GROUND WATER (DYE) TRACING IN MURFREESBORO TO HELP LOCATE POTENTIAL SOURCES OF CONTAMINATION TO SPRINGS ALONG BEAR BRANCH, SPENCE CREEK, AND LEE SPRINGS BRANCH

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GROUND WATER (DYE) TRACING IN MURFREESBORO TO LOCATE POTENTIAL SOURCES OF CONTAMINATION TO SPRINGS ALONG BEAR BRANCH, SPENCE CREEK, AND LEE SPRINGS BRANCH

EXECUTIVE SUMMARY

This fourth year of ground water tracing for Murfreesboro's Stormwater Quality Program has been a very successful one. A total of 8 ground water (dye) traces were conducted and all showed positive results proving a hydrologic connection between the injection points and the monitored springs. No dye traces had ever been conducted to Holcomb Spring, Ayers Spring, Lufkin Spring, Lee Spring, or Marymont Karst Window so significant knowledge has been gained on the recharge area (watershed) of these springs, as well as, those around them to which previous dye traces had been performed. Most of the springs studied provide significant base flow in summer months for the forks of the Stones Rivers to which they enter. Traces conducted in the Spence Creek watershed showed that ground water can cross topographic divides. Two of the traces near the head of the watershed went outside the basin to Overall Creek which diminishes the size of the basin as delineated by topographic divides. Two traces conducted in the Lee Spring Branch watershed showed that some of the area is actually connected to springs along the Middle Fork of the Stones River and not Lee Springs. A nearly 20 foot high pile of chicken manure stored close to the sinking stream that was traced to Lee Spring is the likely source of higher *e coli* levels in Lee Spring Branch. Tracing in the Bear Branch watershed as delineated from topographic maps showed that a significant portion of upper Bear Branch has been diverted by subterranean stream piracy out of the basin to the VA Hospital Spring. That water enters Walter Hill Dam significantly below where Bear Branch enters the East Fork of the Stones River. The tracing also found that the lower portion of Bear Branch loses its water to Lufkin Spring and Ayers Spring. The results of the ground water tracing in Bear Branch, as well as the other study areas this year, demonstrate that ground water can often cross surface water divides which is important for understanding water quality and to aid in responding to accidental spills or underground storage tank leaks. In addition to conducting the dye traces for the project, the authors participated in a 4½ minute news segment for Murfreesboro's TV station simulating a dye trace to show the public why it is important to understand where stormwater diverted into sinkholes goes to. It also can be seen on YouTube. Public education is an important mission of our nation's stormwater program.

More ground water tracing is needed within Murfreesboro's Urban Growth Boundary for better planning to ensure protection of the water quality of our streams. In particular, it is recommended that tracing be conducted along Joe B. Jackson to determine where drainage from the industrial park goes to when it enters the subsurface. This is an area of intense truck traffic where spills will likely occur. Undoubtedly, some of the underground storage tanks at these industries will someday leak, as well. In addition, stormwater retention ponds in the area have a high risk of collapse, and one already has. Finally, it is recommended that a comprehensive study be performed to the largest springs on the East Fork in Rutherford County above Bear Branch. These springs provide the

base flow of the East Fork and significantly affect the water quality at the water intakes for Murfreesboro and the Consolidated Utility District (C.U.D.) This proposed study would not only involve dye tracing to determine the springs' basins, but also would include spring water sampling and measuring spring discharge to determine relative quantity of contaminant load contribution to river flow. The study should be a joint venture between the City and the C.U.D. The information gained from the investigation will become invaluable for protecting our water supply.

INTRODUCTION AND PURPOSE

The West Fork, Middle Fork, and East Fork of the Stones River are relatively pristine waterways. During normal dry summers and early fall, most of the flow of all three forks of the river is a result of spring discharge. Therefore, the water quality of the river is actually the water quality of the ground water when there are no stormwater runoff events. Rutherford County is underlain by cavernous rock in which rain waters and contaminants rapidly enter the ground through sinkholes with little or no filtration. Murfreesboro and the County have been experiencing unprecedented growth that has led to increasing amounts of stormwater runoff that is often laden with chemicals applied to yards and fluids that leak from cars. In addition, the increased growth has resulted in more trucks carrying hazardous chemicals and gasoline, that if spilled, would quickly disappear into a sinkhole without any prior knowledge as to which spring the chemicals are going to emerge. This would result in killing of aquatic species in our surface streams and endangering our water supplies (Percy Priest Lake and Walter Hill Dam). Ground water tracing from sinkholes to springs using non-toxic dyes enables the delineation of surface watersheds that provide water to the subterranean cave streams that feed the springs. Therefore, the primary purpose for conducting the ground water tracing was to determine the surface drainage basins of some of the springs in the three forks of the Stones River to aid in planning growth to insure water quality protection.

Although not the primary purpose for the ground water tracing, the results can aid the city in predicting whether an area with sinkholes that is proposed for development will likely flood during large storm events. The results of this investigation can be used to determine the elevation difference between a sinkhole bottom and the spring to which

it is hydrologically connected. If the bottom is close to the spring elevation, the water table will simply rises quickly from the bottom of sinkholes during large storms. Thus, constructing drainage wells or digging out clay bottoms of sinkholes will not help alleviate the flooding. Past research has shown that if there is approximately 25 feet of difference between a sinkhole bottom and spring, flooding can likely be prevented.

STUDY AREA and HYDROGEOLOGIC SETTING

The study area is located largely within the Murfreesboro Urban Growth Boundary in the upper Stones River. Traces were conducted to springs that flow into the West Fork, East Fork, and Middle Fork of the Stones River. Studied springs that drain to the West Fork include: Three Rivers Spring, Holcomb Spring, Overflow Spring, Marymont Karst Window, and Lee Spring. Lufkin Spring, Ayers Spring, Dry Branch Spring, and the VA Hospital Spring drain into the East Fork of the Stones River. Gaurdrail Spring #1 and Guardrail Spring #2 discharge along the banks of the Middle Fork. No traces have ever been conducted to Lee Spring, Gaurdrail #2 Spring, Holcomb Spring, Overflow Spring, Lufkin Spring, or Ayers Spring prior to this study.

Rutherford County is located in the Central Basin physiographic province, which is underlain by limestones of Ordovician age that have been gently upwarped to form the Nashville Dome. The first detailed geologic map of Rutherford County was made by Galloway in 1919. Detailed geology maps now exist for the entire County. Those of particular interest for this investigation were Wilson Jr. (1964a), Wilson Jr. (1964b), and Wilson Jr. and Miller (1964). Although the overall structure of the Central Basin is a dome, there are numerous small anticlines, synclines, domes, and basins superimposed upon the larger domal structural. Moore et.al, 1969, made a structure contour map for much of the Stones River basin that shows the largest of the synclines. A later structure contour map was made by Rima, et.al, 1977. The two maps were made from different types of geologic data and, as a result, are not the same except for the location of the largest synclines and basins. In general, ground water flows off the anticlinal axes downdip toward the synclinal troughs and basins. Only the traces to the Guardrail

Springs did not follow this conceptual geologic model. Many of the springs in the study area do occur near the location of where a synclinal trough crosses a perennial stream like those in Spence Creek, for example. In general, most of the synclines and ground water traces follow the trend of the West Fork of the Stones River.

The oldest rocks exposed in Rutherford County are those of the Murfreesboro Limestone Formation, which is approximately 400 feet thick. Above the Murfreesboro Limestone is the Pierce Formation (Figure 1-Appendix D), a shaly, thin-bedded limestone that confines water beneath it in the Murfreesboro Aquifer and perches water above it in the Ridley Limestone. The figure also shows the Lower Ridley Confining Unit which occurs about 30 feet above the impermeable Pierce. Wilson and his co-workers commonly mapped the Lower Ridley Confining Unit as the Pierce Limestone. This was documented by a U.S.G.S study by Farmer and Hollyday (1999). The Ridley Limestone underlies most of the area of investigation, and it is the most karstic (cavernous) limestone in Rutherford County. Proprietary files of the Tennessee Cave Survey show that a majority of the 124 caves discovered and explored in Rutherford County occur in the Ridley Limestone aquifer. Snail Shell Cave near Rockvale is the largest with over nine miles of passage.

The first documented dye tracing in the Rutherford County occurred in the area of Snail Shell Cave as part of the State's proposal for the Superconducting Super Collider (Crawford, 1988). One of his traces was pertinent to the present investigation. Since 1988, approximately 130 ground water traces have been conducted in the County by Dr. Albert Ogden. About 30 of the most recent traces have been aided by Josh Upham, the co-author of this report. Five previously funded projects by the Rutherford County Planning Commission, three grants/contracts from the City of Murfreesboro, four MTSU Faculty Research Grants, and a grant from the Rutherford County Board of Education have enabled important discoveries to be made regarding ground water flow directions, causes for sinkhole flooding, and potential sources of spring water contamination. This

research has resulted in a number of publications (Ogden and Scott, 1997; Ogden et.al., 1998; Ogden et.al., 1999; Ogden and Powell, 1999; Ogden, 2000; Ogden et.al., 2001; Ogden et.al., 2002, Ogden, et.al., 2003, James, et.al, 2004, Ogden, et.al., 2006, James, et.al, 2006, Ogden, 2011, Ogden, 2012, Ogden et. al., 2012 and Ogden, 2013). Josh Upham, of Murfreesboro's Water and Sewer Department, has diligently updated the statewide GIS ground water tracing database for Rutherford County that the authors created for the TDEC-Ground Water Management Section in 2003. Approximately 60 new traces have been conducted since 2003.

GROUND WATER TRACING METHODS

The ground water tracing was performed using three fluorescent dyes: sulphorhodamine B (SRB), eosine, and fluorescein. These tracing agents are non-toxic and routinely approved for use by various divisions of the Tennessee Department of Environment and Conservation. Prior to conducting the traces, the Tennessee Underground Injection Control Program was notified in writing as required for their dye tracing registration program (see Appendix A). Material Safety Data Sheets for the dyes can be found in Appendix B. The injected tracing agents were detected by using activated charcoal packets that absorb and concentrate the dye levels in the water. The charcoal packets, called "traps", were suspended in the waters expected to receive the dyes on a stiff wire connected to a concrete base. Prior to tracing, some of the traps were placed in the spring waters for approximately a week to test for background concentrations. The dyes are common coloring agents and frequently found as "contaminants" in the ground water. Once background levels were determined, new packets were set out immediately prior to injection. After injection of the tracing agents, the packets were changed at approximately seven to ten day intervals and sent to the laboratory for analysis. Crawford Hydrology Lab, located at Western Kentucky University, was used to perform the analyses, which were done by a scanning spectrofluorophotometer.

GROUND WATER TRACING RESULTS

A total of eight traces were conducted for this project and all were successful in showing the hydrogeologically connection between the dye injection points and one or more springs. As previously mentioned, the springs studied empty into the West Fork, East Fork, and Middle Fork of the Stones River. No tracing had ever been conducted to several of the springs prior to the present investigation. The following is a discussion of the results by spring basin. Appendix C provides the results from the laboratory.

Three Rivers Spring, Overflow Spring, and Holcomb Spring Hydrologic System

Figure 2 (see Appendix D) shows the dye tracing results for Three Rivers Spring, Holcomb Spring, and Overflow Spring. Geologically, the springs occur in the lower Ridley Limestone. All of the springs are located along Spence Creek except for Overflow

Photograph 1 – Three Rivers Spring

Spring. Three Rivers Spring (Photograph 1) and the Overflow Spring (Photograph 2) occur along a synclinal trough whereas Holcomb Spring and Riverrock Spring occur

close to the trough on the southeast flank of the syncline. Holcomb Spring is about 10 feet higher in elevation than Three Rivers Spring. Figure 3 (see Appendix D) presents an aerial view of Three Rivers Spring and Holcomb Spring to show their close proximity. Spence Creek goes dry during summer months above the Three Rivers Spring's cave

Photograph 2 – Overflow Spring

orifice. Therefore, during drier months, the quality of Spence Creek is a combination of quality of Three Rivers Spring, Riverrock Spring, and Holcomb Spring. Very few sinkholes exist in the suspected drainage basin of Three Rivers Spring which has made tracing to it difficult. There is an overflow spring, the authors called Overflow Spring, located about a mile southwest of the spring that is a flowing spring during wet conditions but a sinkhole that takes water during drier conditions. Three-quarters of a pound of fluorescein were injected into a small pool of water at the bottom of Overflow Spring on October 12th, 2012 when it was not flowing. It was detected at Three Rivers Spring a few weeks later. At that time, Holcomb Spring had not been discovered. Therefore, it is unknown whether it would have tested positive for dye. A new dye trace

conducted for the present investigation strongly suggests that it would not have been positive. On April 28th, 2015, three-quarters pound of fluorescein were injected into a sinking stream located less than a half-mile due south of Holcomb Spring (Photograph 3).

Photograph 3 – Injection to Holcomb Spring

The water feeding the sinking stream comes from Overflow Spring when it is flowing. Holcomb Spring tested positive for the fluorescein (Appendix C). Unexpectedly, the dye injected in the sinking stream did not go to Three Rivers Spring. This strongly indicates that Holcomb Spring is a higher level spring whose basin has been isolated from the Three Rivers Spring basin during drier conditions due to subterranean stream piracy. This hypothesis is partially substantiated by Mr. Holcomb stating that his spring almost dries up in summer months although Three Rivers Spring continues to flow.

On May 6th, 2015, three-quarters pound sulphorhodamine B were injected into a sinkhole in a dried up lake bed located near the intersection of Veterans Parkway and Cason Lane (Photograph 4). Fire hydrant water was used to flush the dye into the

subsurface. The dye was detected at the Overflow Spring. It was not detected at Holcomb Spring or Three Rivers Spring. The water flowing out of Overflow Spring soon enters a pond, and its overflow is the water that was traced to Holcomb Spring.

Photograph 4 - Injection (Veterans Pkwy) to Overflow Spring

Therefore, the dye would have been too diluted by the pond to be detected. The level of dye detected at Overflow Spring was not strong, but significantly above background levels. This is believed due to the thick soil cover at the injection point in the dry lake bed which would have absorbed much of the dye before reaching the water table. This would easily explain why the dye was not detected at Three Rivers Spring despite the trace conducted two years earlier connecting Three Rivers Spring and the Overflow Spring. Since these two were hydrologically connected in 2012, the new trace demonstrates that the large area draining into the injection point is part of the Three Rivers Spring Basin. It is likely that some amount of the discharge of Three Rivers Spring, and possibly most of Riverrock Spring, is from water lost along the streambed of

upper Spence Creek. To confirm this would require a summer dye trace utilizing fire hydrant water to flush dye into a hole in the dry streambed.

Marymont Karst Window/Rucker Spring Basin

Two dye traces were conducted that initially were believed to likely emerge at Three Rivers Spring and/or Overflow Spring due to the injection points being close to a synclinal trough along which the springs occur. As a precaution, a large, impressive karst window (Photograph 5) with a stream flowing through it was also monitored for dye.

Photograph 5 – Marymont Karst Window

The authors called the site Marymont Karst Window due to its close proximity to Marymont subdivision. One trace had been previously conducted by Crawford (1988) to nearby Rucker Spring which empties into Overall Creek. He did not monitor the karst window, but his trace probably would have been detected there, as well as, Rucker Spring

(Figure 2-Appendix D). Both the karst window and Rucker Spring occur in the lower Ridley Limestone. On February 2nd, 2015, about three-quarters pound of fluorescein were injected into a sinking creek that appeared to be at the head of the Spence Creek watershed (Photograph 6). Surprisedly, the dye was only detected at Marymont Karst

Photograph 6

Window which undoubted leads to Rucker Spring, not Overflow Spring and Three Rivers springs, as expected. Then on February 13th, three-quarters pound of sulphorhodamine B were injected into the bottom of a water filled sinkhole the authors called Smith sinkhole after the owner (Photograph 7). Again, geologic structure predicted that the dye should emerge at Three Rivers Spring and Overflow Spring. Instead, the dye was detected at Marymont Karst Window (Figure 2-Appendix D). Not only did the two traces cross geologic structure, but they also crossed topographic divides. Therefore, the size of the Spence Creek Basin, as delineated by topographic divides, has been somewhat diminished by the two dye trace results.

Photograph 7 – Smith Sink

Lee Springs Basin

Lee Spring is at the head of Lee Springs Branch which flows into Lytle Creek (Figure 4-Appendix D). Geologically, Lee Spring is located in the upper Ridley Limestone. The spring basin is believed to be small based on past and present traces that went to the Guardrail Spring(s) basin. The southern boundary of the basin is located just north of Whitworth-Buchanan Middle School, and the western boundary is close to Manchester Pike (Route 41—see Figure 4). Only one trace was conducted to Lee Spring due to there being few sinkholes in the basin to be used for dye injection. Also, most of the sinkholes in the suspected basin were up-gradient of one or more water wells that could have been adversely affected by a dye injection. Nevertheless, the ephemeral sinking stream that was used for dye injection does drain a significant portion of the spring basin.

On March 17th, one-half pound of fluorescein was injected into the sinkhole that drains the sinking stream (Photograph 8). The stream was not flowing at the time of

Photograph 8

injection, so a small amount of flush water was added. The dye was detected at Lee Spring about a week later. Lee Springs Branch has shown elevated levels of *e coli*. The field work prior to the dye injection discovered the likely cause. About 200 feet from the sinkhole where the dye was injected, there was a huge pile of chicken manure perhaps 20 feet high (Photograph 8). Stormwater infiltrating through the manure pile was observed to cause a black leachate to emerge at the bottom. It was certainly high in *e coli* and nutrients. There is no doubt that this leachate enters the karst drainage system throughout the wet season due its close proximity to the sink point of the stream. It is recommended that the farmer be asked to move the stockpiled manure to the top of the hill in the same pasture, far away from the sinking stream.

Gaurdrail Springs Basin

There are two springs approximately 1000 feet apart that empty into the Middle Fork of the Stones River along Elam Road just a short distance downstream of the bridge

Photograph 9 – Guardrail Spring 1

on County Farm Road (Figure 4-Appendix D). The area of the springs was mapped by Wilson (1964b) as being at the contact of the lower Ridley Limestone and shaly Pierce Limestone, but the authors feel the geology map is wrong, and the Pierce Limestone on the map is actually the lower Ridley Confining Unit. The first dye trace in the basin was conducted about 15 years ago by Nick Crawford at the site of the Colonial Pipeline break close to the Buchanan exit of I-24. Crawford named the spring Guardrail Spring. About

Photograph 10 – Guardrail Spring 2

five years later, two additional traces were conducted to the spring by Ogden (2003). These two traces were performed from sinkholes on the Maples property just south of Whitworth-Buchanan Middle School. At that time, the downstream spring had not been discovered. Field reconnaissance for the present investigation found the second spring and temporarily named it No Cow Spring due to a large crudely hand-painted sign across the road that read "this property has No Cows". As a result, the lab report in Appendix C reports dye concentrations for Guardrail Spring and No Cow Spring. Once we determined that the two springs were indeed hydrologically connected, the upstream spring was named Guardrail Spring #1 (Photograph 9) and the other Guardrail Spring #2 (Photograph 10). Both springs emerge from a small water-filled cave at the base of low bluffs. Also, both springs appeared to have approximately the same flow during the investigation Combined, the flow was substantial, although never measured.

On March 2nd, three-quarters pound of fluorescein were injected into a sinkhole that had collapsed at the bottom of a pond (Photograph 11). At that time, the Guardrail

Photograph 11

springs were not monitored for dye because the injection point and a large spring to the north (Jones Spring—Figure 4) are both along the trough of a syncline indicating they should be hydrologically connected. At that time, Jones Spring and Lee Spring were monitored for dye. A small surface drainage pathway led from near the injection point to the head of Lee Springs Branch suggesting the dye could have gone there instead of Jones Spring. No dye was detected at either spring. Another ground water trace was conducted at the pond on April 24th using one pound of fluorescein, but this time Guardrail Spring #1 and Guardrail Spring #2 were monitored. Both springs tested very positive for the dye (Appendix C). Therefore, the ground water in the basin appears to cut across the trough of the syncline which is relatively rare in Rutherford County.

A major subdivision is under construction immediately south of Whitworth-Buchanan School that is in the Guardrail Springs Basin. It has been reported that several hundred homes are to be built and that much of the stormwater will be diverted to sinkholes or retention ponds that will have a high risk of collapse. This stormwater runoff will add a significant contaminant load to the ground water which will ultimately impact the water quality of the Middle Fork of the Stones River. The results of the new trace and the past three trace indicate that this spring basin is very large and likely encompasses part of the industrial park that includes the new Amazon distribution center. Due to all the truck traffic to and from these industries, it is important that subsurface drainage from the area be determined before a truck overturns or an underground storage tank leaks. Therefore, it is recommended that dye tracing be conducted in and around the industrial park to determine what areas go to Guardrail Springs, Jones Spring, or other springs along the Middle Fork and Lytle Creek.

Bear Branch-Lufkin Spring-Dry Branch Spring-Ayers Spring-VA Hospital Spring Hydrologic System

One dye trace was conducted to a cluster of springs that form the beginning of Bear Branch by Ogden in 2012 (Figure-5, see Appendix D). This trace hydrogeologically

connected the northern portions of Scotland Acres subdivision north of Greenland Drive to the springs at the head of Bear Branch. During drier conditions, the creek sinks into its bed at several locations before reaching the East Fork of the Stones River not far upstream from the city water supply intake on Walter Hill Dam. Where the sinking water of Bear Branch emerged to the surface was unknown until the present investigation. Three springs enter Bear Branch close to its confluence with the East Fork (Figure 5). These are: Lufkin Spring (Photograph 12), Dry Branch Spring, and Ayers Springs (Photograph 13). All three springs occur geologically in the lower Ridley Limestone near

Photograph 12 – Lufkin Spring

its contact with the impermeable Pierce Limestone. On April 27th, one-half pound of fluorescein was injected at a known sink point of Bear Branch where it crosses Osborne Lane (Photograph 14). Lufkin Spring, Ayers Springs, and Bear Branch tested positive for dye, but unexpectedly, Dry Branch Spring did not. It is possible that a pond that the spring emerges around the base of diluted the dye. It is also possible that there is a

Photograph 13 – Ayers Spring

separate small watershed that supplies ground water to the spring. The results of this trace demonstrate that a significant portion of the stream flow is pirated to the subsurface before the stream crosses Compton Road.

On May 15th, one and a half pounds of fluorescein and a half pound of sulphorhodamine B were injected at a major sink point incised into the streambed of upper Bear Branch (Photograph 15) at a location approximately 1000 feet south of where it goes under DeJarnette Lane (Figure 4) and about one mile upstream from the former injection point. The next day, a significant storm showed the sink point taking well over 500gpm for hours without backing up until the next day when streamflow increased. The VA Hospital Spring (Black Cat Cave) tested very positive for the dye, but Lufkin, Dry Branch, and Ayers springs all tested negative for the dye. Therefore, a significant amount of water in upper Bear Branch actually leaves the basin due to subterranean stream piracy and emerges in a totally different basin. Figure 4 shows the results of this trace and the

Photograph 14 – Injection near Osborne Ln

three past traces that went to the stream in Black Cat Cave and the VA Spring. The figure also shows the basin boundaries of Bear Branch as delineated from topographic maps versus the drainage basin demonstrated by the dye traces. Since the upper stream sink point is not capable of taking all of the flow during the wet season, the overflow water runs further downstream losing more water along the way on its path to it the East Fork. Lufkin Spring, Ayers Spring, and possibly Dry Branch Spring are the recipients of the lost water from the lower reaches of the stream. Somewhere between the two injection points on Bear Branch there is a sub-drainage divide that separates flow to Ayers and Lufkin springs from the VA Hospital Spring. This is a very complex hydrogeologically karst system, indeed.

The results of the dye traces explain the evolution of the Bear Branch-Lufkin Spring-Ayers Spring-VA Hospital Spring hydrologic system. When the impermeable Lower Ridley Confining Unit was at the surface, Bear Branch flowed to the East Fork of the Stones River without losing water. As the creek eroded down into the Lower Ridley Limestone through relatively recent geologic time, water began to be lost through small joints and cavities to emerge at Lufkin Spring. As surface erosion and dissolution continued, water was pirated even more to the subsurface to a lower level to form Ayers

Spring which is about six feet lower than Lufkin Spring. Then, erosion cut through the confining unit at the head of the basin, and water started to be pirated to the VA Hospital

Photograph 15 – Injection upstream of Dejarnette Ln

Spring. It is hypothesized that in time, Lufkin Spring will totally dry up as the stream continues to carve down into its bed, and Ayers Spring will be the only outlet of storm waters that sink into the lower reaches of Bear Branch. As upper Bear Branch continues to incise into its streambed and the conduit system to the VA Hospital Spring enlarges, all of Bear Branch will sink at that point and the lower portion of the stream will be abandoned of surface flow.

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to delineate the surface watersheds that provide recharge to some of the springs within the somewhat pristine reaches of the West, Middle, and East forks of the upper Stones River. Springs in this area provide most of

the flow of these three forks during late summer and early fall. Therefore, protecting the water quality of the springs ensures protection of our rivers during drier months. A total of eight ground water (dye) traces were conducted for this project and all were successful. Traces were conducted to six springs in which no previous knowledge existed as to the source of their flow.

One focus study area was the Spence Creek Basin. Springs investigated in this basin included Three Rivers Spring, Holcomb Spring, and Overflow Spring. Overflow Spring had been previously connected by dye tracing to Three Rivers Spring. One new trace was successful to Overflow Spring and another trace successful to Holcomb Spring which is in close proximity to Three Rivers Spring. Two traces near the head of the Spence Creek watershed did not go to Three Rivers Spring, as expected, but went to Marymont Karst Window which is very close to a large spring along Overton Creek. A previous trace by Crawford (1988) strongly suggests that the karst window is connected to that same spring. The traces to Marymont Karst Window reduce the size of the Spence Creek watershed as delineated from topographic divides. These traces and former traces conducted by the authors to Barfield Spring and Boiling Spring, now allows for a more accurate watershed delineation.

One trace was conducted to Lee Springs from a sinking stream that drains a significant portion of the suspected basin. Another successful trace did not go to Lee Springs as topographic divides predicted but went to two springs (Gaurdrail Spring #1 and Gaurdrail Spring #2) located along the Middle Fork of the Stones River. These two traces and three previous traces to the Guardrail springs now enables an accurate drainage basin to be delineated when combined with topographic divides. Another discovery in the Lee Spring basin was the likely source of *e coli* contamination to the spring and Lee Spring Branch. That contamination source is a large chicken manure pile, perhaps 20 feet high that a farmer has stored within nearly 200 feet of the sinking stream where the dye trace was conducted. This manure pile, apparently used for fertilizer during planting season, should be stored far away from the sink point or any sinkhole within the basin.

Two traces in the Bear Branch basin provided important and unexpected results. The first trace was conducted from an inconspicuous sink point in Bear Branch's streambed where it crosses Osbourne Lane. The dye was detected at Lufkin Spring and Ayers Spring which all empty into lower Bear Branch close to its confluence with the East Fork of the Stones River. These springs provide the only flow for Bear Branch throughout most of the summer and early fall. The second trace was performed at a deeply incised streambed sink point about 1000 feet north of where the branch crosses DeJarnette Lane. Instead of the dye going to Lufkin, Dry Branch, and/or Ayers Spring as expected, it went to the VA Hospital Spring that emerges from Black Cat Cave. This trace crossed the drainage divide of the Bear Branch basin. Therefore, the Bear Branch watershed as predicted from topographic divides, is not accurate for upper Bear Branch. Even when Bear Branch flows all the way to the Middle Fork during the wet season, a significant amount of the water is being diverted to the VA Hospital Spring drainage basin due to subterranean stream piracy. The results of the ground water tracing in Bear Branch, as well as the other study areas this year, demonstrate that ground water can often cross surface water divides which is important for interpreting water quality data and responding to accidental spills or underground storage tank leaks.

RECOMMENDATIONS

The results of this year's ground water tracing now provide subterranean drainage information for many square miles of the City in which no previous knowledge existed. The last four years of investigating ground water flow paths in Murfreesboro have provided valuable insight to possible sources of ground water contamination within nearly fifteen different spring drainage basins. The results of the tracing to Lufkin Spring, Ayers Spring, and the VA Hospital Spring have delineated areas that provide contaminants close to our water supply intake on Walter Hill Dam. The water quality of these three springs, particularly during summer months when many East Fork tributaries cease to flow, accounts for a

significant amount of the contaminant load to the reservoir. It also affects the water quality at the city's other water intake which is located downstream near the head of Percy Priest Lake. Similarly, it affects the water quality supply of the Consolidated Utility District intake located not far downstream from the city's. Several large springs have been identified in Rutherford County on the East Fork of the Stones River upstream of Bear Branch which also undoubtedly provide significant loads of contaminants that reach our water intakes. It is recommended that a comprehensive study be performed to the largest of the springs that would involve not only dye tracing to determine the springs' basins, but water sampling of the springs, and measuring spring discharge to determine the relative quantity of contribution to river flow. This should be a joint venture between the City and the Consolidated Utility District. The results of the investigation would be invaluable for planning future growth to ensure protection of our water supply. In addition, it is recommended that a smaller scale ground water tracing investigation be conducted that focuses on the area of the industrial park along Joe B. Jackson where there is a high risk of trucks turning over at the cloverleaf of I-24 and where many underground storage exist that may someday leak.

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APPENDIX A

Dye Tracing Registration Form submitted to the

Tennessee Department of Environment and Conservation-UIC Program

Albert E. Ogden, Ph.D.
Professor Emeritus-MTSU
6478 Jones Lane, Murfreesboro, TN 37127
(615) 907-0004; aogden@mtsu.edu

1/15/15

Dear Sir or Madam:

I will be conducting approximately 8 to 10 dye traces for the City of Murfreesboro as I have done three of the last 4 years. Tracing will begin in about 3 weeks. Tracing will continue until about mid-May. City personnel have identified several springs in which the streams they flow into have been designated as impaired. To help understand where pollution sources may exist, the spring basins have to be determined. Background charcoal dye detectors will be placed at the springs shown on the attached maps. The springs are all within the Murfreesboro Urban Growth Boundary. Sinkholes will be used as dye injection points when there are large rain storms. The exact locations of the sinkholes have not yet been determined as field work to locate them has just begun. The sinkholes will all be within the red boundaries shown on the attached maps. Lufkin Spring is the only spring involved in the study that is within 2 miles of the city water intake that is located in the lake created by the Walter Hill dam on the East Fork of the Stones. The regional landfill is located on the other side of the river from the intake. Special care will be taken to use conservative amounts of dye in this spring basin, and if the spring should turn colored, the dye will quickly be diluted by the lake before reaching the intake. The spring is about a mile upstream from the intake. If you have any questions, please feel free to contact me. Thank you.

Albert E. Ogden

Albert E. Ogden, Ph.D.

TENNESSEE DEPARTMENT OF ENVIRONMENT & CONSERVATION
DIVISION OF WATER RESOURCES – DRINKING WATER UNIT
William R. Snodgrass - Tennessee Tower
312 Rosa L. Parks Avenue, 11th Floor, Nashville, Tennessee 37243-1102

Tennessee Department of Environment & Conservation
Dye Trace Registration

Name, Address, Phone number of the Owner/Operator of the Facility Necessitating the Trace	Name, Address, Phone Number of the Person/Company performing the Trace
None	Albert E. Ogden 6478 Jones Lane, Murfreesboro, TN 37127 (615) 907-0004
Name and Address and Phone Number of the Property Owner Various owners yet to be identified although a couple have already been contacted	**Reason For the Trace** Research
If State or Federal Agency Oversight, Give Agency Contact Information Josh Upham, Murfreesboro Water and Sewer Dept, 220 NW Broad St, P.O. Box 1477, Murfreesboro, TN 37133 (615) 848-3200	**Is the Area Served by a Public Water System** ☒ Yes: Name the Water System Murfreesboro City Wa ☐ No: Estimate Percentage of Private Well/Spring Use Versus Public Water Use

Dyes to Be Used

Type	Amount	Location
Eosine	Approximately 1 lb of	
Fluorescein	tracers will be used	
Rhodamine	during each trace	
		Locations of the
		sinkholes to be used as injection
		points are within the boundaries of the 3 basins shown on the attached maps

Receptors

☒ Type Charcoal
☐ Visual

Location of Receptors

Lee Spring	3 Rivers Spring
Riverrock Spring	Barfield Spring
Jones Spring	

Describe Injection Point(s) and Include a copy of a Topographic Map with the locations of the injection points and the locations of receptors (include a Latitude and Longitude for the primary injection point.)

Injection points will all be sinkholes. Their exact locations have not been determined yet, but will be within the real boundaries shown on the map

Public Water Systems: List Surface Water Intakes, Wells or Springs within 2 Miles of the Injection Point(s):

One of the city water intakes is within a mile of Hoskin Spring (see map. Special care will be taken to use conservative amounts of dye in this basin

Certification

I certify under penalty of law that this document and all attachments were prepared by me, or under my direction or supervision. The submitted information is to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment. As specified in Tennessee Code Annotated Section 39-16-702(a)(4), this declaration is made under penalty of perjury.

Name and Official Title(please print)	Signature	Date Signed
	Albert E. Ogden	1/15/15

There are currently no regulations requiring dye trace registration in Tennessee, unless there is the potential to impact a public water system. This registry is designed to avoid cross contamination and re-performing the same or similar trace. The dye tracing registry allows the Department to make informed responses to water pollution inquiries so that dye traces are not mistakenly identified as pollution to waters of the state.

APPENDIX B

Summary of Laboratory Results

Material Safety Data Sheet
(FLUORESCEIN)
15174 URANINE C

CHEMCENTRAL/Dyes & Pigments
13395 Huron River Drive
Romulus, MI 48174

REVISION DATE: 12-6-00
CHEMTREC: 800-424-9300
EMERGENCY: 734-941-4800

SECTION I - IDENTIFICATION

TRADE NAME: ..... 15174 URANINE C
CHEMICAL NAME: ..... Acid Yellow 73 CAS# 6417-85-2
CHEMICAL FAMILY: ..... Xanthene

SECTION II - HAZARDOUS INGREDIENTS

HAZARDOUS INGREDIENT	PERCENT	CAS NUMBER	PEL
NONE as per 29CFR part 1910.1200 or Sara Title III			

HMIS HAZARD RATINGS (if applicable):
HEALTH: 1
FIRE 0
REACTIVITY 0

SECTION III - PHYSICAL DATA

APPEARANCE: ..... Orange powder, no characteristic odor.
BOILING POINT: ..... N/A
MELTING POINT: ..... N/A
FREEZING POINT: ..... N/A
VAPOR PRESSURE: ..... N/A
VAPOR DENSITY (AIR=1): ..... N/A
SPECIFIC GRAVITY: ..... Approximately 1
pH: ..... N/A
SOLUBILITY IN WATER: ..... Moderate
VOLATILITY: ..... N/A

SECTION IV - FIRE AND EXPLOSION DATA

FLASH POINT: ..... N/A
EXTINGUISHING MEDIA: ..... Water fog, CO_2, or Dry chemical.
FIRE FIGHT PROCEDURES: ... Fire fighters should be equipped with self contained breathing apparatus and turnout gear.
UNUSUAL FIRE HAZARD: ..... Adequate ventilation and clean up must be maintained to minimize dust accumulation. May form explosive dust/air mixture.

Material Safety Data Sheet
(FLUORESCEIN)
15174 URANINE C

SECTION V - REACTIVITY DATA

STABILITY: ..... Stable
CONDITIONS TO AVOID: ..... N/A
HAZARDOUS POLYMERIZATION: Does not occur
POLYMERIZATION TO AVOID: N/A
INCOMPATIBILITY: ..... Avoid contact with strong oxidizing agents
DECOMPOSITION: ..... Carbon monoxide,Carbon dioxide,and oxides of Nitrogen and Sulfur.

SECTION VI - HEALTH DATA

THRESHOLD LIMIT VALUE:.. Not Established
OVER EXPOSURE EFFECTS: Contact with eyes may result in severe irritation. Contact with skin may result in irritation. Ingestion may result in gastric disturbances. Inhalation of dust may irritate respiratory tract.

SECTION VII FIRST AID

FIRST AID PROCEDURES: Flush eyes with flowing water at least 15 minutes. If irritation develops, consult a physician. Wash affected skin areas thoroughly with soap and water. If irritation develops, consult a physician. Remove and launder contaminated clothing before reuse.

If swallowed, dilute with water and induce vomiting. Get immediate medical attention. If inhaled, move to fresh air. Aid in breathing, if necessary, and get medical attention.

NEVER GIVE FLUIDS OR INDUCE VOMITING IF PATIENT IS UNCONSCIOUS OR HAS CONVULSIONS.

SECTION VIII EMPLOYEE PROTECTION

RESPIRATORY PROTECTION: NIOSH/OSHA approved dust respirator as necessary.
PROTECTIVE GLOVES: ..... To prevent skin contact.
EYE PROTECTION: ..... Goggles.
ADDITIONAL MEASURES: ..... Eye wash fountains should be easily accessible.
HANDLING AND STORAGE:... Keep away from excessive heat and moisture. Keep containers closed.
VENTILATION: ..... Local exhaust to control dusts.

SECTION IX - SPILL AND DISPOSAL DATA

SPILL: ..... Spills should be contained and placed in suitable containers.
WASTE DISPOSAL: ..... Do not discharge into sewers or waterways. Dispose of in accordance with local regulations.

Material Safety Data Sheet
(FLUORESCEIN)
15174 URANINE C

SECTION X - TRANSPORTATION DATA

PROPER SHIPPING NAME: ..... Ink Material NMFC Item #101720
HAZARD CLASS AND LABEL: MFR LABEL ONLY
UN NUMBER: ..... N/A
REPORTABLE QUANTITY: ..... N/A

SECTION XI - ADDTIONAL INFORMATION

FOOT NOTES: This information is furnished without warranty, representation, or license of any kind, except that it is accurate to the best of CHEMCENTRAL Corporation's knowledge or obtained from sources believed by CHEMCENTRAL Corporation to be accurate.

The CHEMCENTRAL Corporation does not assume any legal responsibility for use or reliance upon same. Customers are encouraged to conduct their own tests. Before using any product, read its label.

Material Safety Data Sheet
(SULPHORHODAMINE B)
17152 Acid Rhodamine DW

CHEMCENTRAL/Dyes & Pigments
13395 Huron River Drive
Romulus, MI 48174

REVISION DATE: 10/17/01
CHEMTREC: 800-424-9300
EMERGENCY: 734-941-4800

SECTION I - IDENTIFICATION

TRADE NAME: ..... 17152 Acid Rhodamine DW
CHEMICAL NAME: ..... Acid Red 52 (Color Index Name) CAS # 3520-42-1
CHEMICAL FAMILY: ..... Xanthene

SECTION II - HAZARDOUS INGREDIENTS

HAZARDOUS INGREDIENT	PERCENT	CAS NUMBER	PEL
None as per 29CFR part 1910.1200 or Sara Title III			

HMIS HAZARD RATINGS (if applicable):
HEALTH: 2
FIRE 1
REACTIVITY 0

SECTION III - PHYSICAL DATA

APPEARANCE: ..... Black powder, mild odor.
BOILING POINT: ..... N/A
MELTING POINT: ..... N/A
FREEZING POINT: ..... N/A
VAPOR PRESSURE: ..... N/A
VAPOR DENSITY (AIR=1): ..... N/A
SPECIFIC GRAVITY: ..... Approximately 1
pH: ..... N/A
SOLUBILITY IN WATER: ..... Soluble
VOLATILITY: ..... N/A

SECTION IV - FIRE AND EXPLOSION DATA

FLASH POINT: ..... N/A
EXTINGUISHING MEDIA: ..... Water fog, CO_2, or Dry chemical.
FIRE FIGHT PROCEDURES: ... Fire fighters should be equipped with self contained breathing apparatus and turnout gear.
UNUSUAL FIRE HAZARD: ..... Adequate ventilation and clean up must be maintained to minimize dust accumulation. May form explosive dust/air mixture.

APPENDIX C

Material Safety Data Sheets for the Dyes used for Tracing

Lab Results

Lab ID	River	Date Collected	Feature Name	TIM	Peak	Results	Conc in ppb	Center [nm]	Results	Conc in ppb	Center [nm]	Results	Conc in ppb	Center [nm]	Comments
EL-001-0	01	02/10/15	OVERFLOW SPRING	-		B	0.767	393.0	+	0.166	514.8	ND			
EL-001-1	02	02/26/15	OVERFLOW SPRING	-		B	0.531	393.0	++	0.759	515.2	ND			
EH-001-0	03	05/18/15	OVERFLOW SPRING	-					B	0.011	513.4	+?	5.129	576.4	
EH-002-0	01	02/10/15	MERRIMONT KARST WINDOW	-		ND			+++	101.226	515.8	ND			
EH-002-1	02	02/26/15	MERRIMONT KARST WINDOW	-		ND			+++	6.870	515.4	++	1.394	575.2	
EH-002-0	03	03/13/15	MERRIMONT KARST WINDOW	-					+++	6.193	515.8	++	2.367	574.8	
EL-002-0	04	05/19/15	MERRIMONT KARST WINDOW	-					B	0.057	510.4,POR	B	0.921	570.4,POR	
EL-003-0	01	02/10/15	THREE RIVERS SPRING	-					B	0.708	520.2,POR	ND			
EL-003-0	02	02/26/15	THREE RIVERS SPRING	-		ND			B	0.711	521.0,POR	++	1.725	574.4	
EL-003-0	03	03/16/15	THREE RIVERS SPRING	-					B	0.526	521.0,POR	+	0.420	572.3	Manual peak pick on SRB
EH-003-0	05	05/05/15	THREE RIVERS SPRING						++	3.632	516.6				
EL-003-0	04	05/18/15	THREE RIVERS SPRING						++	0.493	517.2	ND			
EH-004-0	01	02/10/15	LEE SPRING	-		ND			+++	8.398	515.6	ND			
EL-004-1	02	02/26/15	LEE SPRING	-		ND			+	0.126	512.4	ND			
EL-004-0	03	03/09/15	LEE SPRING	-					ND			ND			
EH-004-0	04	03/23/15	LEE SPRING	-					+++	39.059	516.0	++	1.464	573.8	
EH-004-1	05	03/31/15	LEE SPRING	-					+++	42.907	515.8	++	0.980	573.8	
EH-005-0	01	03/09/15	JONES SPRING	-					+?	6.770	515.0	ND			
EL-005-0	02	03/31/15	JONES SPRING	-					ND			ND			
EH-006-0	01	05/05/15	NO COW SPRING	-					+?	75.600	516.2				
EH-007-0	01	05/05/15	GUARDRAIL SPRING						+?	217.300	515.6				DILUTED 1:100
EH-008-0	01	05/05/15	LUFFKIN SPRING						+?	332.600	515.6				
EH-009-0	01	05/05/15	HOLCOMB SPRING						+?	21.378	515.6				
EH-010-0	01	05/10/15	BEAR BRANCH						+?	70.252	516.2				
EH-011-0	01	05/10/15	AYERS SPRING						+?	47.329	516.2				
EH-009-0	01	05/19/15	HOLCOMB SPRING						+?	75.966	515.6	ND			
EL-012-0	01	05/18/15	BARFIELD SPRING						B	0.017	507.6,POR	ND			

Approved by: L.Bledsoe on 05/28/15

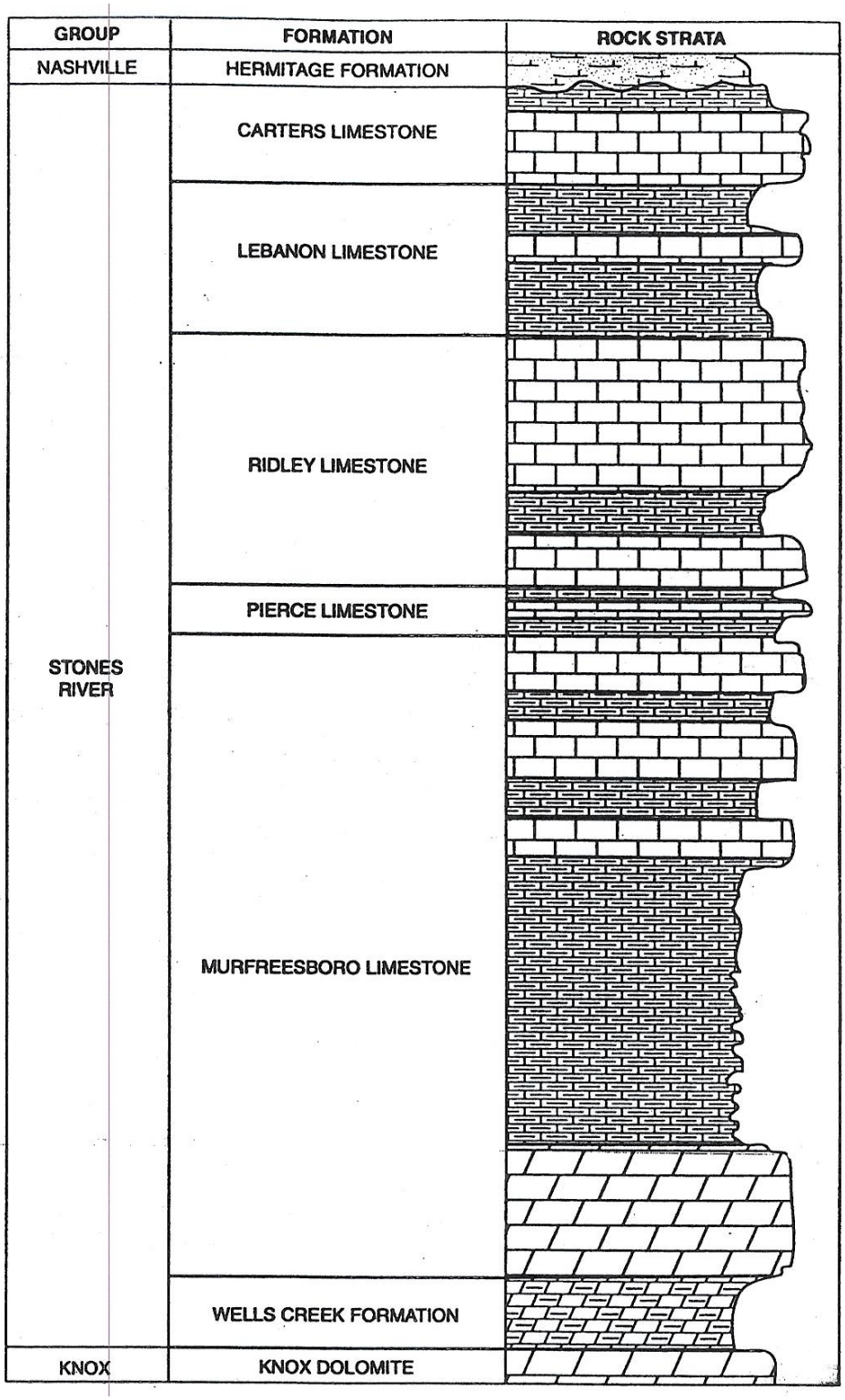
Comments: Peak for SRB at Three Rivers Spring manually picked - shoulder on FL peak could not be identified in Shimadzu Software.

DUP = Field Duplicate
NS = No Sample Recovered
Q = Lab Duplicate
B = Background
GS = Grab Sample
+ = Positive
ND = No Detection
NPI = No Peak Identified
?+ = Questionable Positive, needs two hits in a row to equal +
IB = Initial Background
POR = Peak Out of Range
Peakfit Utilized

APPENDIX D

Figures for Report

Figure 1: Stratigraphic column of the study area (adapted from Farmer and Hollyday, 1999).



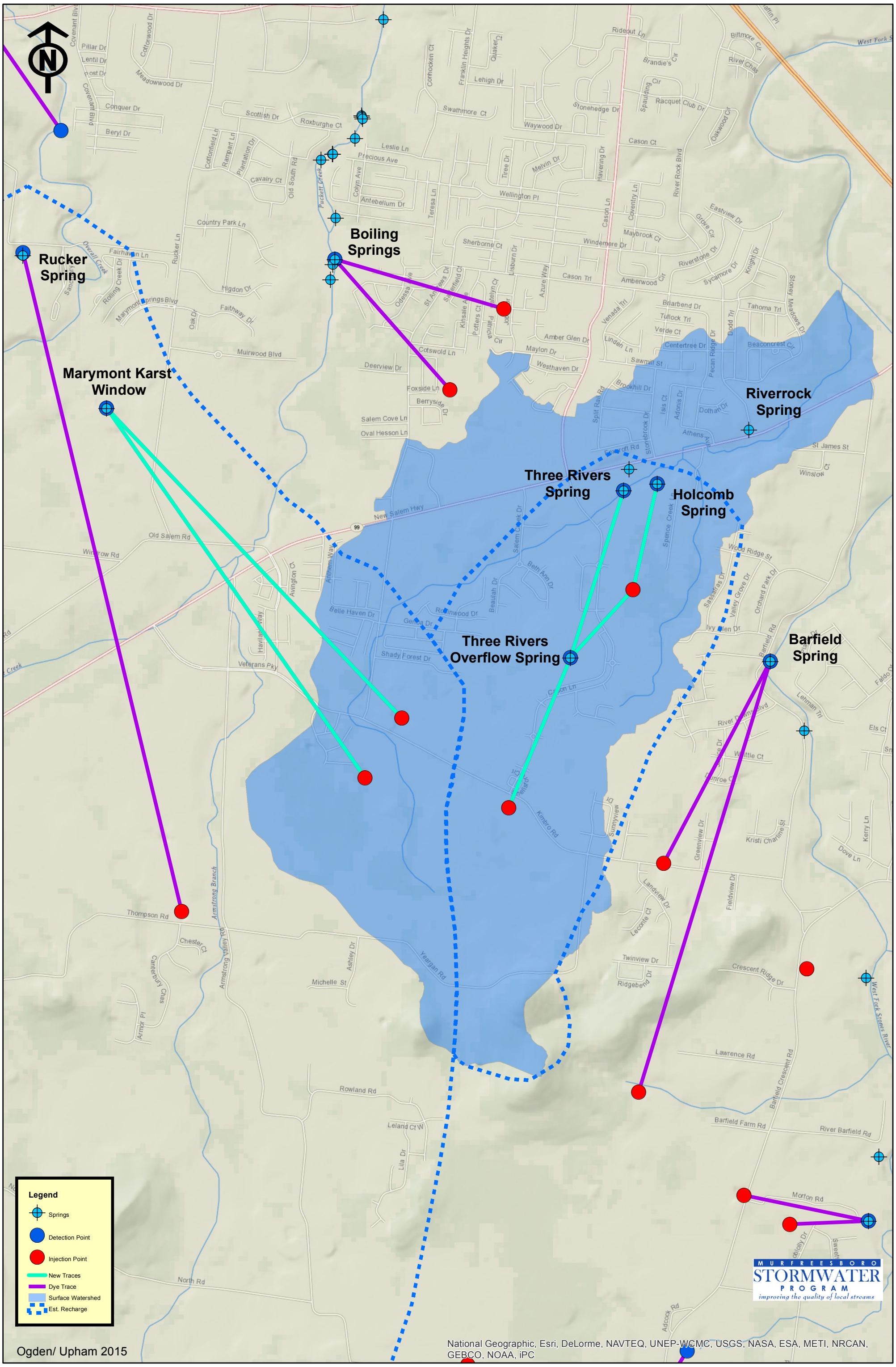


Figure 2: Spence Creek Watershed - Springs and Dye Trace Results with Watershed and Estimated Recharge Basins

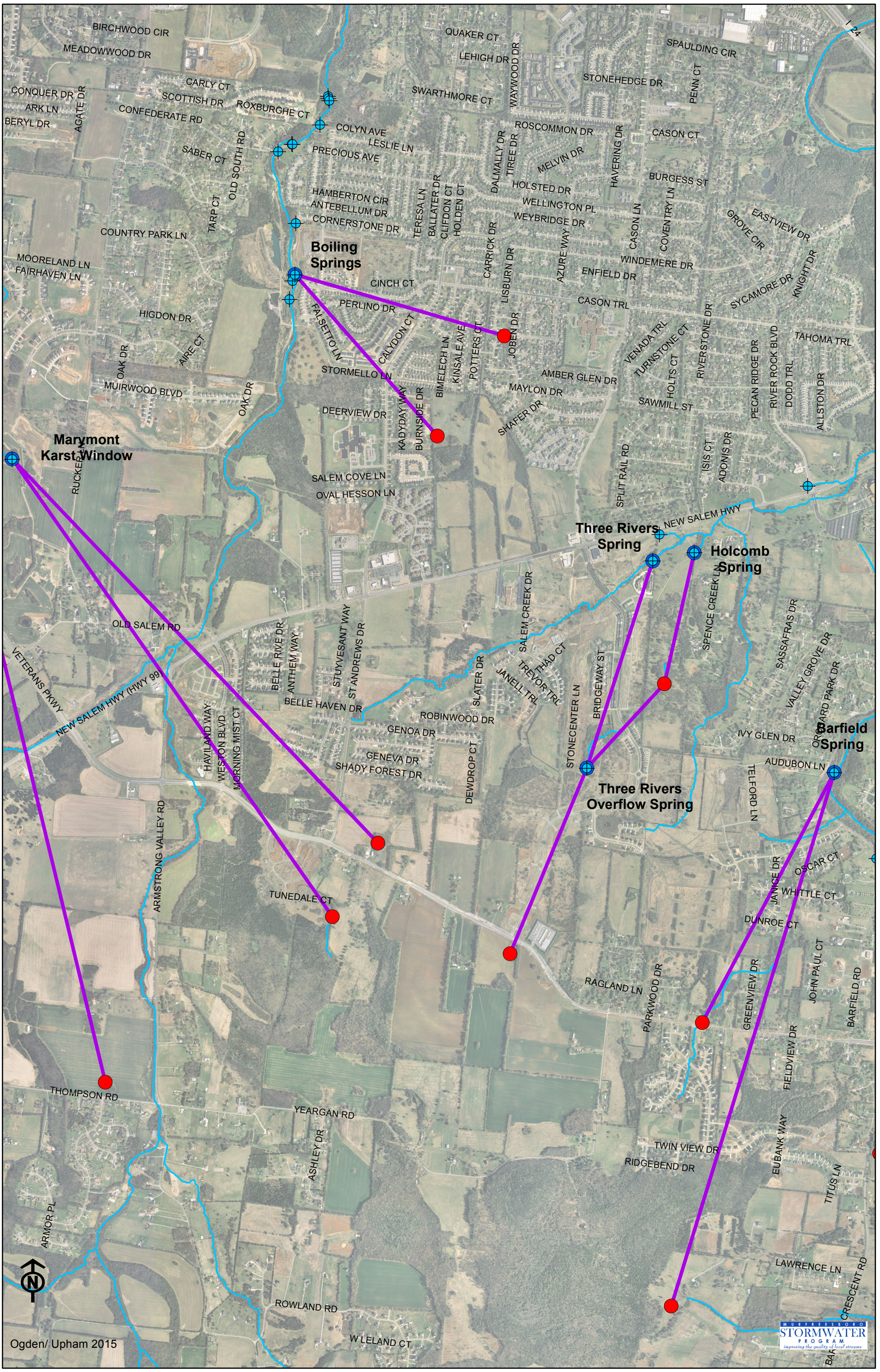

Boiling Springs
Marymont Karst Window
Three Rivers Spring
Holcomb Spring
Three Rivers Overflow Spring
Barfield Spring
BIRCHWOOD CIR
MEADOWWOOD DR
CONQUER DR
ARK LN
BERYL DR
AGATE DR
CARLY CT
SCOTTISH DR
CONFEDERATE RD
ROXBURGHE CT
SABER CT
OLD SOUTH RD
COLYN AVE
LESLIE LN
PRECIOUS AVE
HAMBERTON CIR
ANTEBELLUM DR
CORNERSTONE DR
TARP CT
COUNTRY PARK LN
MOORELAND LN
FAIRHAVEN LN
HIGDON DR
AIRE CT
OAK DR
MUIRWOOD BLVD
QUAKER CT
LEHIGH DR
SWARTHMORE CT
WAYWOOD DR
SPAULDING CIR
STONEHEDGE DR
PENN CT
ROSCOMMON DR
CASON CT
DALMALLY DR
TIREE DR
MELVIN DR
HAVERING DR
BURGESS ST
HOLSTED DR
WELLINGTON PL
WEYBRIDGE DR
TERESA LN
BALLATER DR
CLIFDON CT
HOLDEN CT
CARRICK DR
LISBURN DR
AZURE WAY
CASON LN
COVENTRY LN
GROVE CIR
EASTVIEW DR
WINDEMERE DR
ENFIELD DR
CINCH CT
PERLINO DR
CASON TRL
SYCAMORE DR
KNIGHT DR
FALSETTO LN
CALYDON CT
JOBEN DR
BIMELECH LN
KINSALE AVE
POTTERS CT
STORMELLO LN
AMBER GLEN DR
MAYLON DR
SHAFER DR
VENADA TRL
TURNSTONE CT
RIVERSTONE DR
TAHOMA TRL
HOLTS CT
SAWMILL ST
PECAN RIDGE DR
RIVER ROCK BLVD
DODD TRL
ALLSTON DR
DEERVIEW DR
KADYDAY WAY
BURNSIDE DR
SALEM COVE LN
OVAL HESSON LN
RUCKER LN
SPLIT RAIL RD
ISIS CT
ADONIS DR
NEW SALEM HWY
OLD SALEM RD
VETERANS PKWY
NEW SALEM HWY (HWY 99)
BELLE RIVE DR
ANTHEM WAY
STUYVESANT WAY
ST ANDREWS DR
BELLE HAVEN DR
SALEM CREEK DR
THAD CT
TREVOR TRL
JANELL TRL
SLATER DR
ROBINWOOD DR
GENOA DR
GENEVA DR
SHADY FOREST DR
DEWDROP CT
STONECENTER LN
BRIDGEWAY ST
SPENCE CREEK LN
SASSAFRAS DR
VALLEY GROVE DR
ORCHARD PARK DR
IVY GLEN DR
AUDUBON LN
TELFORD LN
HAVILAND WAY
WESTON BLVD
MORNING MIST CT
ARMSTRONG VALLEY RD
TUNEDALE CT
JANICE DR
OSCAR CT
WHITTLE CT
DUNROE CT
RAGLAND LN
PARKWOOD DR
GREENVIEW DR
JOHN PAUL CT
BARFIELD RD
FIELDVIEW DR
THOMPSON RD
YEARGAN RD
ASHLEY DR
TWIN VIEW DR
RIDGEBEND DR
EUBANK WAY
TITUS LN
ARMOR PL
LAWRENCE LN
CRESCENT RD
ROWLAND RD
W LELAND CT
I 24
Ogden/ Upham 2015
MURFREESBORO STORMWATER PROGRAM
improving the quality of local streams

Figure 3: Three Rivers and Holcomb Springs

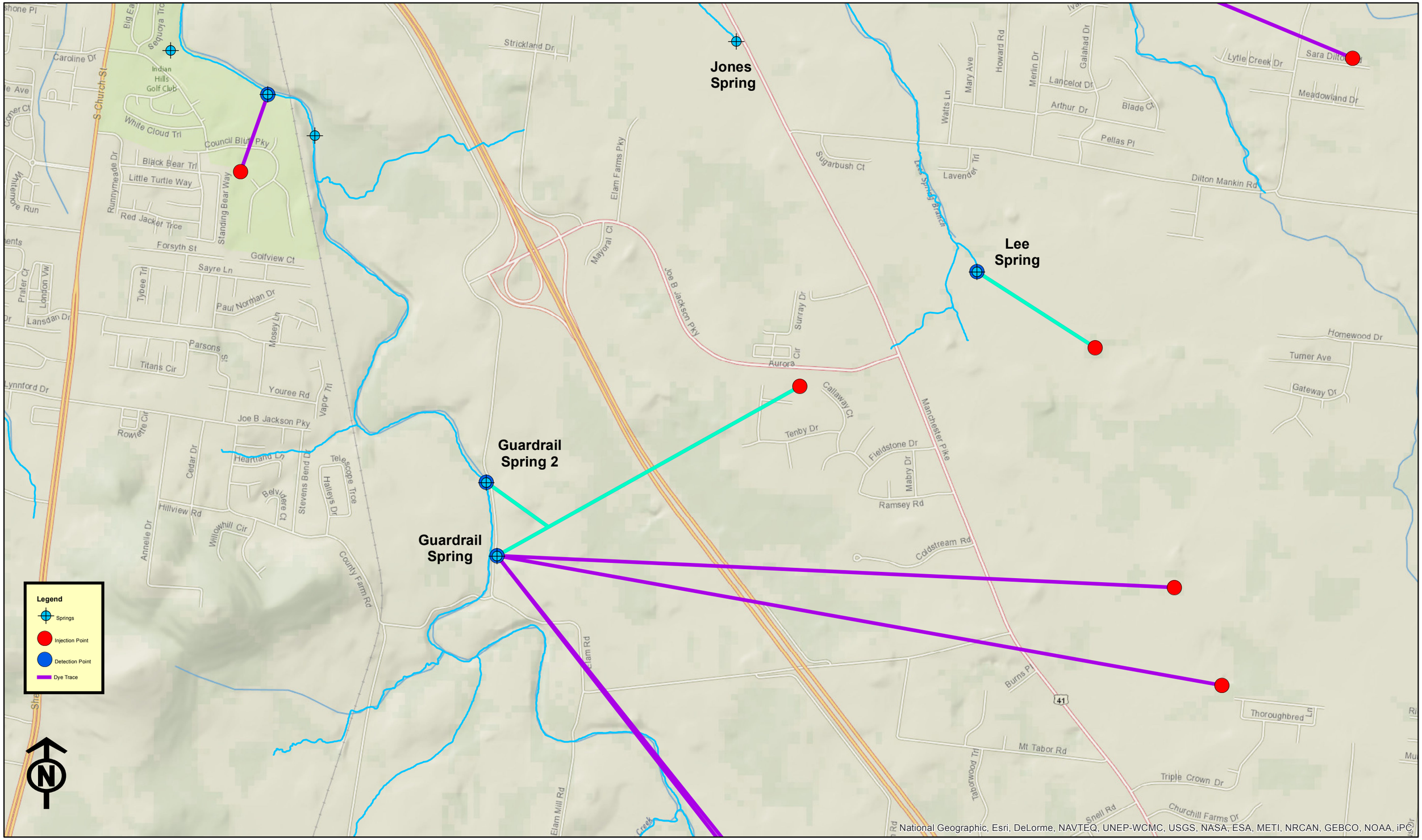
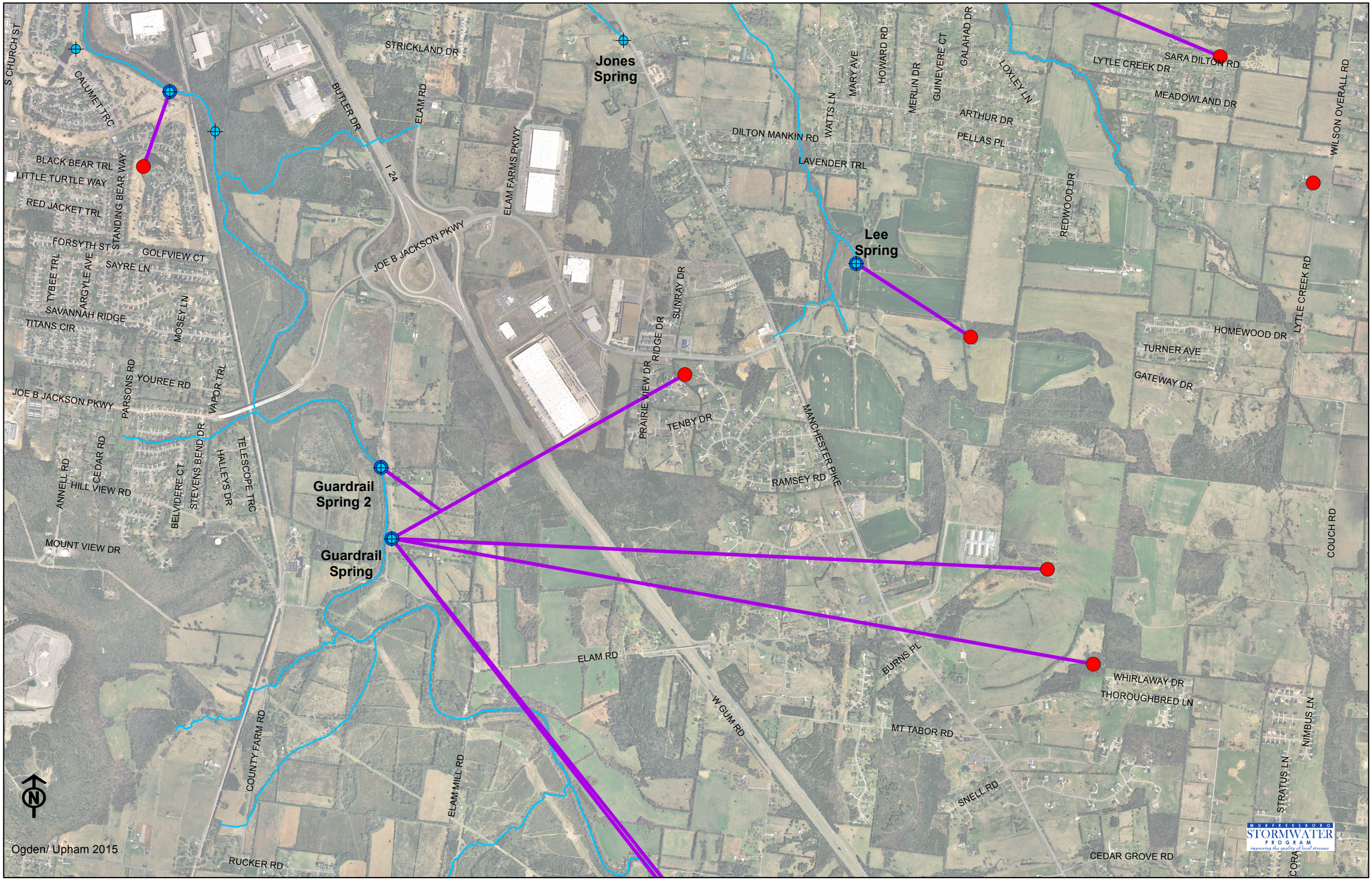


Figure 4: Lee Spring and Guardrail Spring Dye Trace Results

Ogden/ Upham 2015

MURFREESBORO STORMWATER PROGRAM
improving the quality of local streams


Jones Spring
Lee Spring
Guardrail Spring 2
Guardrail Spring
S CHURCH ST
CALUMET TRC
BLACK BEAR TRL
LITTLE TURTLE WAY
RED JACKET TRL
STANDING BEAR WAY
FORSYTH ST
GOLFVIEW CT
SAYRE LN
TYBEE TRL
ARGYLE AVE
SAVANNAH RIDGE
TITANS CIR
MOSEY LN
JOE B JACKSON PKWY
PARSONS RD
YOUREE RD
VAPOR TRL
ANNELL RD
CEDAR RD
HILL VIEW RD
BELVIDERE CT
STEVENS BEND DR
HALLEYS DR
TELESCOPE TRC
MOUNT VIEW DR
STRICKLAND DR
BUTLER DR
ELAM RD
I 24
ELAM FARMS PKWY
SUNRAY DR
RIDGE DR
PRAIRIE VIEW DR
TENBY DR
MANCHESTER PIKE
RAMSEY RD
DILTON MANKIN RD
LAVENDER TRL
WATTS LN
MARY AVE
HOWARD RD
MERLIN DR
GUINEVERE CT
GALAHAD DR
LOXLEY LN
ARTHUR DR
PELLAS PL
REDWOOD DR
LYTLE CREEK DR
SARA DILTON RD
MEADOWLAND DR
WILSON OVERALL RD
LYTLE CREEK RD
HOMEWOOD DR
TURNER AVE
GATEWAY DR
COUCH RD
BURNS PL
W GUM RD
MT TABOR RD
SNELL RD
WHIRLAWAY DR
THOROUGHBRED LN
NIMBUS LN
STRATUS LN
CEDAR GROVE RD
CORA
COUNTY FARM RD
ELAM MILL RD
RUCKER RD
N
Ogden/ Upham 2015
MURFREESBORO STORMWATER PROGRAM
improving the quality of local streams

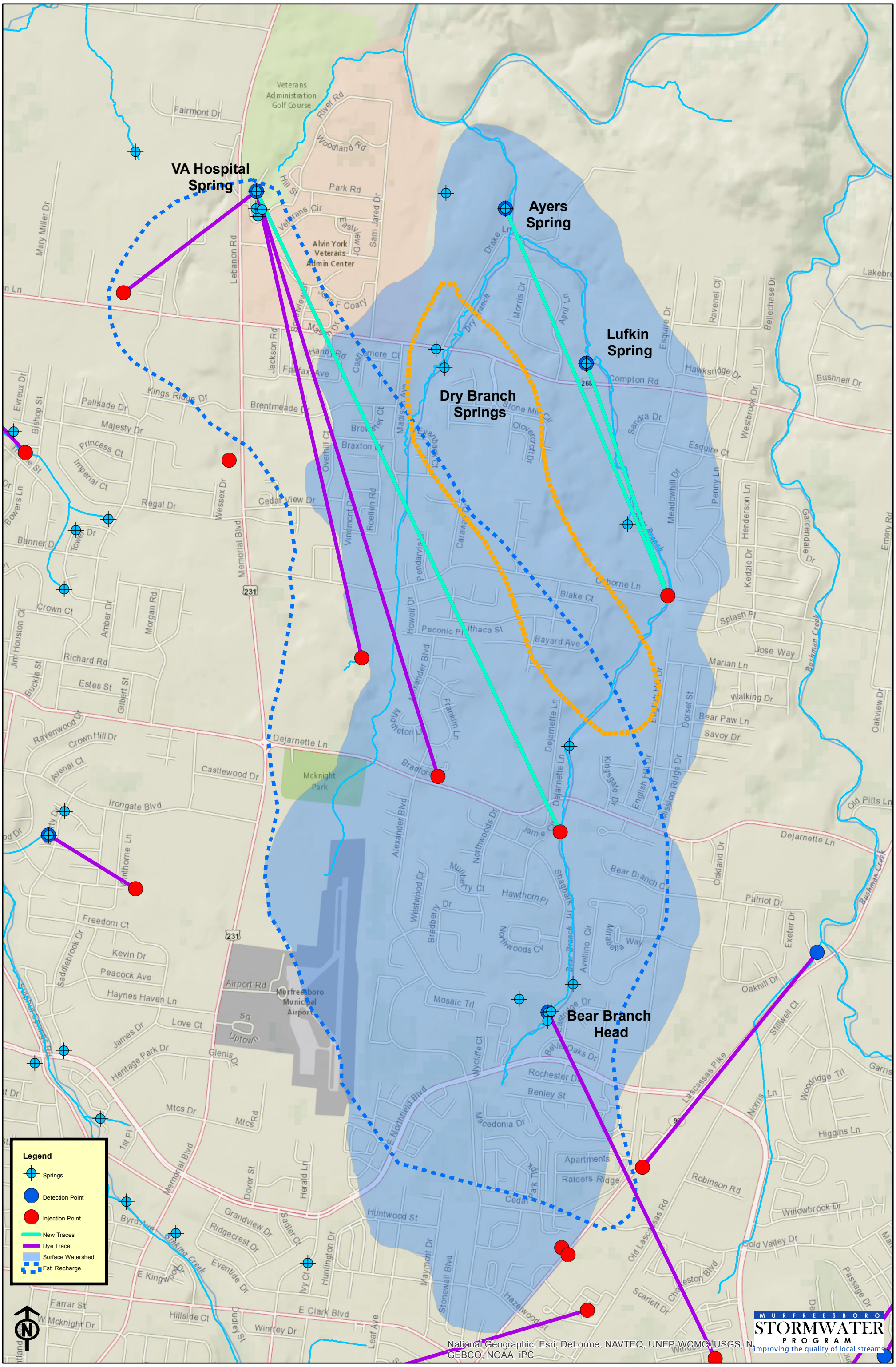
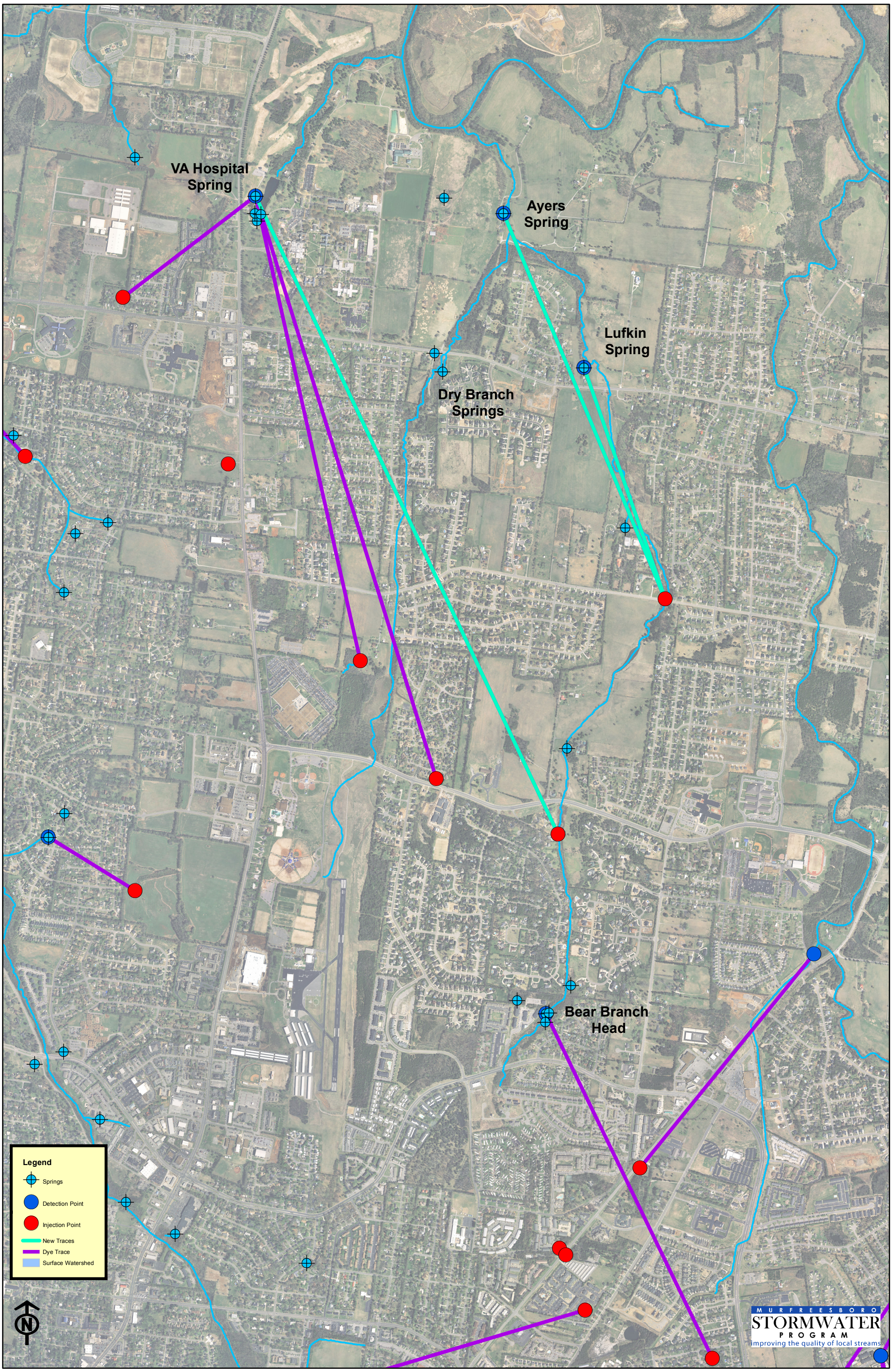


Figure 5: Bear Branch Watershed - Springs and Dye Trace Results with Estimated Recharge Basins

Ogden/ Upham 2015



Ogden/ Upham 2015

Bear Branch Watershed - Dye Trace Results

APPENDIX E

Miscellaneous Photos of Field Work

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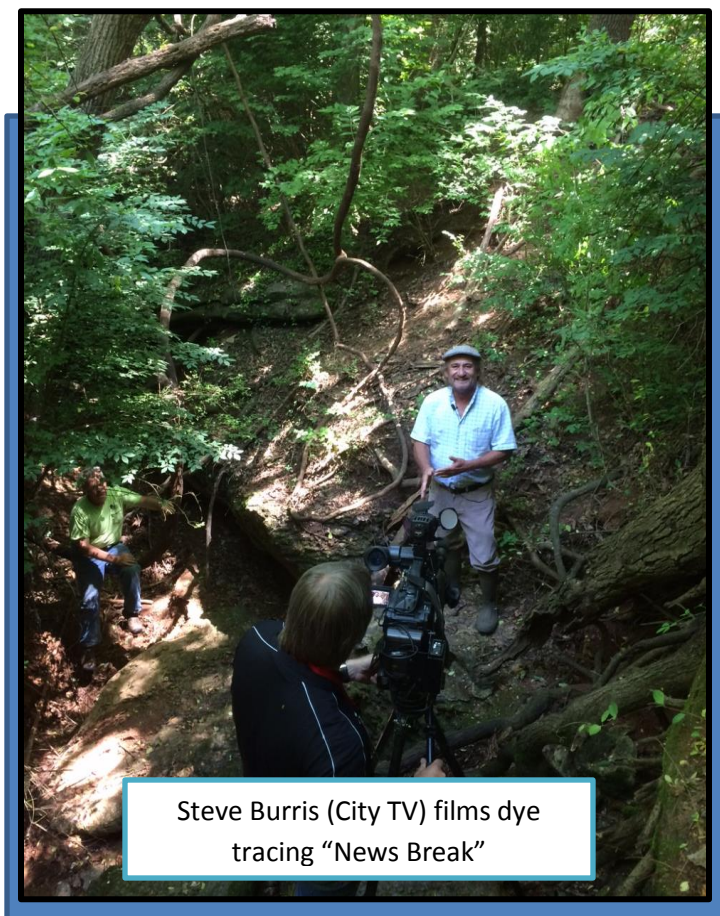
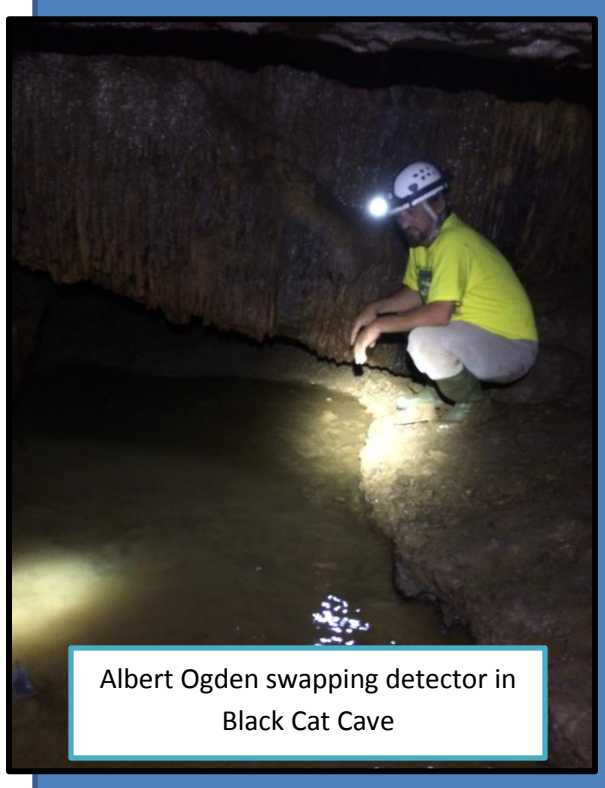
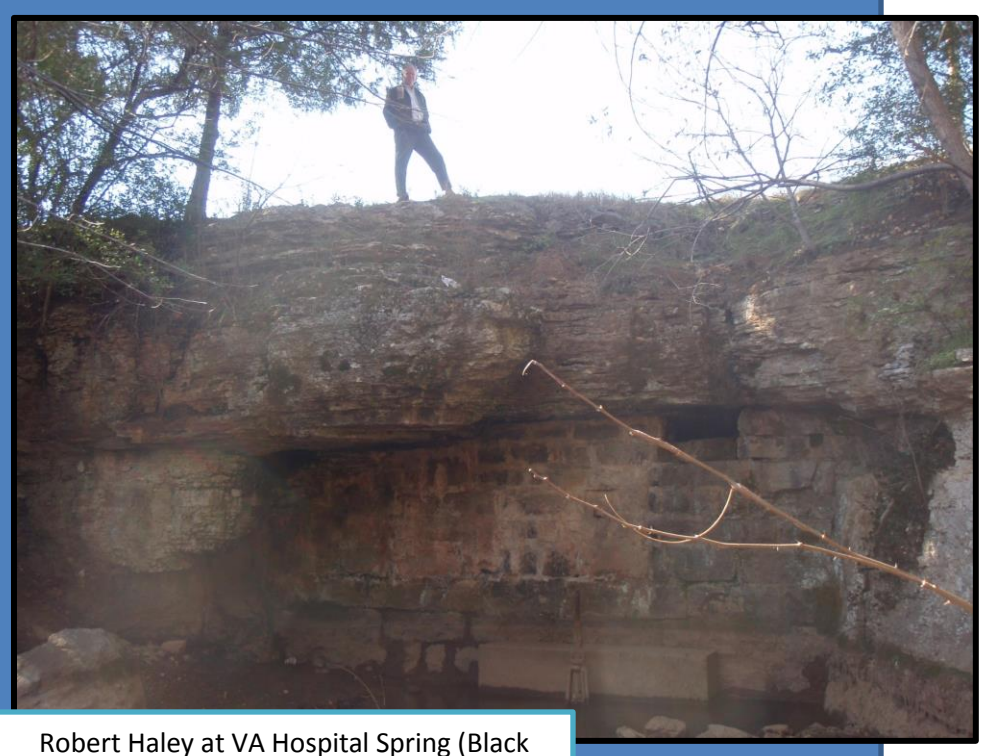


Steve Burris (City TV) films dye tracing “News Break”

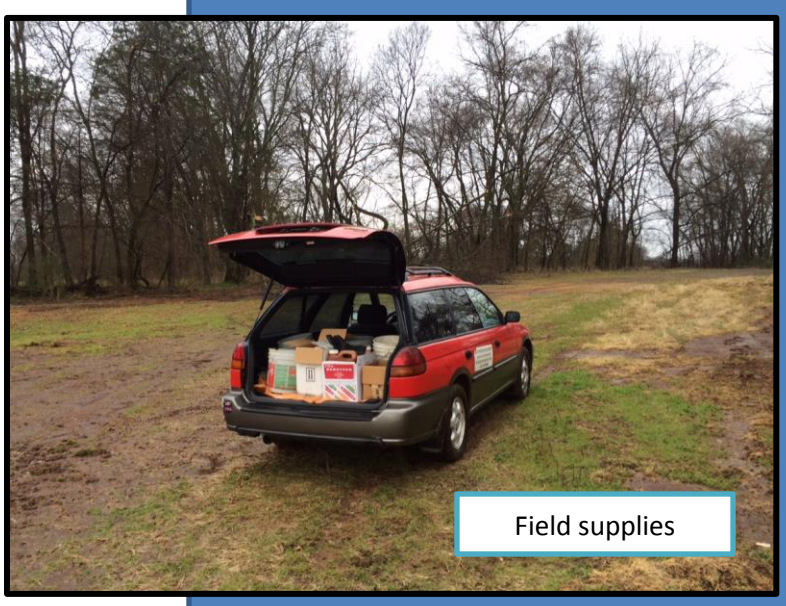
Flushing dye with rain barrel in upper Bear Branch near Osborne Ln



Albert Ogden swapping detector in Black Cat Cave



Robert Haley at VA Hospital Spring (Black Cat Cave) while lake was lowered



Field supplies

Injecting optical brightener in the Lee Spring Watershed

Flushing dye in Veterans Pkwy dry lake