours, 0.5 pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into storm water runoff flowing in a sinkhole. The location of the dye introduction point was 38.35878^{o} N and 90.22110^{o} W at an elevation of approximately 520 feet msl. Flow in the sinkhole was estimated to be approximately eight gpm at the time of dye introduction. The purpose of the trace was to help delineate the boundary between Andys Run Spring and the Antler-Annbriar Springs recharge area. Figure 21 shows the diagrammatic flow path demonstrated by the McBride Road Trace.

Dye from Trace 08-337 was detected at the following sampling station:

Dye Detection from Trace 08-337: Station 343 – Andys Run Spring.

Sampling Period	Peak Emission Wavelength (nm)	Eosine B Concentration (ppb)
11/6 to 11/25/08	ND	ND
11/25 to 12/31/08	542.6	3.00
12/31/08 to 1/7/09	541.1	19.8
1/7 to 1/20/09	540.4	8.91
1/7 to 1/20/09 duplicate	540.6	9.50

Dye from Trace 08-337 was detected only at Andys Run Spring, which demonstrates that the McBride Road sinkhole recharges Andys Run Spring and lies outside the Antler-Annbriar Springs recharge area.


Figure 21
Monroe County Recharge Area Delineation
Trace 08-337: McBride Road Trace
Portion of the Waterloo Quadrangle
345
344
343
342
311
339
340
341
332
334
333
319
309
346
310
307
308
318
321
327
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
1000
0
1000 Feet

4.3.19 Trace 08-338: Luhr Trace

On December 27, 2008 at 1606 hours, 0.5 pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into storm water runoff flowing in a sinkhole. The location of the dye introduction point was 38.33326° N and 90.21468° W at an elevation of approximately 545 feet msl. Flow in the sinkhole was estimated to be approximately 15 gpm at the time of dye introduction. The purpose of the trace was to help delineate the boundary between the Antler-Annbriar Springs and the Dual Springs recharge areas. Figure 22 shows the diagrammatic flow path demonstrated by the Luhr Trace.

Dye from Trace 08-338 was detected at the following sampling stations:

Dye Detection from Trace 08-338: Station 307 – Dual Spring East.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Concentration (ppb)
10/14 to 11/25/08	ND	ND
11/25 to 12/31/08	515.5	4.57

Dye Detection from Trace 08-338: Station 308 – Dual Spring West.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Concentration (ppb)
10/28 to 11/25/08	ND	ND
11/25 to 12/31/08	515.9	4.45
12/31/08 to 1/7/09	515.5	1.91

Trace 08-338 demonstrated that the Luhr sinkhole recharges Dual Spring and is the second trace to be detected at the wet-weather spring Dual Spring East. The trace also demonstrates that the dye introduction point does not recharge Antler-Annbriar Springs.

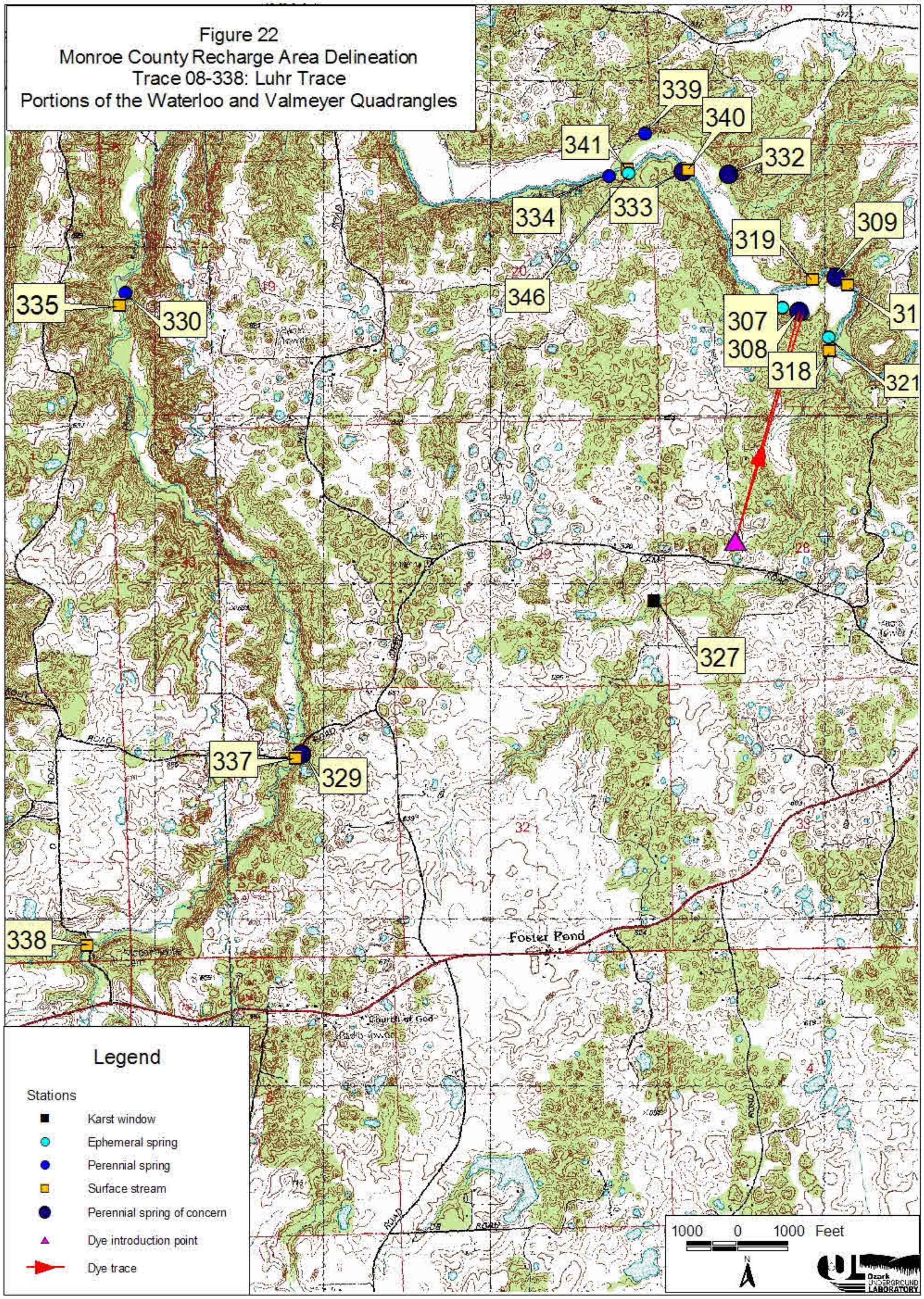


Figure 22
Monroe County Recharge Area Delineation
Trace 08-338: Luhr Trace
Portions of the Waterloo and Valmeyer Quadrangles
339
340
341
332
334
333
309
319
346
335
330
307
308
318
321
327
337
329
338
Foster Pond
Church of God
Legend
Stations
Karst window
Ephemeral spring
Perennial spring
Surface stream
Perennial spring of concern
Dye introduction point
Dye trace
1000 0 1000 Feet
N

4.4 Recharge Area Delineations

Recharge area delineation is essential for protection and management of important groundwater systems. 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 that contributes water under some or all flow conditions to that particular spring. Unless otherwise noted, the recharge area for a cave includes both lands overlying known cave passages plus other lands which contribute water to the spring or springs through which water from the cave discharges.

We commonly refer to the groundwater system associated with a particular spring. The lateral boundaries of a spring's groundwater system are identical with the lateral boundaries of the spring's recharge area only if there are no sinking streams in the 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. However, there is not necessarily a groundwater system underlying sinking stream upstream of their sink points.

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

Delineation of the Schnellbecher Spring and Andys Run Spring recharge areas was not required in the contract. However, enough traces were detected 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. These groundwater systems have been examined at least once biologically (Lewis *et al*., 2003) and are not known to provide habitat for aquatic species of management concern. There is further discussion of these additional delineations in Sections 4.4.5 and 4.4.6.

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 dye traces (those done under this contract and previous tracing), topographic features, and relevant 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 previous studies, and more such areas probably exist. Finally, some areas 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. Water entering the groundwater system after significant travel distances as surface water (allogenic recharge) or which enters the groundwater system via diffuse (laminar) flow is much less likely to adversely impact groundwater quality than is water that directly and rapidly enters the groundwater system. Precipitation that falls directly on the karst is called autogenic recharge. Precipitation that falls on land that is not karst, but then flows onto karst and some or all of the water enters the karst groundwater system is called allogenic recharge.

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. This flow is turbulent and quite energetic. Discrete recharge can generally transport suspended sediment and in very open recharge features, transport bed load. Diffuse recharge is dispersed flow which seeps and oozes through the soil and rock to enter the groundwater system. This recharge falls within the laminar flow regime and is incapable of transporting suspended sediment. Sinkholes and losing streams are common local examples of discrete recharge features.

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 enter karst groundwater systems rapidly which can result 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 groundwater habitat is impacted by the contaminant which follows the longer underground 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 that yield all of their runoff to the groundwater system are likely to have a greater impact on associated cave systems than areas that yield only part of their runoff to the groundwater system.

4.4.1 Antler-Annbriar Springs

One of the characteristics that make the Antler-Annbriar Springs groundwater system important is that it provides habitat for the Illinois cave amphipod. Aley and Moss (2001) provided a partial delineation of the Annbriar Spring recharge area. The size of the area was estimated to be approximately 6.0 square miles at low flow and approximately 12.1 square miles at high flow. The difference arises because most of the Pautler Cave Recharge Area to the east of the Antler-Annbriar Springs low flow recharge area can overflow to the Antler-Annbriar groundwater system under high flow conditions (Aley and Moss, 2001). The current investigation revised the low flow recharge area down to approximately 5.6 square miles and the high flow recharge area to 11.6 square miles.

There is some significance to the geographic setting of both Antler and Annbriar Springs. Annbriar Spring is actually a complex of ever-changing discharge points, almost all of which are in the bed of Fountain Creek. After major flood events, the channel gravels are rearranged and often old outlets clog and new outlets open up. Antler Spring, however, is a single orifice spring on the north side of the Fountain Creek floodplain. It is more intuitive to recognize that a spring rising in a creek bed might be recharged from both sides of the creek in which it is located, as is the case with Annbriar Spring. However, it is not particularly intuitive that a spring, such as Antler Spring, at one edge of a valley whose floor is about 700 feet wide would be recharged by lands on both sides of the creek and has in fact, much longer flow paths from the south than from the north side where Antler Spring discharges.

The 2001 Annbriar Spring recharge area delineation was conducted, in part, because the adjacent Pautler Cave recharge area delineation did not require all of the funding allocated to it. One of the purposes of this investigation was to raise the standard of the Annbriar Spring recharge area delineation to the quality of Pautler Cave (Aley and Moss, 2001), Fogelpole Cave, Illinois Caverns, Krueger-Dry Run Cave System, and Stemler Cave (Aley *et al*., 2000).

In the 2001 report, an assumption was made that the land overlying the probable location of the underground conduit between Reverse Stream and Annbriar Spring also recharged Annbriar Spring. The current investigation showed that, to the contrary, the discrete recharge features between the karst window known as Reverse Stream (Station 327) and Annbriar Spring does not recharge Annbriar Spring, but instead recharges Dual Spring, as a result of the data from the new dye tracing, specifically Traces 08-329, 08-332, and 08-338. The recharge area for Antler-Annbriar Springs includes two areas; an area north of Fountain Creek that is discontinuous from the portion of the recharge area south of Fountain Creek. Figure 23 shows the revisions to the Antler-Annbriar Springs Recharge Area. On Figure 23, the thick blue boundary is the low flow recharge area for Antler-Annbriar Springs. The thin red boundary is the 2001 understanding of the low flow recharge area of Annbriar Spring. The thin purple boundary is the high flow recharge area boundary, which includes most of the Pautler Cave recharge area. In some areas, all three boundaries coincide. The geographic relationship among the Waterloo subkarst recharge areas is shown on Figure 29.

The difference in land area makes no difference in terms of habitat for the Federally-listed endangered Illinois cave amphipod since the land that was considered to be in the Annbriar Spring groundwater system is now understood to be part of the Dual Spring groundwater system and both groundwater systems provide habitat for the Illinois cave amphipod.

Delineation Rationale – Antler-Annbriar Springs Recharge Area North of Fountain Creek

Starting at Annbriar Spring, the boundary follows the topographic divide between a tributary of Fountain Creek tested for leakage by Trace 08-328, Gall Road Trace (Figure 12) and the sinking stream demonstrated to recharge Antler Spring by Trace 08-324, Frank Trace (Figure 8). The topographic divide is then continued north until it meets the topographic divide between the Frank sinking stream and Andys Run. Andys Run was tested for leakage to the Antler-Annbriar Springs groundwater system by Trace 08-326 (Figure 10) and no leakage was detected from that trace. The topographic divide is the boundary between Andys Run and two more sinking streams draining toward the south (the westernmost stream in the northern recharge area is a sinking stream, although it is not shown as such on the topographic map).

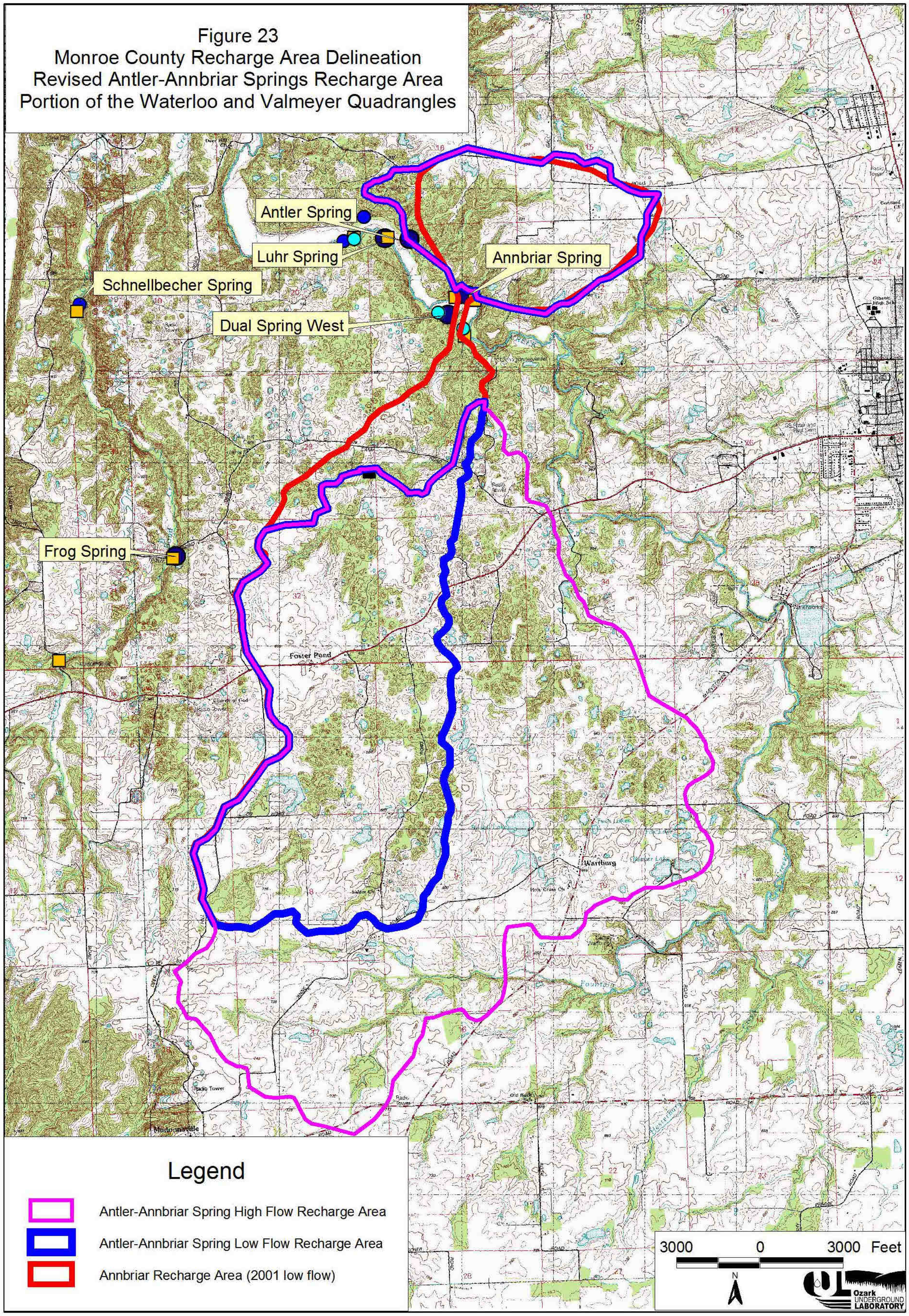


Figure 23
Monroe County Recharge Area Delineation
Revised Antler-Annbriar Springs Recharge Area
Portion of the Waterloo and Valmeyer Quadrangles
Antler Spring
Luhr Spring
Annbriar Spring
Schnellbecher Spring
Dual Spring West
Frog Spring
Foster Pond
Wartburg
Legend
Antler-Annbriar Spring High Flow Recharge Area
Antler-Annbriar Spring Low Flow Recharge Area
Annbriar Recharge Area (2001 low flow)
3000 0 3000 Feet
N
Ozark UNDERGROUND LABORATORY

The northwest part of the recharge area boundary lies between sinkholes, instead of separating streams. The boundary lies between traces flowing north to Andys Run Spring (Traces 08-323, 08-335, and 08-337) and those that flow south to southeast to Antler Spring and sometimes Annbriar Spring (Traces 97-09, 98-03, and 08-321). In the southeastern part of the recharge area, the boundary was drawn approximately halfway between a cave known to discharge at Sore Knee Spring (Station 339) and another cave known to discharge at Antler Spring. Both caves flow southeast and converge on the axis of the Columbia Syncline. This boundary continues approximately southeast until it reaches Antler Spring.

Between Antler Spring and Annbriar Spring, the boundary approximates the top of the Fountain Creek valley, separating lands which contribute runoff to Fountain Creek directly from those lands containing sinkholes and other karst recharge features.

Delineation Rationale – Antler-Annbriar Springs Recharge Area South of Fountain Creek

Starting in the northeast part of the recharge area, the boundary includes the portion of Pautler Cave that overflows to Annbriar Spring (Aley and Moss, 2001). The boundary runs southeast roughly parallel to an unnamed stream. This particular stream is dry under low to moderate flow, a sinking stream under high flow conditions, and a losing stream some of whose flow discharges through the surface channel into Fountain Creek under very high flow conditions. Under high flow conditions, Trace 08-329 demonstrated that this stream reach (between Station 327, Reverse Stream, and the sink point) recharged Dual Spring and is therefore outside the Antler-Annbriar Spring recharge area. This boundary continues along the creek channel separating the channel valley from the adjacent sinkholes until the boundary crosses the channel at Reverse Stream (Station 327). Numerous traces have shown that Reverse Stream (except for its overflow) recharges both Antler and Annbriar Springs and is therefore included in the recharge area. This same stream channel continues upstream of Reverse Stream.

The stream channel upstream of Reverse Stream, sinks at Reverse Stream and is thus included in the Antler-Annbriar Spring recharge area. The boundary runs roughly southeast, but now including the stream channel and its immediate valley and excluding the sinkholes shown to recharge Dual Spring by the TNC Trace shown on Figure 16 (Trace 08-332). The boundary then extends still farther southeast separating another sinking stream known to flow through Reverse Stream (OUL unpublished data) from a sinkhole area shown to recharge Schnellbecher Spring by Traces 97-01 and 97-03, which are shown on Figure 3 (Aley *et al.*, 1998). The boundary then separates the recently mentioned sinking stream basin from sinkhole areas shown to recharge Frog Spring by Trace 00-314 shown on Figure 3 (Aley and Moss, 2001) and Trace 08-330 (Figure 14).

From there, the boundary turns south and then southeast again along a topographic divide separating the watersheds of two sinking streams, each traced to different spring systems. Trace 08-322 (Figure 6) showed that sinking stream recharges Antler-Annbriar Springs, while the more western sinking stream was shown by Trace 08-327 (Figure 11) to recharge Frog Spring. The boundary follows the topographic divide south and then turns east to form the southern boundary. The southern boundary is along the topographic watershed of Fountain Creek, which has been shown to recharge Pautler Cave (Aley and Moss, 2001), but this stream reach was not shown to recharge any other groundwater system. So the watershed is excluded from the low flow recharge area boundary, but is included in the high flow boundary (Figure 23) since it is upstream of the point at which the Pautler Cave groundwater system can overflow into the Antler-Annbriar Springs groundwater system. This makes part of Fountain Creek shared recharge (at very high flows) between Pautler Cave and the Antler-Annbriar Springs groundwater systems.

The boundary along Fountain Creek and then north between the Pautler Cave recharge area and the Antler-Annbriar Springs recharge area is unchanged from that reported by Aley and Moss (2001). The high flow boundary is also unchanged from the 2001 report.

4.4.2 Dual Spring Recharge Area

Dual Spring gets its name from a pair of rise pools that are about 30 feet apart. Dual Spring West has perennial flow, while Dual Spring East flows only under relatively high flow conditions. One of the characteristics that make the Dual Spring groundwater system important is that it provides habitat for the Illinois cave amphipod. Previous tracing, in particular Trace 97-11 shown on the inset on Figure 3, (Aley *et al.*, 1998) demonstrated that Fountain Creek loses some of its water which is then discharged from Dual Spring. This is the best example of allogenic recharge currently known in the southwest Illinois karst. It also requires inclusion of the entire topographic watershed of Fountain Creek upstream of the losing point. This extends the recharge area into areas that are not mapped as karst and do not appear to function as karst. This area includes about half of the City of Waterloo.

Since Pautler Cave discharges into Fountain Creek upstream of the losing point that recharges Dual Spring, the Pautler Cave recharge area is entirely shared with Dual Spring (as well most of it being shared with Antler-Annbriar Springs at very high flows, which was discussed in the previous section).

Like the Antler-Annbriar Springs recharge, Dual Spring also has different recharge areas under normal and very high flow conditions. The Dual Spring recharge area contains a large allogenic recharge area, it receives a portion of the Pautler Cave discharge, and it has a small area of autogenic recharge which only recharges Dual Spring. Figure 24 shows both the high and low flow recharge areas and the purely autogenic and purely allogenic portions of the recharge area are labeled as such. The purely autogenic portion of the Dual Spring recharge area is approximately 0.94 square miles, but the entire low flow recharge area encompasses approximately 27.7 square miles. Under high flow conditions when the part of the Antler-Annbriar Springs recharge area south of Fountain Creek overflows from Reverse Stream, the recharge area includes approximately 31.7 square miles. The geographic relationship among the Waterloo subkarst recharge areas is shown on Figure 29.

Because much of the Fountain Creek watershed is part of the Dual Spring recharge area, lands on both sides of Fountain Creek recharge Dual Spring, like Antler-Annbriar Springs recharge area.

Snow White Cave is within the Dual Spring autogenic recharge area and flows northeast toward the axis of the Columbia Syncline. This is essentially a mirror image of the cave passage patterns observed on the north side of Fountain Creek in caves flowing to Fountain Creek.

Delineation Rationale – Dual Spring

The southern, eastern, and northern Dual Spring recharge area boundaries are defined by the topographic watershed boundaries of Fountain Creek upstream of the dye introduction point for Trace 97-11 as shown on the inset on Figure 3 (Aley *et al*., 1998). Trace 08-328 confirmed the fact that Fountain Creek still recharges Dual Spring. Since Pautler Cave discharges into Fountain Creek approximately 1,500 feet upstream of the losing point, its recharge area also recharges Dual Spring. It should be noted that the amount of water currently lost from Fountain Creek into the groundwater system is small enough to not be apparent without flow measurement or dye tracing. The Pautler Cave recharge area delineation is discussed in detail by Aley and Moss (2001).

From the northern boundary near Dual Spring, the low to moderate flow boundary runs southwest separating sinkhole areas shown to be recharging Luhr Spring by Traces 00-317 shown on Figure 3 (Aley and Moss, 2001), and Traces 08-325 (Figure 9) and 08-333 (Figure 17) from sinkhole areas shown to recharge Dual Spring by Trace 08-332 (Figure 16). The boundary then turns south and separates sinkhole areas shown to recharge Schnellbecher Spring by Traces 97-01 and 97-03 as shown on Figure 3 (Aley *et al*., 1998). Then the boundary turns back to the northeast and is the boundary described in the Antler-Annbriar Springs recharge area section as separating the Dual Spring recharge area from the Antler-Annbriar Springs recharge area.

At high flows, Reverse Stream overflows into a sinking stream that was shown by Trace 08-329 (Figure 13) to recharge Dual Spring. Therefore, the part of the Antler-Annbriar Springs recharge area south of Fountain Creek also recharges Dual Spring and is entirely shared recharge under these flow conditions. At very high flows, the sinking stream becomes a losing stream with some of its flow reaching Fountain Creek through its surface channel. The surface channel enters Fountain Creek approximately 225 feet upstream of the losing point of Fountain Creek and there is the opportunity for additional recharge to Dual Spring from water that passes through the overflow channel to Fountain Creek.

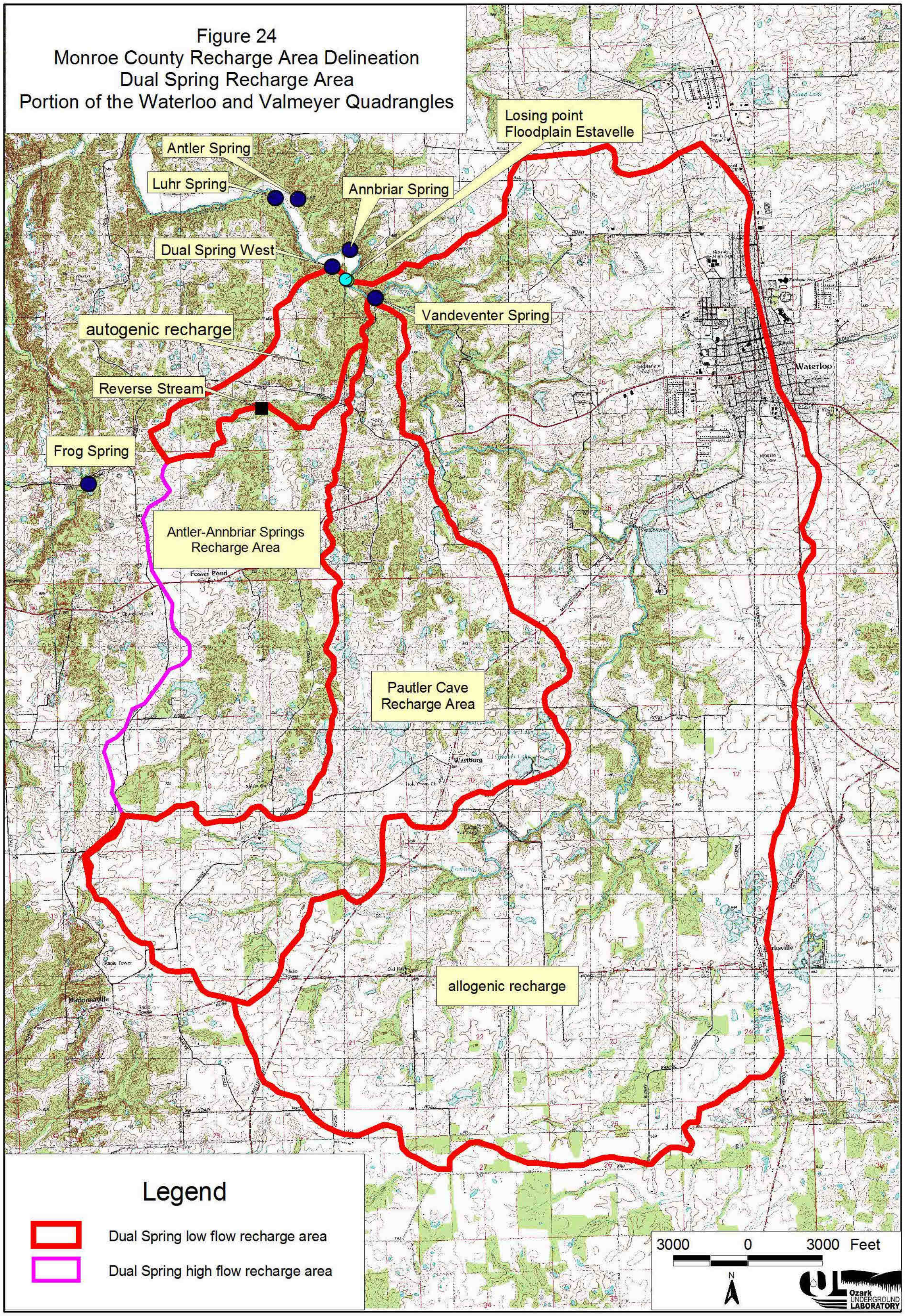


Figure 24
Monroe County Recharge Area Delineation
Dual Spring Recharge Area
Portion of the Waterloo and Valmeyer Quadrangles
Losing point
Floodplain Estavelle
Antler Spring
Luhr Spring
Annbriar Spring
Dual Spring West
Vandeventer Spring
autogenic recharge
Reverse Stream
Frog Spring
Antler-Annbriar Springs
Recharge Area
Pautler Cave
Recharge Area
allogenic recharge
Waterloo
Legend
Dual Spring low flow recharge area
Dual Spring high flow recharge area
3000 0 3000 Feet
N
Ozark Underground Laboratory

4.4.3 Luhr Spring

The Luhr Spring recharge area lies adjacent to and generally east of the Dual Spring recharge area. One of the characteristics that make the Luhr Spring groundwater system important is that it provides habitat for the Illinois cave amphipod. The recharge area includes approximately 1.3 square miles, all of which lies on the south side of Fountain Creek. The Luhr Spring recharge area has a cave system whose main axis is to the northeast and converges on the axis of the Columbia Syncline, essentially parallel to Snow White Cave in the Dual Spring recharge area. Figure 25 shows the Luhr Spring recharge area, which is entirely autogenic. Luhr Spring has the same recharge area under all flow conditions and no part of its recharge area has been shown to be shared with any other groundwater system. The geographic relationship among the Waterloo subkarst recharge areas is shown on Figure 29.

Delineation Rationale – Luhr Spring

Starting at Luhr Spring, the boundary runs generally south along the top of the Fountain Creek valley separating lands that shed runoff directly into Fountain Creek from sinkhole lands which recharge Luhr Spring as demonstrated by Trace 00-317 shown on Figure 3 (Aley and Moss, 2001). The boundary continues in this direction until it intersects and joins the northeastern boundary of the Dual Spring recharge area. The boundary then runs southwest separating sinkhole areas shown to be recharging Luhr Spring by Traces 00-317 shown on Figure 3 (Aley and Moss, 2001), and Traces 08-325 (Figure 9) and 08-333 (Figure 17) from sinkhole areas shown to recharge Dual Spring by Trace 08-332 (Figure 16).

From the boundary between the Dual Spring recharge area and the Luhr Spring recharge area, the boundary runs roughly northwest along a boundary that separates sinkhole areas recharging Schnellbecher Spring from sinkhole areas recharging Dual Spring. The traces to Schnellbecher Spring are Traces 97-01 and 97-03 (Figure 3) and Trace 08-334 (Figure 18). The boundary then turns back to the northeast and separates sinkhole areas shown by Trace 08-336 (Figure 20) to recharge Barker Spring from the sinkhole areas that recharge Luhr Spring. This section of the boundary was drawn approximately halfway between Trace 08-336 and the passage mapped in Multi-Bo Cave that discharges at Luhr Spring. This boundary continues along this orientation until it reaches Luhr Spring.

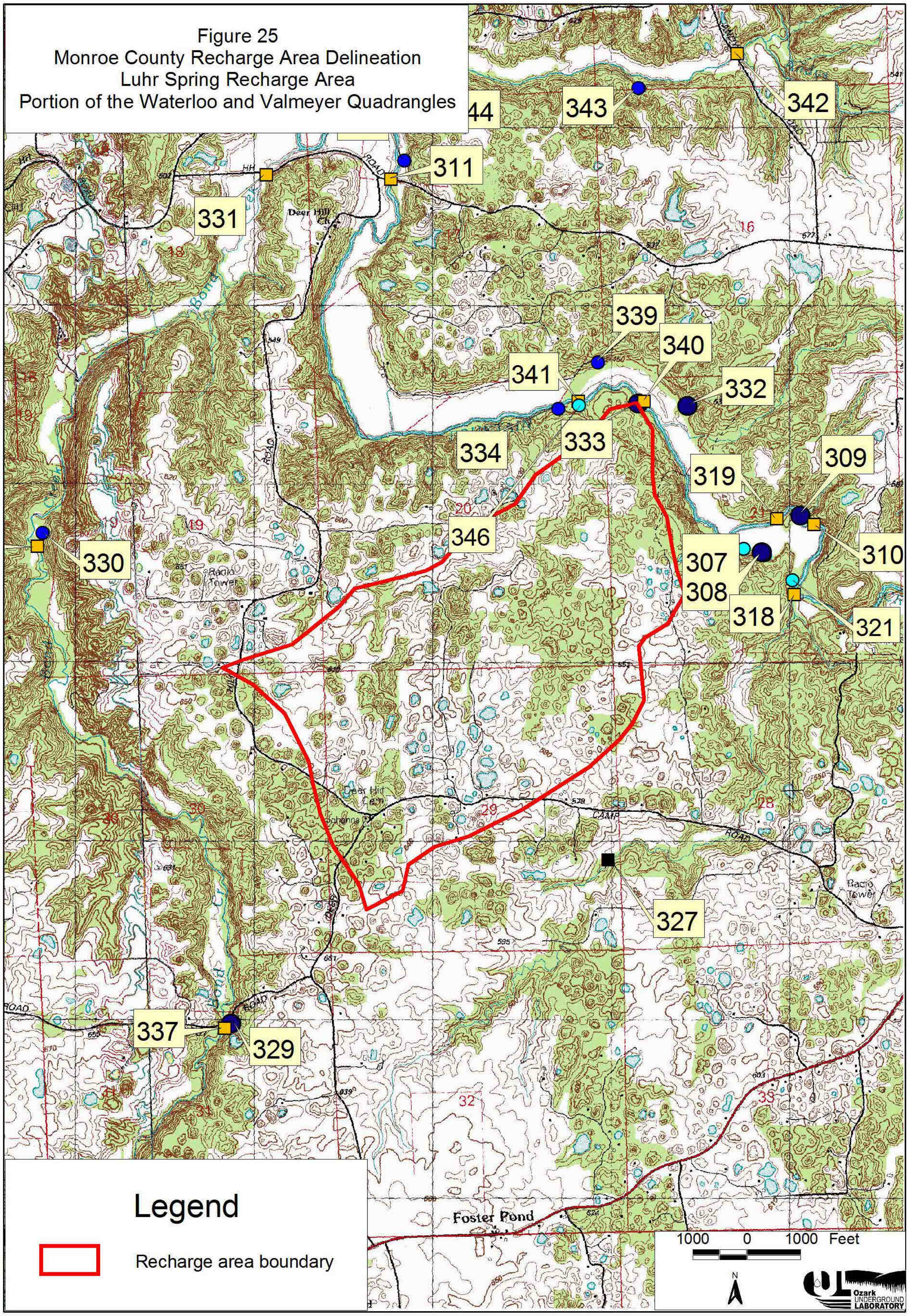


Figure 25
Monroe County Recharge Area Delineation
Luhr Spring Recharge Area
Portion of the Waterloo and Valmeyer Quadrangles
343
342
311
331
339
340
341
332
333
334
319
309
346
330
310
307
308
318
321
327
337
329
Foster Pond
Legend
Recharge area boundary
1000 0 1000 Feet
Ozark Underground Laboratory

4.4.4 Frog Spring

Frog Spring is the only groundwater system known to provide habitat for the Illinois cave amphipod that discharges on Bond Creek. Bond Creek is a major tributary of Fountain Creek, it flows north roughly parallel to the Mississippi River valley bluff line and generally about one mile east of the bluff line.

Frog Spring's recharge area appears to be the same under all flow conditions and no recharge areas have been identified as shared with any other groundwater system. Figure 26 shows the Frog Spring recharge area, which has both allogenic recharge from sinking streams and autogenic recharge from sinkholes. The Frog Spring recharge area encompasses approximately 2.2 square miles. The geographic relationship among the Waterloo subkarst recharge areas is shown on Figure 29.

Delineation Rationale – Frog Spring

Starting at the northern end of the recharge area at Frog Spring, the boundary runs roughly south along the top of the Bond Creek valley separating lands that shed runoff directly into the creek from sinkhole areas that recharge Frog Spring. Bond Creek was tested for leaks that recharge Frog Spring by Trace 08-320 (Figure 4) and Bond Creek was shown not to recharge Frog Spring or any other sampled springs. Trace 08-331 (Figure 15) demonstrated that the sinkhole area adjacent to Bond Creek recharges Frog Spring.

The boundary continues south until it reaches the Monroe City Creek watershed, which drains to the southwest. The boundary turns east a short distance until it reaches the Fountain Creek watershed and then turns back to the north to include the sinking stream shown by Trace 08-327 to recharge Frog Spring (Figure 11) and the sinking stream to the west of the tested one. The boundary running north is the boundary between the Frog Spring recharge area and the Antler-Annbriar Spring high flow recharge area boundary. The eastern boundary runs along a topographic divide separating the watersheds to two sinking streams, each traced to different spring systems. Trace 08-322 (Figure 6) showed that sinking stream recharges Antler-Annbriar Springs, while the more western sinking stream was shown by Trace 08-327 (Figure 11) to recharge Frog Spring.

The boundary runs north until it extends slightly north of Frog Spring and turns to exclude lands shown to recharge Schnellbecher Spring by Trace 97-03 (Figure 3) and continues west until the boundary closes at Frog Spring.

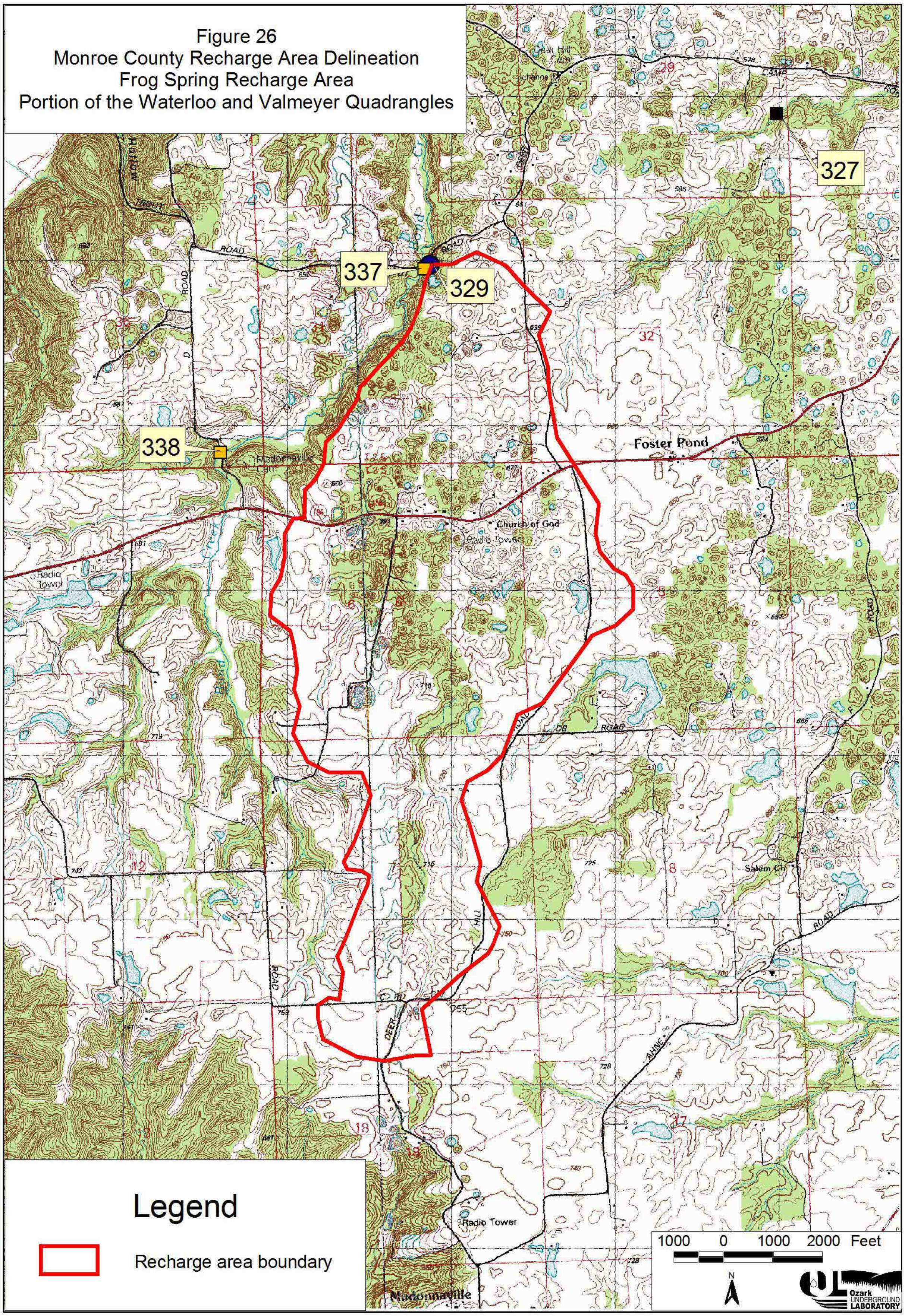


Figure 26
Monroe County Recharge Area Delineation
Frog Spring Recharge Area
Portion of the Waterloo and Valmeyer Quadrangles

4.4.5 Schnellbecher Spring

The recharge area of Schnellbecher Spring is not one that was listed in our contract to delineate. However, we believe that sufficient data now exists to do so and its recharge area delineation is included for completeness and potential utility for land use decisions. The Schnellbecher Spring groundwater system is not known to have particular biological significance (Lewis *et al*., 2003).

Schnellbecher Spring's recharge area is entirely autogenic and does not change boundaries with changing flow conditions. Schnellbecher Spring, like Frog Spring to the south, discharges on Bond Creek. There is no evidence of Schnellbecher Spring sharing recharge with any other groundwater systems. The recharge area encompasses approximately 0.6 square miles and is shown on Figure 27. The geographic relationship among the Waterloo subkarst recharge areas is shown on Figure 29.

Delineation Rationale – Schnellbecher Spring

Starting at Schnellbecher Spring, the boundary roughly parallels the Bond Creek Valley. However, the boundary moves away from the top of the valley as it extends up the valley since there are some small springs on the east side of Bond Creek and we believe that the boundary approximates the area that recharges those small springs.

The boundary then intersects the recharge area boundary of Frog Spring and that boundary is slightly north of Frog Spring and turns to include lands shown to recharge Schnellbecher Spring by Trace 97-03 (Figure 3). The boundary then extends east coincident with the Frog Spring recharge area boundary until it intersects the Antler-Annbriar Springs recharge area boundary. The boundaries coincide until they reach the Dual Spring recharge area boundary. The Schnellbecher Spring recharge area boundary then turns northwest and coincides with the Dual Spring boundary. The trend of the Schnellbecher Spring boundary continues as it coincides with the Luhr Spring recharge area boundary.

The Schnellbecher Spring recharge area boundary continues northwest separating sinkhole areas shown to recharge Barker Spring by Trace 08-336 (Figure 20) and those sinkhole areas shown to recharge Schnellbecher Spring by Trace 08-334 (Figure 18). The recharge area then extends slightly north of Schnellbecher Spring and then closes on Schnellbecher Spring.


Figure 27
Monroe County Recharge Area Delineation
Schnellbecher Spring Recharge Area
Portion of the Waterloo and Valmeyer Quadrangles
345
344
343
311
339
340
341
334
333
346
335
330
327
337
329
338
Foster Pond
Church of God
Radio Tower
Legend
Recharge area boundary
1000
0
1000
Feet
N
Ozark
UNDERGROUND
LABORATORY

4.4.6 Andys Run Spring

The recharge area of Andys Run Spring is not one that was listed in our contract to delineate. However, we believe that sufficient data now exists to do so and its recharge area delineation is included for completeness and potential utility for land use decisions. The Andys Run Spring groundwater system is not known to have particular biological significance (Lewis *et al*., 2003).

Andys Run Spring's recharge area is entirely autogenic and does not change boundaries with changing flow conditions. Andys Run Spring discharges on Andys Run and is the only groundwater system delineated that discharges on Andys Run. There is no evidence of Andys Run Spring sharing recharge with any other groundwater systems. The recharge area encompasses approximately 0.3 square miles and is shown on Figure 28. It should be noted that the western boundary is not well defined at this time. The geographic relationship among the Waterloo subkarst recharge areas is shown on Figure 29.

Delineation Rationale – Andys Run Spring recharge area

Three traces have been detected at Andys Run Spring. They are Traces 08-323, 08-335, and 08-337 which are shown on Figures 7, 19, and 21, respectively. These traces demonstrate that the sinkhole area containing these dye introduction points recharges Andys Run Spring. This sinkhole area lies within a strip of land bounded by Andys Run on the north, the headwaters of Andys Run and Fountain Creek on the east, and Fountain Creek on the south and west. There are several springs along Andys Run both upstream and downstream of Andys Run spring. There are also at least two springs on the Fountain Creek reach that forms the western edge of this strip of land.

The western boundary was not well defined by dye tracing as the only relevant traces were detected at Andys Run Spring. However, based on the presence of other nearby springs and the volume of discharge from Andys Run Spring, the western boundary as shown in Figure 28 is our estimation of the boundary location based on all of the available data.

When the boundary gets closer to Fountain Creek, it turns to the east and is drawn about halfway between Trace 08-337 and cave passage running southeast and discharges at Sore Knee (Station 339). The boundary then turns northeast and coincides with the Antler-Annbriar Springs recharge area boundary north of Fountain Creek, which is shown on Figure 29.

The boundary continues northeast until it reaches a topographic divide and then turns northwest and follows that topographic divide back to Andys Run Spring.

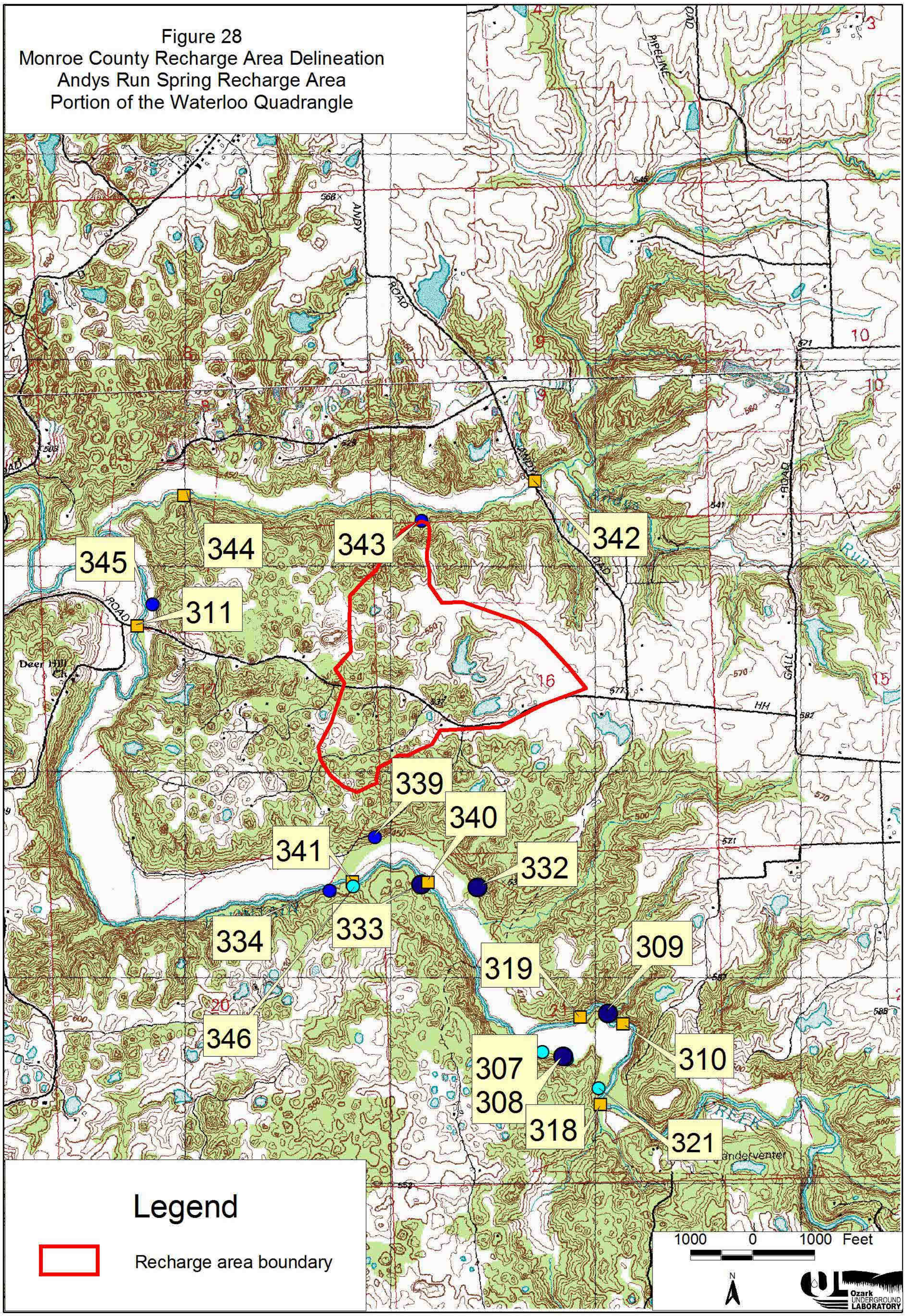


Figure 28
Monroe County Recharge Area Delineation
Andys Run Spring Recharge Area
Portion of the Waterloo Quadrangle
343
344
345
311
342
339
340
341
332
333
334
319
309
346
310
307
308
318
321
Legend
Recharge area boundary
1000 0 1000 Feet
N

5.0 SUMMARY AND CONCLUSIONS

Our proposal estimated that 15 new dye introductions would be needed. In fact, 19 new dye introductions were made which demonstrated 24 groundwater flow paths. Table 3 summarizes dye introduction locations and Table 4 summarizes trace lengths and gradients. These groundwater traces, 15 previous groundwater traces, and proprietary cave map overlays were used as the basis for the recharge area delineation of Frog Spring, Luhr Spring, Dual Spring, and to complete and revise the Antler-Annbriar Springs System. Two other recharge areas not required by our contract were also completed. The additional recharge areas are of Schnellbecher Spring and Andys Run Spring. This makes a total of seven recharge areas delineations completed (including the previously delineated Pautler Cave) in the Waterloo subkarst and these are all shown on Figure 29.

Our proposal estimated that we would establish 23 sampling stations. In the event, 27 sampling stations were used for more a more comprehensive sampling network. There were dye detections at least once at 23 of the 27 sampling stations established for this investigation.

In addition to the utility of these recharge areas for land use decision making generally, all of the groundwater systems known to provide habitat for the Illinois cave amphipod now have delineated recharge areas. The Illinois cave amphipod (*Gammarus acherondytes*) is listed as a Federal and State endangered species and is a globally-rare species.

Table 3. Summary of Dye Introductions.

Trace Number	Trace Name	Latitude	West Longitude	Date	Dye Type
08-320	Bond Creek Trace	38.29449	90.25713	1/1/08	eosine
08-321	Antler Trace	38.35670	90.21511	1/1/08	fluorescein
08-322	Hoffman Trace	38.29757	90.22849	1/6/08	rhodamine WT
08-323	Schmatt Trace	38.36048	90.21915	2/8/08	eosine
08-324	Frank Trace	38.34733	90.20092	3/2/08	rhodamine WT
08-325	Flag Trace	38.33568	90.22068	3/3/08	fluorescein
08-326	Andys Run Tributary Trace	38.36041	90.19985	3/18/08	eosine
08-327	Deer Hill Road Trace	38.28238	90.24704	4/10/08	sulforhodamine B
08-328	Gall Road Trace	38.35059	90.17946	4/10/08	fluorescein
08-329	Reverse Stream Overflow Trace	38.33248	90.21156	5/7/08	rhodamine WT
08-330	Glaenzer Trace	38.30491	90.23931	6/6/08	eosine
08-331	Dairy Farm Trace	38.30930	90.25072	12/27/08	sulforhodamine B
08-332	TNC Trace	38.32878	90.22670	6/12/09	sulforhodamine B
08-333	Cemetery Trace	38.33393	90.23357	10/15/08	rhodamine WT
08-334	Steinmann Trace	38.33844	90.24379	10/15/08	fluorescein
08-335	Heck Trace	38.36108	90.21562	10/17/08	sulforhodamine B
08-336	Bicklein Trace	38.34374	90.23287	12/27/08	eosine
08-337	McBride Road Trace	38.35878	90.22110	12/27/08	eosine
08-338	Luhr Trace	38.33326	90.21468	12/27/08	fluorescein

Table 4. Summary of Groundwater Trace Lengths and Gradients.

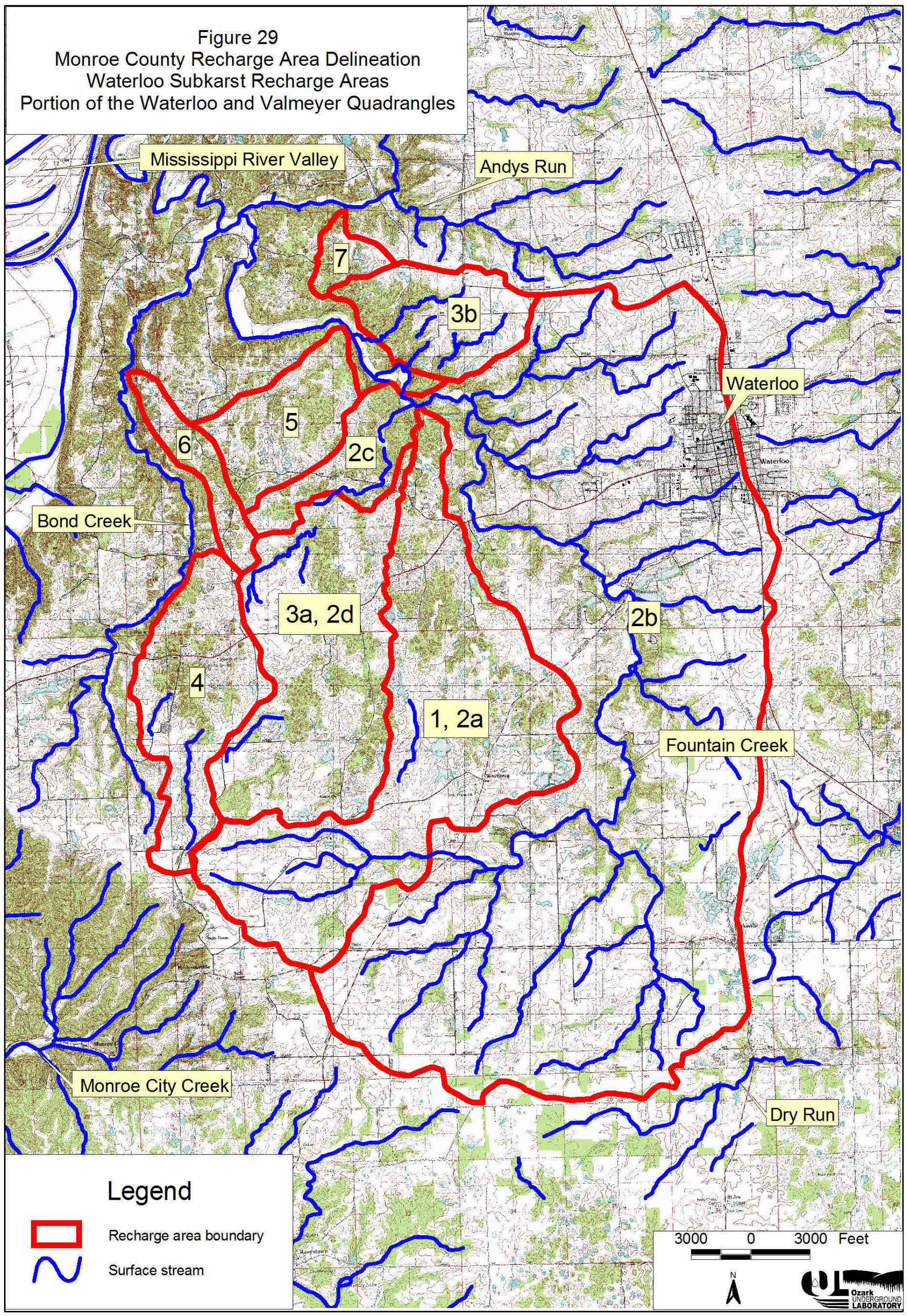
Trace Number	Trace Name	Dye Recovery Location	Trace Length	Gradient (feet per mile)
08-320*	**Bond Creek Trace**	**Bond Creek at HH Road**	**29,811**	**43**
08-321	Antler Trace	Antler Spring	1,425	178
08-322	Hoffman Trace	Antler Spring	20,526	59
08-322	Hoffman Trace	Annbriar Spring	19,311	62
08-323	Schmatt Trace	Andys Run Spring	3,155	100
08-324	Frank Trace	Antler Spring	4,369	58
08-325	Flag Trace	Luhr Spring	6,384	103
08-326*	**Andys Run Tributary Trace**	**Downstream Andys Run**	**10,417**	**79**
08-327	Deer Hill Road Trace	Frog Spring	14,590	69
08-328*	**Gall Road Trace**	**Fountain Creek at HH Road**	**20,431**	**41**
08-328	Gall Road Trace (from losing point)	Dual Spring	830	19
08-329	Reverse Stream Overflow Trace	Dual Spring West	4,708	67
08-329	Reverse Stream Overflow Trace	Dual Spring East	4,670	68
08-329	Reverse Stream Overflow Trace	Floodplain Estavelle	4,291	73
08-330	Glaenzer Trace	Frog Spring	6,559	64
08-331	Dairy Farm Trace	Frog Spring	5,060	130
08-332	TNC Trace	Dual Spring West	7,721	89
08-333	Cemetery Trace	Luhr Spring	8,333	114
08-334	Steinmann Trace	Schnellbecher Spring	4,781	182
08-335	Heck Trace	Andys Run Spring	2,896	292
08-336	Bicklein Trace	Barker Spring	6,164	158
08-337	McBride Road Trace	Andys Run Spring	3,897	95
08-338	Luhr Trace	Dual Spring West	4,606	126
08-338	Luhr Trace	Dual Spring East	4,582	127

* The bolded traces are surface flow paths included for completeness and comparison with the groundwater flow paths.

Significant Findings

Of particular note is that this investigation resulted in a revision of the Annbriar Spring Recharge Area on the south side of Fountain Creek. The Reverse Stream Overflow Trace demonstrated that land that almost certainly overlies conduits which discharge at Annbriar Spring actually recharges Dual Spring. However, that should not affect any IDNR consultation or other endangered species affected decision-making since both groundwater systems provide habitat for the Illinois cave amphipod.

It has also been illuminating to witness and document the evolution of the Annbriar Spring groundwater system, which over the last ten years or so has changed from most of the water being discharged from the Annbriar Spring Complex to now being primarily discharged from Antler Spring. Antler Spring has been shown in this study to be connected directly to the same groundwater flow paths which discharge or formerly discharged at Annbriar Spring.



Key to Figure 29

1. Pautler Cave recharge area
2. Dual Spring recharge area; 2a – Pautler Cave part, 2b – allogenic part, 2c – autogenic part, 2d – high flow part (southern part of Antler-Annbriar Springs)
3. Antler-Annbriar Springs; 3a – southern part, low flow; 3b – northern part; not shown – the high flow section of the southern part
4. Frog Spring recharge area
5. Luhr Spring recharge area
6. Schnellbecher Spring recharge area
7. Andys Run Spring recharge area

For planning purposes we believe that it is important to understand that the allogenic part of the Dual Spring recharge area is generally less vulnerable than the rest of the recharge area for three reasons:

- Only a small percentage of the water in Fountain Creek recharges Dual Spring, thus not all contamination moving down Fountain Creek enters the groundwater system.

- The groundwater path to the spring seems relatively short and is unlikely to pass through much Illinois cave amphipod habitat. The flow path's straight-line length is less than 850 feet. Undoubtedly, the actual flow path has some sinuosity and is somewhat longer than 850 feet. By not traveling far through the groundwater system, there is less potential habitat impacted and fewer individual Illinois cave amphipods dependent on the water quality along that flow path. It is also likely that this flow path is completely filled with water, which is not thought to be ideal cave amphipod habitat.

- Since most of the flow path for this water is on the surface, there is much more opportunity for natural cleansing of the water than there is along underground flow paths.

The investigation revealed a great deal of complexity in the groundwater systems of Antler-Annbriar Springs and Dual Spring. The major complexities are listed below:

1) The Pautler Cave recharge area all contributes some water to Dual Spring since Pautler Cave discharges upstream of the losing point in Fountain Creek and that water is, in turn, discharged from Dual Spring.

2) The majority of the Dual Spring recharge area is from land that is not karst, but happens to be in the Fountain Creek watershed upstream of the losing point in Fountain Creek that recharges Dual Spring.

3) Dual Spring also is recharged by water that overflows out of Reverse Stream under high flow conditions. First, by water that is lost through the overflow channel and then through the losing point in Fountain Creek when conditions in which overflow is high enough to reach Fountain Creek.

4) Most of the Pautler Cave recharge area is shared with the Antler-Annbriar Springs groundwater system under high flow conditions. At high flows, Pautler Cave overflows into the Antler-Annbriar Springs groundwater system.

5) Part of the Antler-Annbriar Springs groundwater system underlies land which recharges Dual Spring.

6) The Antler-Annbriar Springs recharge area is in two, discontinuous parts; one north of Fountain Creek and the other south of Fountain Creek, which are separated by about 3,500 feet.

7) There is flow crossing under Fountain Creek which discharges at Antler Spring.

Other findings of note and generalizations from the complexities noted above:

8) There are hydrologic connections between some of the groundwater systems. Since selected sinkholes were used as dye introduction points and dye tracing was not conducted under all possible flow conditions, not all of the existing hydrological connections may have been identified.

9) The lands overlying a groundwater system may not recharge that system via discrete recharge features.

10) The sources of spring water in the southwest Illinois karst can come from great distances from the spring and may originate well off the karst area.

11) Groundwater velocities through karst conduits are fast, typically on the order of thousands of feet per day.

12) The persistence of dye pulses is highly variable. If we consider tracer dye as a surrogate for groundwater contamination, it is clear that grab samples of water can easily miss contaminant pulses unless they are very high frequency samples, such as a daily collection.

13) Streams mapped as surface streams may be losing or sinking streams.

14) There is no substitute for comprehensive dye tracing in understanding groundwater movement in karst. It is also reasonable to consider that more complexity in karst groundwater movement is recognizable with more detailed investigations of groundwater movement.

6.0 RECOMMENDATIONS

The recharge areas are generally interpolations between dye introduction points. The recharge area boundaries are often zones having appreciable width instead of a finite line, except when a topographic divide is the boundary. When a change of land use is being considered which could significantly impact water resources is proposed or planned near a recharge area boundary and if there is not already site-specific groundwater tracing data, site-specific dye tracing should be done prior to significant investment in or approval of the proposed change. The site-specific tracing would provide direct, empirical evidence of which groundwater system or systems have the potential to be impacted.

In the southwest Illinois karst, a great deal of effort has gone into the groundwater tracing work to delineate recharge areas. 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 and plans in the region. Data left on the shelf do not help to enhance or protect public health or natural resources. It is important that the recharge area delineation rationales be read and understood, instead of placing sole reliance on paper or digital maps.

Vulnerability mapping should be conducted for the delineated recharge areas. As briefly mentioned in this report, the vulnerability of a karst 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 its fauna. 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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