Water Resources Report Number 76

Revised Recharge Areas of Selected Large Springs in the Big Four Region of the Ozarks

By
James W. Duley and Cecil Boswell

MISSOURI
DEPARTMENT OF
NATURAL RESOURCES
Missouri Geological Survey

Cover photo: Greer Spring in Oregon County. Missouri Geological Survey file photo. Circa 1890

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Library of Congress Control Number: 2017947379
Missouri Classification Number: MO/NR Ge9:76

Missouri Department of Natural Resources, Missouri Geological Survey 2017
Revised Recharge Areas of Selected Large Springs in the Big Four Region of the Ozarks
Water Resources Report Number 76, 155 pages, 110 figures, 10 tables.

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Units

The following units are used throughout this report as described below.

Discharge: Greater than 50 gallons per minute (gpm) is given in cubic feet per second (ft^3/s).

Conversion: 1.0 ft^3/s = 444.8 gpm
Discharge: Less than or equal to 50 gpm is given in gpm.

Altitude is given as distance above mean sea level (msl) in feet.

Temperature is given in degrees Celsius (°C).

Conversion: °F = (1.8 x °C) + 32
Specific conductance is given in microsiemens per centimeter at 25°C.

Acknowledgements

Countless hours of work were completed by a diverse group of investigators who went before us: Tom Aley, Everett Chaney, Mickey Fletcher, and Chuck Tryon (U. S. Forest Service), Tom Dean (Missouri Geological Survey), Jim Vandike. (then a graduate student at South Dakota School of Mines and Technology) and Tony Aide (a West Plains High School student at that time). Their work, which was largely completed without the aid of fluorescence spectrometry, is the foundation for all of the new traces. They did extraordinary work considering the limited amount of baseline data available to them. Mike Kleeschulte (retired U.S. Geological Survey) kindly offered data from more recent tracing efforts in the Big Four Springs region, much of which had not been previously published.

This work could never have been completed without the gracious support of the generous landowners and land managers throughout the Big Four Spring region. They allowed routine access to some of the most scenic and fascinating private property in the state of Missouri to allow dye injections and monitoring. Our intent is to give Missouri landowners the most accurate information that we can to help them in their daily efforts to manage and protect their priceless heritage. Thank you all!

Numerous agencies and organizations assisted in the completion of this study. Technical support, equipment and funding were provided by the Missouri Geological Survey, a division of the Department of Natural Resources. Special thanks go out to State Geologist Joe Gillman and Assistant State Geologist, Jerry Prewett, for their direction and patience in support of the project. Mark Twain National Forest provided financial support as well as access to a number of monitoring and injection sites. The Missouri Department of Conservation also provided access for monitoring and injection sites while the National Park Service provided access to Ozark National Scenic Riverways for monitoring sites. Mammoth Spring State Park in Arkansas allowed access for monitoring and the installation of an in-stream fluorometer. Grand Gulf State Park in Missouri allowed access for a dye injection.

While a number of Missouri Geological Survey staff contributed to the actual field work, the assistance of Fred Shaw was especially important to the completion of the project. He lost more than one walking stick in completion of his duties, but always had a smile on his face and a spring in his step, even when climbing out of the hole at Greer Spring.

Others who contributed to the field work included: Kurt Hollman, John Pate, Michelle Oglesby Jeremiah Jackson, James Papin, Sherri Stoner, Fletcher Bone and John Corley. Many helpful editorial comments were received from: Dr. Cheryl Seeger (Missouri Geological Survey), Doug Mugel (U.S. Geological Survey) and Dr. Doug Gouzie (Missouri State University).

REVISED RECHARGE AREAS OF SELECTED LARGE SPRINGS IN THE BIG FOUR REGION OF THE OZARKS

By
James W. Duley and Cecil Boswell

Introduction

The largest springs in the Ozarks are major discharge points of groundwater from the Ozark Aquifer-a group of fractured and solution-weathered carbonate bedrock layers that serve as the principal water source for private and public wells throughout the region. These springs and their outflow are host to delicate flora and fauna that serve as indicators of the condition of the aquifer as a whole and human influence upon it. Springs have served as natural power sources for all types of endeavors from grist, flour, wool carding and lumber mills to electrical power generation. They supply much of the flow so vital to maintenance of the floating, fishing and scenic tourism industry in Missouri. They also serve as sources of inspiration and awe for each new generation. Greater understanding is required if we are to protect and preserve them for the future.

The objective of this study is to gather information that improves the understanding of the largest springs in the Ozarks. Beginning in 2013, the Missouri Geological Survey (MGS) conducted a number of water traces with the goal of better defining the recharge areas of Big Spring in Carter County, Missouri; Greer Spring, in Oregon County, Missouri(Figure 1); Rainbow, North Fork, and Hodgson Mill springs, in Ozark County, Missouri; and Mammoth Spring in Fulton County, Arkansas. It is suggested that this area be called the "Big Four Region" as these are the four largest spring systems in the Ozarks if Rainbow, North Fork and Hodgson Mill springs are considered a single complex.

The springs of Blue, Althea, and Wilder in Ozark County; Big in Douglas County; Boze Mill, Bill Mac, Warm Fork, and the spring complexes of Blue/Morgan, Dennig, Graveyard and Rookery Tree in Oregon County were included in the study because they play an important role in groundwater movement in the region.

A classic treatise by Vineyard and Feder (1974) is the most complete description of Missouri springs. "The Springs of Missouri" was possible because of earlier work by Bridge (1930), Beckman (1927), and Beckman and Hinchey (1944)-as well as by students like Bolon (1935) and Doll (1938) based on stream flow measurements and precipitation records that became available in the early part of the 20th century.

These researchers were just beginning to understand impacts of pollution resulting from industrial discharges such as one from Midco Iron Works which reportedly contaminated the discharge of Big Spring in Carter County in 1918 (Beckman and Hinchey, 1944, p 55). Until water tracing techniques were used, only imprecise estimates of recharge area boundaries could be made. The first comprehensive attempt to produce a map that delineated the recharge areas of major springs in the Big Four Region was by Doll in 1938 (Figure 2).

The late James F. Quinlan who worked for the National Park Service on characterization of the Mammoth Cave system in Kentucky, was a major proponent of water tracing as a method for delineating karst aquifers. His business card in the 1980s contained the following sentiment:

Panoramic photo by Bill Duley/Photo editing by Mark Gordon

Figure 1. Panoramic view of upper Greer Spring (left) and the spring branch leading to lower Greer Spring.

"One properly planned, suitably executed, and correctly interpreted water trace is worth more than five potentiometric maps, ten computer groundwater models and a hundred expert witnesses."

Several decades after Dr. Quinlan penned those words, the wisdom they contain remains unassailable in karst terranes. While potentiometric maps, groundwater models and expert witnesses all have their place, when it comes to determining which areas contribute recharge to individual springs, a "properly planned, suitably executed and correctly interpreted water trace" is still the gold standard.

A great deal of effort has been spent in planning, executing and interpreting water traces in Missouri over the years. In the latter half of the 20th century, the U.S. Forest Service and the National Park Service began serious efforts to define the recharge areas of some of the largest springs in the south-central Missouri Ozarks using water tracing techniques. The scientific community is indebted to dedicated professional investigators such as Tom Aley, Everett Chaney, Mickey Fletcher, and Chuck Tryon who completed numerous water traces in the region.

In addition, students provided pertinent tracing information as well. Tony Aide, a high school student, completed the first recorded water trace to Mammoth Spring and Jim Vandike, as a graduate student at the South Dakota School of Mines and Technology, conducted numerous traces in the North Fork watershed.

These water tracing endeavors were groundbreaking since there had been no previous organized effort to determine recharge areas of Ozark springs. Techniques used were state-of-the-art for US investigators at the time. Most of the work employed activated carbon packets to collect fluorescein dye. Packets were anchored in springs and other monitoring points, and replaced on a routine basis. Collected packets were then eluted with a basic solution. Dye detection was routinely conducted by visual analysis of the eluate from each packet. Light sources used to excite dye included ultraviolet lamps, high intensity lamps and direct sunlight.

The traces completed by these researchers and the resulting approximations of recharge areas for the Big Four Region are shown in Figure 3. Groundwater flow paths are depicted as straight lines measured between the end members of the trace - the injection point and recovery point. The actual path is normally unknown, but may be quite sinuous. While most of the older traces still fit into existing recharge area paradigms, questions have arisen about the accuracy of some traces. If previous traces are in error, associated recharge area boundaries should be reinterpreted as well.

Most of the MGS work during this study was completed using basic techniques similar to those used decades ago: dye collection via carbon packets, which are eluted by a basic alcohol solution. The following techniques were used to improve upon legacy methods:

- Eluate was analyzed with a fluorescence spectrometer at the MGS Water Tracing Laboratory;
- Additional monitoring points were used based on past work and new findings;
- In all but a few instances monitoring was more extensive, with multiple packets collected to characterize background conditions and obtain more complete dye recovery curves;
- The peak/valley ratio (PVR) method was developed to better standardize dye recovery data;
- Glacial acetic acid was added to selected eluate samples to adjust pH as a means of separating degraded Rhodamine WT™ from fluorescein and reducing spectral overlap between fluorescein and other dyes.

Fluorescent spectrometric methods remove a great deal of the inherent subjectivity of visual detection and quantification of dyes and allows the concurrent use of multiple fluorescent tracers. Detection limits are improved. Some time-of-travel information collected during this study was obtained with an in-stream fluorometer and associated logger at Mammoth Spring. In addition, data from unpublished traces conducted by the MGS and the U.S. Geological Survey (USGS) from the 1980s through the early 2000s that employed fluorescent spectrometric methods are included and summarized. Interpretations of recharge areas in the early 21st century are shown on Figure 4.

The intent of this study was not to undermine the pioneering work completed decades ago by a number of forward-thinking individuals and organizations, but rather to improve legacy information by adding to, enhancing, and refining the work of those pioneers. It is the expectation and hope of the authors that others will follow with additional information to further refine recharge area boundaries and learn more about groundwater movement through the karst of the Big Four Region. The job is not finished, but this study simply produces a new approximation based on more and better data.

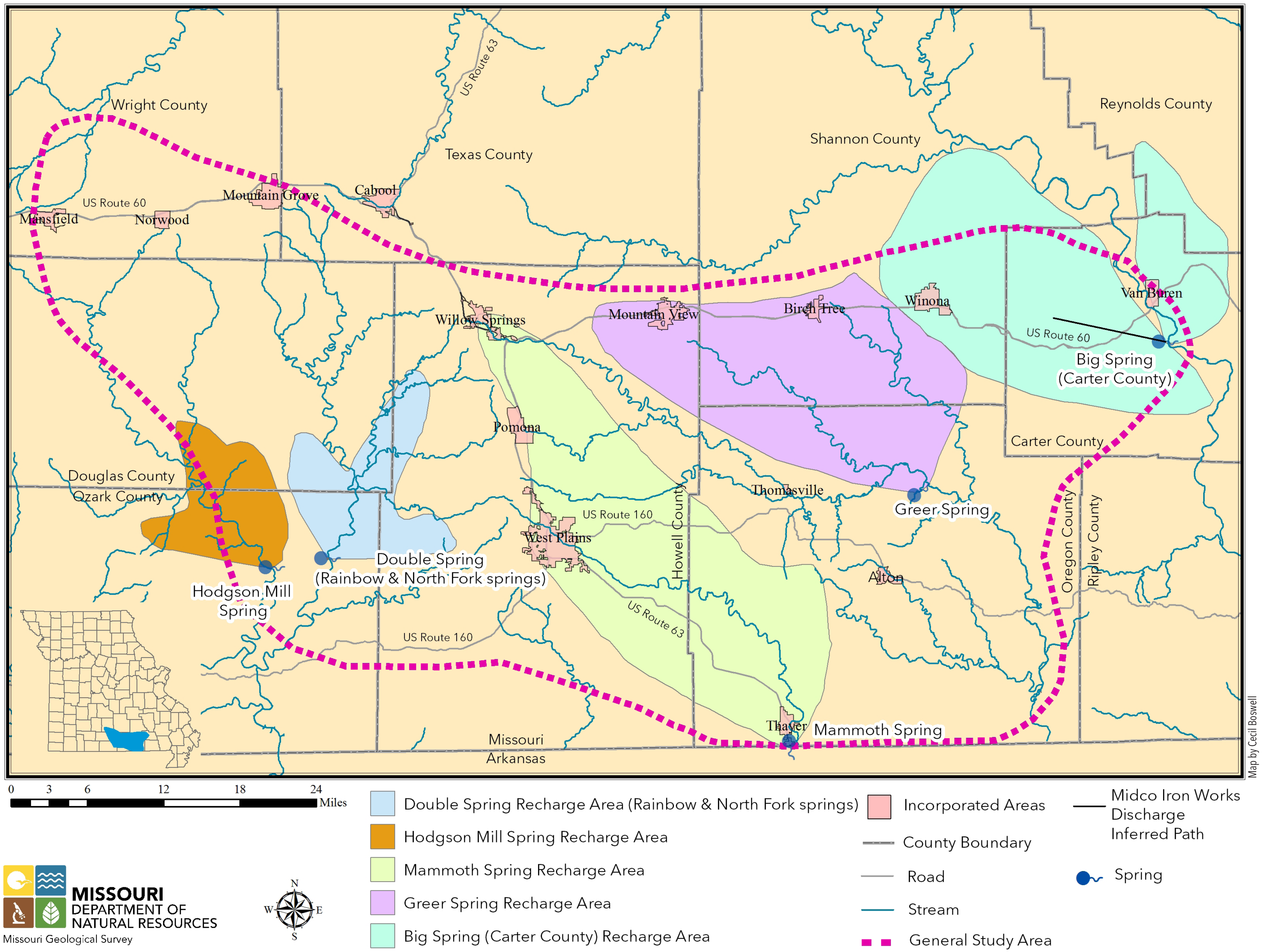


Figure 2. Recharge area approximations Big Four Region circa 1938, modified from Doll (1938).

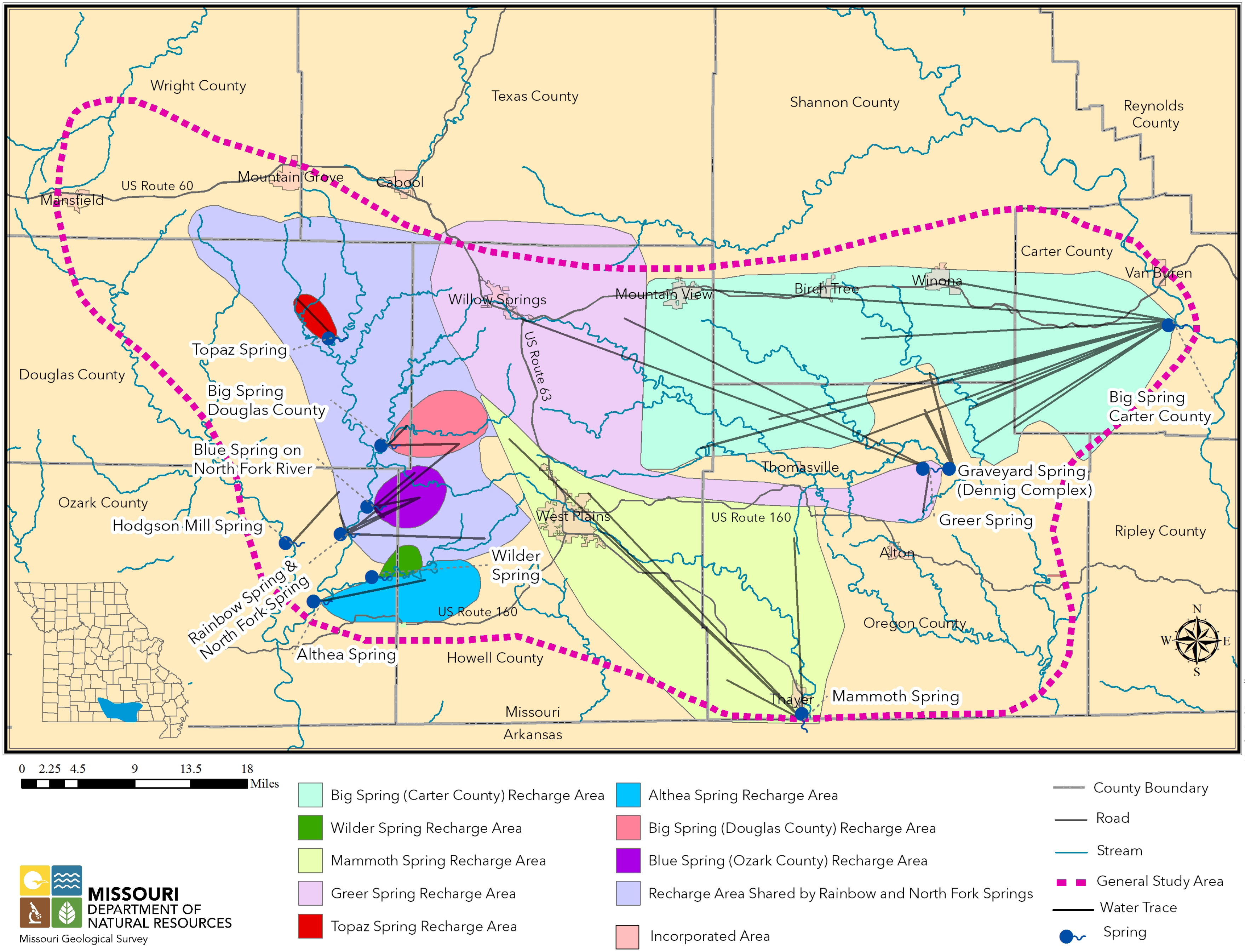


Figure 3. Recharge area approximations Big Four Region circa 1980, modified from Aley, (1975) and Vandike, (1979).

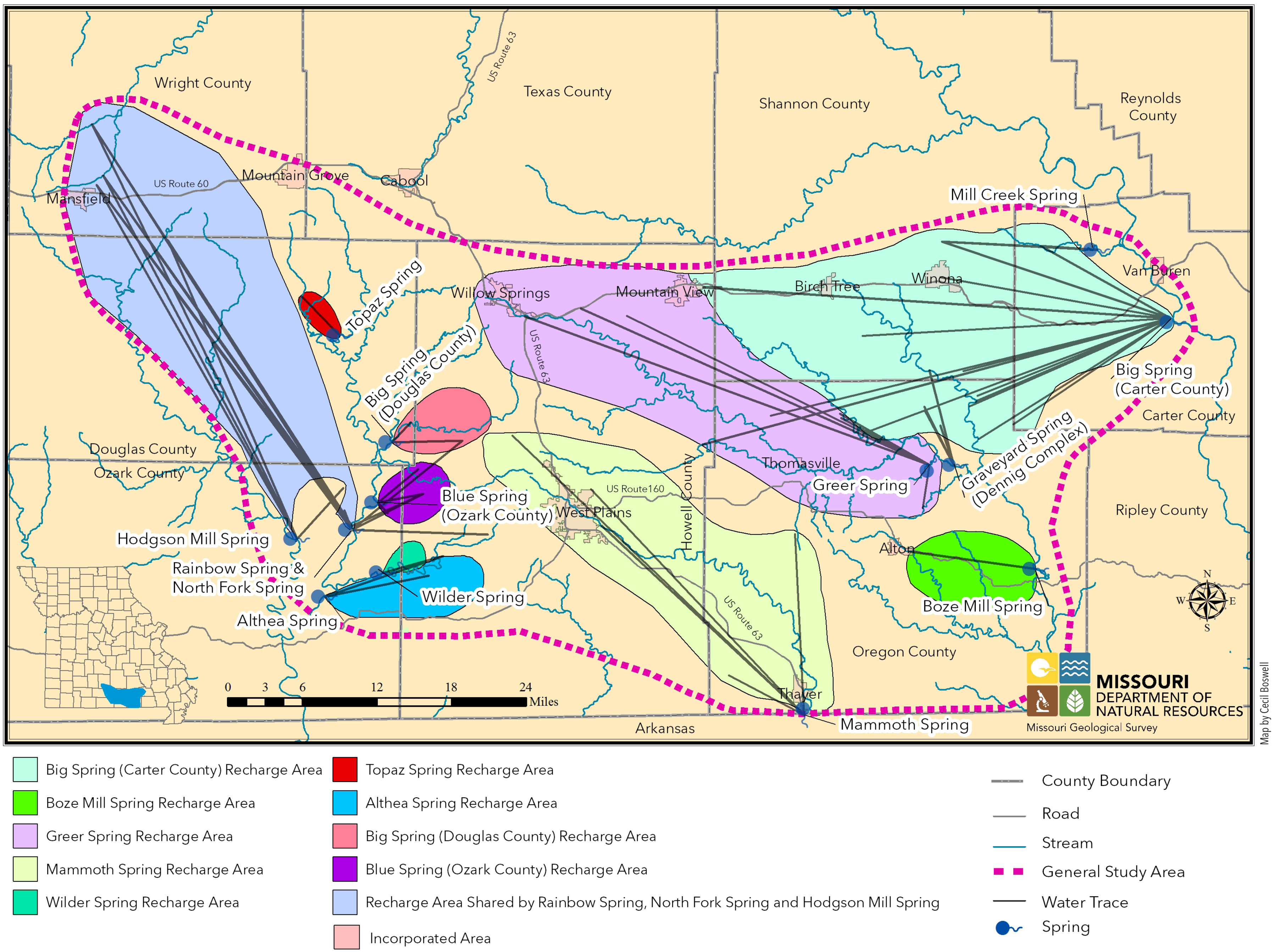


Figure 4. Recharge area approximations Big Four Region circa 2010 modified from Imes et al., (2007) and Vandike, (1979).

Geohydrology of the Big Four Study Area

Geologic mapping at the 1:24,000 scale is available for some of the 7.5 minute quadrangles along the scenic riverways (Harrison and McDowell, 2003; Harrison et al., 2002; McDowell, 1998; Orndorff, 2003; Orndorff and Harrison, 2001; Weary, 2008; Weary and McDowell, 2007; Weary and Schindler, 2004; Weary et al., 2002 and 2013). Detailed geologic mapping is not available for most of the study area.

All available mapping shows that the uppermost bedrock is primarily fractured and dissolution-weathered dolomite of the Ordovician-age Cotter, Jefferson City, Roubidoux and Gasconade formations with some fractured sandstone of the Roubidoux Formation. All of these units contain varying amounts of chert. In many areas the Jefferson City and Cotter formations display relatively low permeability, but locally are prone to extremely deep weathering with associated sinkholes, and losing streams.

The Roubidoux Formation is typically fractured and permeable and hosts karst features such as sinkholes and losing streams. Speleologists have noted for decades that the upper part of the Gasconade Dolomite is a prime bedrock unit for cave development in the central Ozark region. While the Cambrian-age Eminence Dolomite is not well exposed in the study area, deeper groundwater circulation does move through voids in this unit as illustrated at Big Spring in Carter County.The above formations are included in the Ozark Aquifer as delineated by Miller and Vandike (1997). Although there is no single continuous low-permeability aquitard in these units, local zones of low permeability exist, especially in the Jefferson City and Cotter formations. On a local basis, the Jefferson City/Cotter acts as host to a shallow perched aquifer above the more permeable Roubidoux Formation. A number of the injection points listed in this study used perched water issuing from shallow solution-enlarged joints in the Jefferson City and Cotter formations to carry tracers into and through the deeper part(s) of the system.

In some locations the Ordovician-age rocks are overlain by thin, discontinuous deposits of Mississippian and Tertiary-age. While these units may play a localized role in groundwater recharge, storage and flow in the study area, they are so limited in areal extent as to have little significance with respect to regional hydrology.

The Ozark Aquifer is underlain by the St. Francois Confining Unit, which is principally composed of fine-grained dolomite and shale. Schumacher and Kleeschulte (2010) in a study of a single well location in Oregon County show that during dry conditions the St. Francois Aquifer may exhibit higher head (nearly 23 feet) than the Ozark Aquifer. This upward gradient abruptly reverses when precipitation recharges the Ozark Aquifer with the downward gradient measured at 138 feet or more. Hydrographs and water quality data suggest little direct connection between the two aquifers. While faults and poorly constructed wells may breech these strata locally, the unit is relatively effective in retarding water movement between the Ozark and St. Francois aquifers.

The Cambrian-age Bonneterre Formation and Lamotte Sandstone comprise the St. Francois Aquifer. The Bonneterre is largely composed of fine- to medium-crystalline dolomite while the Lamotte is primarily permeable sandstone. Although these units do yield moderate amounts of water to wells, none of the large springs in the Ozarks are known to issue from the St. Francois Aquifer (Table 1).

Past tracing efforts (Kleeschulte and Duley, 1985; Williams, 1986, 1987; Brown, 1989) have shown that geologic structures are often important in directing flow in karst aquifers in Missouri. The limited available geologic mapping conducted at a detailed scale (1:24,000) has shown that faulting is common. Some notable structures are discernible on reconnaissance mapping as well (Figure 5). Work by Lowell et al. (2010) and Weary et al. (2014) has implied a number of sizable structures, apparently interpolated from remote imagery. However, without detailed geologic mapping throughout much of the region, the impact, and even presence of these structures can only be surmised.

Deep weathering of the bedrock in the region produced thick deposits of cherty clay residuum. Flatter uplands are locally capped by limited amounts of loess. Major river valleys are characterized by variable thicknesses of clay, silt, sand and gravel. Detailed surficial material mapping is needed to unravel the complex history of Ozark streams. It is likely that some valleys have been affected by faulting and folding. Several valleys, like the Eleven Point River near Thomasville, alternate between wide alluvial floodplains and narrow bedrock-walled canyons. Alluvial terraces which represent older river floodplain levels are locally present along major drainages.

System	Geologic Unit	Thickness in Feet	Lithologic Character	Hydrologic Remarks/Well Yield in Gallons/Minute (gpm)	Classification	Associated Spring Orifice(s) in the Study Area
Quaternary	Alluvium	0-100	Clay, silt sand and gravel	Low to high permeability	Locally an aquifer	
	Loess	0-5	Windblown silt and clay	Low to moderate permeability	Not a significant aquifer	
	Residuum	0-300	Weathering products of limestone, cherty dolomite and dolomitic sandstone	Low to high permeability		
Tertiary through Mississippian undifferentiated	Undifferentiated formations	0-100	Various lithologies: limestone, shale, dolomite, thin sandstone	Locally small yields to wells (3 to 5 gpm)		
Ordovician	Cotter Dolomite	200 (Avg)	Fine- to medium-crystalline cherty dolomite with green shale partings; some thin sandstone beds	5 to 15 gpm locally	Ozark Aquifer	Mammoth Spring
	Jefferson City Dolomite	200 (Avg)				Blue/Morgan Complex
	Roubidoux Formation	170 (Avg)	Cherty, sandy dolomite and dolomitic sandstone; oolitic	15 to 35 gpm where shallow, 50 to 75 where deeply buried		Big Spring (Douglas County); Wilder Spring; Bill Mac Spring; Rookery Tree Complex, Althea Spring
	Upper Gasconade Dolomite	40 (Avg)	Massively-bedded, coarse-crystalline, chert-free dolomite	Yields 50 to 75 gpm		Rainbow/North Fork/Hodgson Mill Complex; Upper Greer Spring
	Lower Gasconade Dolomite	250 (Avg)	Very cherty dolomite, stromatolitic reef zones in upper part			Graveyard Complex; Dennig Complex; Boze Mill Spring; Lower Greer Spring; Blue Spring (Ozark County)
	Gunter Sandstone Member	25-30 (Avg)	Sandstone or sandy dolomite	40 to 50 gpm–normal yield 200 to 500 gpm locally		
Cambrian	Eminence Dolomite	220 (Avg)	Medium- to coarse-grained dolomite with low chert content	Moderate yields 75 to 250 gpm		Big Spring (Carter County)
	Potosi Dolomite	200 (Avg)	Fine- to medium-crystalline dolomite, with abundant quartz druse	Yields from 200 to 1000 gpm		
	Derby-Doerun Dolomite	150 (Avg)	Fine-grained dolomite in upper part, shaley near base with glauconite	Yields of 30 to 50 gpm available locally in upper part, usually not a significant aquifer	St. Francois Confining Unit	
	Davis Formation	180 (Avg)	Shale, siltstone, fine-grained sandstone, limestone and dolomite conglomerates	Not a significant water-bearing unit		
	Bonneterre Formation	350 (Avg)	Fine- to medium-crystalline dolomite, sandy at base	Low yields 10-15 gpm	St. Francois Aquifer	
	Lamotte Sandstone	0-300	Sandstone and dolomitic sandstone, arkosic near base, locally absent	Moderate yields 75 to 125 gpm		
Precambrian	Undifferentiated formations		Igneous rocks and minor metamorphic rocks		Basement confining Unit	

Table 1: Generalized geohydrologic column modified from Miller and Vandike (1997).

The Ozarks of southern Missouri and northern Arkansas contain some of the best examples of karst features observed anywhere in the United States. Of particular note are broad upland areas characterized by numerous sinkholes and losing (influent) streams that recharge groundwater, largely through discrete macropores. A thick mantle of variable-permeability residuum through which recharge occurs via both diffuse and discrete flow complicates recharge area determinations.

Spring systems that discharge more than 100 cubic feet of water per second (ft^3/s) are termed "first magnitude." As defined herein the Big Four Region in south-central Missouri contains the recharge areas of a number of first magnitude springs including the four largest in the Ozarks. Big Spring (Carter County), Greer Spring (Oregon County) and Mammoth Spring (just south of the Missouri state line in Fulton County, Arkansas) have long been recognized as the three largest spring systems in the Ozarks. Water tracing has shown that Rainbow, North Fork and Hodgson Mill springs (Ozark County) are all part of a single complex (Williams, 1986, 1987; Brown, 1989). The combined discharge of these three springs makes the Rainbow/North Fork/Hodgson Mill Complex the fourth largest system in the Ozarks.

Study Methodology

Prioritizing Traces for Replication

The overriding consideration in determining recharge area boundaries in deeply weathered karst regions is the need for consistent repeatable water traces that are sufficient to determine which areas drain to which springs. While many historical traces completed in the Big Four region of south-central Missouri and north-central Arkansas agree with current interpretations of recharge areas, recharge area boundaries shown in Aley (1975) and Vandike (1979) are largely based on traces completed in the latter part of the 20th century. The majority of completed traces used subjective visual methods to determine the presence or absence of tracers at monitoring points and to "quantify" recoveries.

Later studies that estimated recharge areas of the major springs still relied, to some extent, on those older traces. Few new traces had been undertaken and few old traces had been replicated using updated detection methods. As the USGS collected new seepage run and potentiometric data, (Kleeschulte, 2000; Mugel et al. 2009; and Imes et al. 2007) some of the older traces came under scrutiny. Several do not fit current interpretations of groundwater flow that are based upon these later investigations. During this study, MGS researchers attempted to test the validity of some of the questioned legacy traces through replication efforts and to supplement them with additional traces.

As used in this study, the term "replication" means a trace with the same injection point, or an injection point as close as possible to the original injection point, of an earlier trace. The term "semi-replication" means a trace with an injection located in the same area as an earlier trace but with a notable change such as into a losing stream rather than a sinkhole. Some semi-replication attempts were initiated due to preferable flow conditions at the new injection point, while others were conducted to gain more useful data with regard to recharge area boundaries or potential contaminant sources.

There is no absolute method to determine which legacy traces are valid without attempting to replicate them. Even when replication attempts are done, variable precipitation, runoff and evapotranspiration can lead investigators to conclusions that may be correct during one condition and incorrect under other hydrologic conditions. A number of replications may be needed to assess flow directions under a variety of conditions. Karst systems can be extremely dynamic. Precipitation and associated runoff quickly affect recharge via losing streams and sinkholes. The potential exists for flow directions to change as potentiometric head varies at many different locations in the karst aquifer.

It is useful to think about portions of the study area in terms of master springs with a series of subordinate springs. As the master spring (or lower) system is flooded, groundwater flows into progressively higher outlets that feed short-lived springs that may flow at a relatively high discharge rate for hours, days, weeks or even months. When the water level in the master system lowers, discharge from the subordinate (or pop-off) springs may decrease significantly or even cease entirely.

In order to prioritize traces for replication, MGS staff considered a number of factors. Two overriding concerns were: 1) injecting tracers into natural flow where the likelihood of success is good and 2) selection of traces where a reasonable monitoring effort is likely to produce the most valuable data in a relatively short period of time. Legacy traces were then evaluated by comparing them to current understanding and standards. A list of

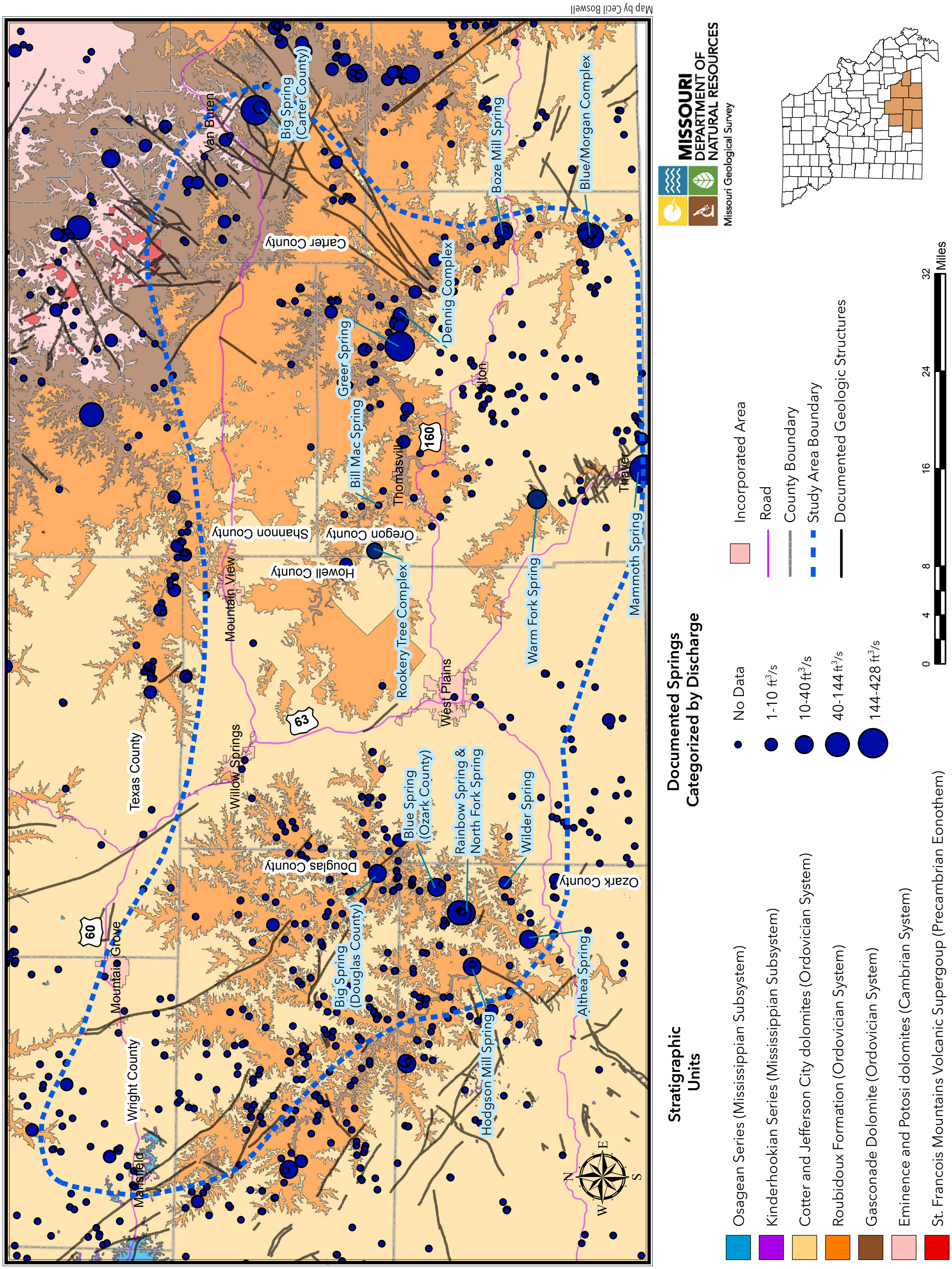


Figure 5. Geohydrologic map of study area modified from Missouri Department of Natural Resources (2006B, 2010).

criteria applicable to selected past traces in question has been prepared to assist others in future similar endeavors (Table 2). Note: Trace identification designations in Table 2 and throughout this report consist of a two-letter abbreviation for the county of dye recovery and a three-digit sequential number as listed in Missouri Department of Natural Resources (2016A; 2016B; 2016C). An explanation of each criterion's potential impact on the reliability of traces follows.

Specific Concerns	Alton Sinkhole (Aley, 1972) No ID#	Grand Gulf Cave (Aide 1968) Or 001	Middle Fork Eleven Point River (Aley, 1975) Or 009	Rattlesnake Spring (Vandike, 1979) Oz 012	Granny Meyers Spring (Aley, 1975) Or 007	Simpson Pond Spring (Fletcher, 1972D) Or 010	Dry Creek Howell Co. (Aley, 1975) Or 013
Discounted by Other Studies	✓		✓				
Potentiometric Map Conflict							✓
Subjective Detection Method	✓	✓	✓	✓	✓	✓	✓
Questionable Timing			✓	✓		✓	✓
Single Recovery of Tracer	✓						✓
Near Recharge Area Boundary	✓		✓	✓	✓	✓	✓
Lacks Monitoring Point Data				✓		✓	✓

Table 2. Criteria Used to Prioritize Replication of Selected Legacy Traces.

Traces Discounted in Subsequent Studies
Past traces are often evaluated by later investigators trying to piece together intimate details about a given karst groundwater system. If experienced investigators omit a legacy trace from recharge area determinations, it suggests either a lack of confidence in the data or in the interpretation of the data. Therefore, attempts should be made to replicate these traces.

Traces that Conflict with Potentiometric Data
Potentiometric (water level) maps have long been used to determine directions of groundwater flow in groundwater studies including those dealing with karst. In the past some investigators have rightly observed that karst water movement may represent a localized zone not represented by a regional potentiometric map. They have also noted that potentiometric maps are limited by the number and location of wells included, the number and timing of measurements of wells included, inconsistent well construction standards, and wells that represent multiple aquifers or different zones within a single aquifer.

Nevertheless, in deeply weathered karst terranes these maps often offer information that can be used to predict groundwater movement. If water trace data disagree, further investigation should be conducted to determine the cause or causes of the disagreement.

Traces Completed with Subjective Detection Methods
Most of the traces completed in the karst of south central Missouri prior to this study used visual detection methods in conjunction with fluorescein dye. Light sources used included direct sunlight, ultraviolet lamp and high intensity lamp. Fluorescein is an excellent tracer, especially when used with activated carbon dye collectors and subsequent elution by a suitable basic solution. Nevertheless, serious problems may arise when the method used to detect dye is subjective. Fluorescent background is difficult to distinguish from fluorescein dye when minute amounts of the tracer are present. Not all observers are gifted with the same degree of visual acuity or the same degree of objectivity to assure the presence of dye. Background fluctuations can confuse observers as well.

A similar problem may be encountered using a fluorometer to detect fluorescent tracers. While fluorometers can filter out some background issues, they do not yield precise wavelength-specific peak data. Rhodamine WT™ has been effectively used with fluorometric analysis but even this tracer cannot always be separated from large fluctuations in background or large concentrations of other tracers that are excited or fluoresce in a similar part of the spectrum.

Because of the subjective nature of early methods, investigators likely misjudged some "positive" dye recoveries and "negative" traces as well. Repeating traces with more sensitive equipment discounts some traces and establishes some connections that were previously overlooked.

Traces with Questionable Injection Timing (Tracer Overlap)
Some early investigators operated under the assumption that the tracers they injected passed through the groundwater system quickly in a single pulse. While this assumption could be correct in some systems, the transit of groundwater through large spring systems like the Big Four can be complex. Water movement through preferential zones with subsurface flow paths dozens of miles in length often complicates dye recoveries. Depending on weather and aquifer conditions, more than one dye pulse may pass through the system. Injecting the same tracer at different locations within a short period of time may make it impossible to distinguish one injection from another. Sometimes an investigator who desires rapid results might make this mistake. However, the same issue occurs when two investigators unknowingly inject the same tracer at more than one location in the recharge area of a spring during the same time frame. This has happened in this region on more than one occasion. Since not all dye injections were reported or recorded for the sake of posterity, it is not possible to know how many legacy traces have been impacted by tracer overlap.

Traces with a Single Recovery
When a fluorescent tracer is injected into karst systems with relatively long subsurface flow distances such as the karst of south-central Missouri, dye normally takes a number of weeks or months to pass through the system. It is normal practice for investigators employing water samples or field fluorometers to conduct multiple analyses to establish a reasonable dye recovery curve. Multiple recoveries of dye in carbon packet dye collectors also yield valuable recovery curve data.

Some early investigators did not provide data that can be used to evaluate how many samples or dye collectors were examined. If only a single collector was believed to contain dye during a specific trace, questions arise. Was the collector contaminated? Does the single collector represent a single error in observation? The most reasonable way to verify or deny the connection is to repeat the trace.

Traces near the Boundary of the Recharge Area in Question
Traces on the fringe of recharge areas may be crucial in determining boundaries of multiple recharge areas. Traces initiated from a point less than 10 percent of their length from the outer recharge area boundary for the spring in question should be considered for replication. This is not to imply that the location of an injection near a recharge area boundary makes the trace less reliable. Replication is suggested due to the significance of decisions that may be based on the original information.

Traces with Inadequate Monitoring Point Data
Many investigators, not just early ones, have not shared supporting data as to which points, other than dye recovery points, were monitored during a trace. Recovery data are often lacking. Some monitoring points were not monitored long enough to rule out a minor or even a major recovery of the tracer. Tracers can be recovered at multiple points in different watersheds depending on how the karst system functions (see below). Preconceived notions can lead to partially correct or completely inaccurate traces. If all monitoring points, associated recovery data monitoring periods and associated recovery data are not shared, future investigators cannot accurately assess legacy traces. Thus redundant traces may be necessary using resources that could have been spent more productively.

This category also includes traces without a recorded background analysis. Background analysis is crucial when there is a concern about tracer overlap. If the same dye is passing through the monitoring point immediately prior to the injection, interpretation becomes difficult at best, and often leads to incorrect conclusions.

MGS Techniques and Modifications

Baseline Data Collection
File and field investigations to locate suitable dye injection and monitoring points began in Aug. 2013 and continued throughout the data collection phase of this study. Water temperature and specific conductance were measured at potential monitoring points using a YSI Model 30 Salinity Conductivity and Temperature probe calibrated to a 1000 microsiemen/centimeter conductivity standard. Field data recorded on-site for monitoring points included monitoring point name, date, time, water temperature, specific conductance and other pertinent remarks such as estimates of flow and turbidity. Dye injection details recorded included global positioning system location of the injection point, date, time, type of tracer, amount of tracer injected and flow conditions at the time of injection.

Losing streams are watercourses that recharge groundwater rapidly through solution-weathered

Figure 6. Coauthor replacing a carbon packet at upper Greer Spring.

bedrock. They are important sources of recharge and can receive contaminated runoff that negatively impacts groundwater quality. Points where streams lose significant flow are excellent locations to inject tracers because flow upstream carries tracers into the subsurface, where the rapid movement of water and tracer through large openings recharges springs. Although a large percentage of smaller streams in the Big Four Region would likely be characterized as losing, only a small portion of these streams have been evaluated systematically.

Much of the upper portion of the Eleven Point River is losing. Water loss zones were documented in this study at least as far downstream as two miles upstream of Thomasville. Although simple flow observations or stream measurement can be used to classify streams as losing, smaller streams often require geomorphic analysis or subsurface investigations through borings or other means of excavation with attendant groundwater level monitoring.

During this study, limited resources and access prevented exhaustive evaluations of streams for losing and gaining stream determinations. Observations were made, largely at road crossings, while measurements of stream flow were made at selected locations to quantify water loss and spring discharge. Stream flow measurements were obtained using a SonTek/YSI FlowTracker® handheld acoustic Doppler velocimeter using procedures outlined by the Missouri Department of Natural Resources (2015).

Dye Collection and Analysis using Carbon Packets

MGS staff compared two protocols for collecting and detecting fluorescent tracers during this study. The standard protocol (Protocol 1) used by MGS in recent years involves use of activated coconut charcoal (6 to 12 mesh) to collect fluorescent tracers in the field. Charcoal (about 9.5 grams) is placed in packets constructed of common nylon window screen. Packets are then secured in the water at the monitoring point for periods ranging from days to weeks (Figure 6). They are replaced on a regular basis and analyzed in the MGS Water Tracing Laboratory using fluorescence spectrometry techniques. Background packets are normally collected and analyzed for periods ranging from weeks to months prior to dye injection to assure that the impact of other fluorescent compounds can be minimized.

The charcoal packets are washed under a high pressure water stream and placed in disposable 100 ml cups with screw top lids. The dyes are eluted from the charcoal using approximately 30 ml of a solution of 5 percent ammonium hydroxide in ethyl alcohol for one hour. Eluate is pipetted from the top of the charcoal and placed in disposable polystyrene cuvettes produced specifically for fluorescence studies. At the time of this study, analyses are completed using a Hitachi F7000 synchronously scanning fluorescence spectrophotometer.

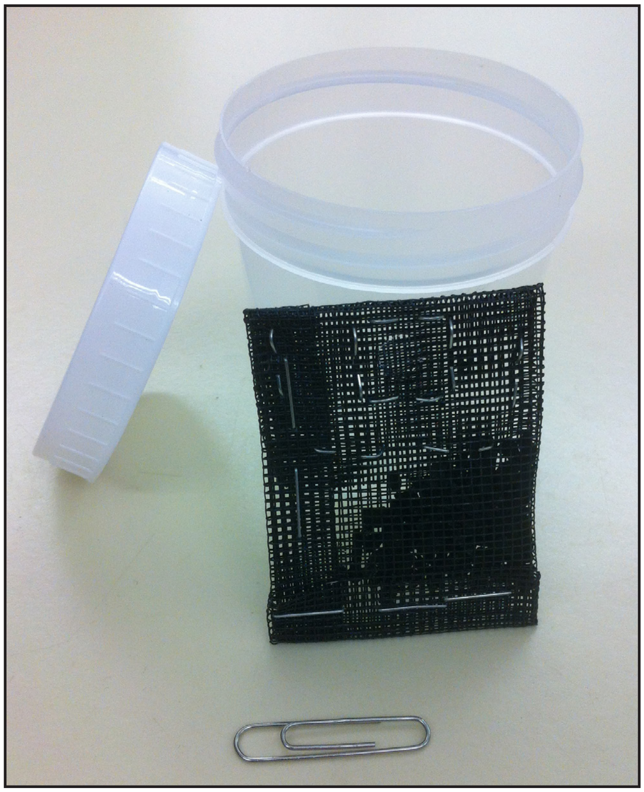


Photo by Bill Duley.

Figure 7. Typical packet for Protocol 2.

Analysis involves synchronously scanning the eluate with a seventeen nanometer (nm) separation between excitation and emission using procedures similar to those developed by Duley (1986). This separation yields suitable detection limits when analyzing eluate containing fluorescein (acid yellow 73), Rhodamine WT™ (acid red 388) eosine (acid red 87) and sulphorhodamine B (acid red 52), all in a single instrumental scan. The spectrophotometer measures and records fluorescent intensity from 450 nm to 620 nm excitation (467 nm to 637 nm emission). Results are plotted on the excitation wavelength axis.

The second protocol (Protocol 2) would best be described as an evolutionary change to the methodology described above. Under this protocol, carbon in the packet was reduced to about 1.1 gram (Figure 7) and elution was completed using 10 ml of 5 percent ammonium hydroxide in ethyl alcohol solution for one hour. All other procedures described above are unchanged. The new protocol reduces the amount of tracing supplies required, reduces waste disposal, yields more consistent results with respect to quantitative measurements and appears to yield a small but noticeable improvement in dye peak resolution.

The first protocol was used for all traces completed during the study until Feb. 4 2014. Double packets representing both protocols were used at six monitoring stations from Nov. 5, 2013, to Feb. 4, 2014, to compare the protocols under field conditions where tracers were present. Because of the improvements noted above, after Feb. 4, 2014, only Protocol 2 was utilized.

Using both protocols, fluorescent dyes are typically indicated by the presence of background-modified, but otherwise symmetrical, bell curve peaks. Fluorescent background is not symmetrical and it overshadows lower intensity dye peaks, especially at wavelengths below an excitation wavelength of about 550 nm. Peaks of the dyes used by MGS staff are superimposed on the declining side of a rather amorphous fluorescent background. Dyes that are excited at lower wavelengths and emit at lower wavelengths are most impacted by background fluorescence, which decreases significantly between about 450 and 550 nm.

Fluorescein is indicated by a well-defined peak between 495 and 505 nm with an optimum peak wavelength of about 501.1 nm. Eosine is indicated by the presence of a well-defined peak occurring between 521 and 525 nm with an optimum peak wavelength of about 523.1 nm. Rhodamine WT™ is indicated by a well-defined peak occurring between 544 and 553 nm; optimum peak wavelength is about 549.3 nm. Limited experience with sulphorhodamine B suggests the optimum peak wavelength using both MGS protocols is approximately 560 nm.

When more than one tracer is present in the same eluate, their fluorescent spectra partially overlap. If one tracer is found at a particularly high concentration, detection of other tracers may be problematic. For this reason MGS staff typically stagger dye injections to allow the large pulse of one tracer to dissipate prior to recovery of a second or third tracer.

MGS staff have also developed a simple chemical method to lower the pH of samples to a level that lowers fluorescein fluorescence so that it does not overshadow eosine or Rhodamine WT™. When a large fluorescein peak is detected, 50 microliters of glacial acetic acid is added to each sample of four milliliters eluate prior to a repeat analysis. The peak wavelengths of both eosine and Rhodamine WT™ increase (up to several nanometers above normal) when this method is used.

Idstein and Ewers (2002) report Rhodamine WT™ has two alkylated amine groups that control fluorescence wavelength. The dye can degrade by deaminoalkylation, shifting the fluorescence to lower wavelengths. Rhodamine WT™ has been known to degrade in certain instances in as short a time as one month in groundwater tracing work. MGS staff were among the earliest investigators in the U.S. to note the degradation of Rhodamine WT™ and have found degradation, not only in field samples, but in at least one container purchased for injection (Duley, 1986). The largest concern about degraded Rhodamine WT™ is that the degradation product fluoresces near the wavelength of fluorescein and can lead to faulty conclusions. To alleviate degradation concerns the pH adjustment technique mentioned above is applied by MGS staff when fluorescein or a fluorescein-like peak is found. Using this technique, fluorescein essentially ceases to fluoresce while the degraded Rhodamine WT™ is largely unaffected.

Interpretation of Carbon Packet Analyses

Analysis of carbon packets using the procedures described above does not yield strict quantitative results. Numerous variables are involved in dye collection, via adsorption on charcoal as well as the analysis for dyes, which requires desorption from the charcoal. Some of these variables include the amount of flow passing through the packet, water quality, and pH in the field; and the efficiency and consistency of the desorption process in the laboratory. While it is possible to compare peak heights of the sample eluate to standards made with the eluent, the resulting dye recovery curves often show inconsistencies from one sample to the next.

In order to reduce these inconsistencies and compare data from the array of analytical instruments used by the MGS over the last thirty years, a simple method was developed to normalize spectral data. When possible, the instrumental dye peak height value (as measured from zero on the X-axis in any instrumental unit) is divided by the value of the lowest intensity of the spectral valley that occurs between the fluorescent background maxima and the dye peak in question (Figure 8). This peak to valley ratio (PVR) gives the investigator a quick and simple way to compare data from a variety of instruments ranging from those with analog print-outs to those producing digital data. Background fluorescence is essentially used as an internal "standard" that compensates for inconsistencies in dye adsorption in the field and desorption in the lab. No comparisons have been made to instrumental analyses of other investigators except for a small sample of digital data obtained from the USGS. It is possible that other eluents and procedures may not yield comparable results to those obtained by MGS, but the method clearly simplifies and standardizes MGS dye recovery curves.

By definition, the PVR must be greater than 1.0 to indicate the presence of dye. If there is no dye peak, there is no valley, and the PVR is 1.0. MGS interpretations of different PVRs are shown in Table 3. PVR values, produced from carbon packet eluate, are plotted logarithimically on the Y axis versus packet recovery date on the X axis on a number of line graphs throughout this report. Figure 9 is a simple example of how the results are interpreted. In some instances, data from duplicate packets that represent the same monitoring point have been used to fill in blanks where the original packets were lost or not recovered due to high water. Lines connect the data points for specific recovery locations. The first recovery of dye is interpreted to have occurred

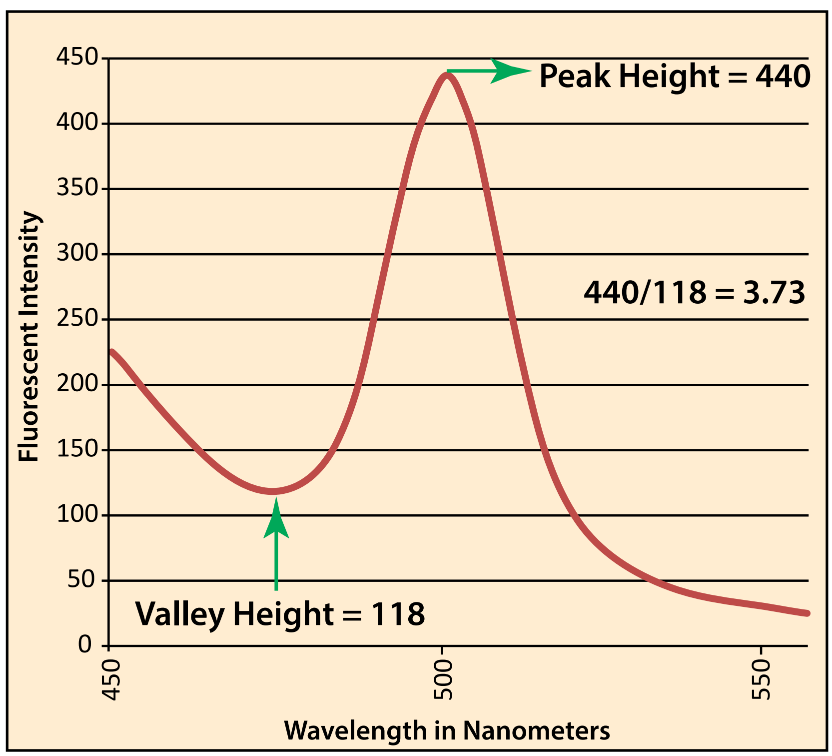


Figure 8: Peak/valley ratio (PVR) determination example.

between the point at which the line deviates upward from background levels to the first PVR value above background. Maximum dye concentration (peak) is interpreted to have occurred between the largest PVR value recorded and the previous packet recovery point.

Peak/Valley Ratio	MGS Classification	Interpretation
1	No Dye Recovered	No Dye Peak. Typical of background conditions.
>1.0 to 2.0	Small Dye Recovery	In background packets indicates presence of sewage or other source of tracers. If background analyses consistently have a PVR of 1, indicates connection to the current injection.
>2.0 to 5.0	Moderate Dye Recovery	Unless significant background issues are present, indicates a significant connection to a current injection.
>5.0 to 10.0	Large Dye Recovery	Normally indicates a strong connection to a current injection.
>10.0	Very Large Dye Recovery	A strong and direct connection to a current injection.

Table 3: Missouri Geological Survey Peak Valley Ratio Classification System.

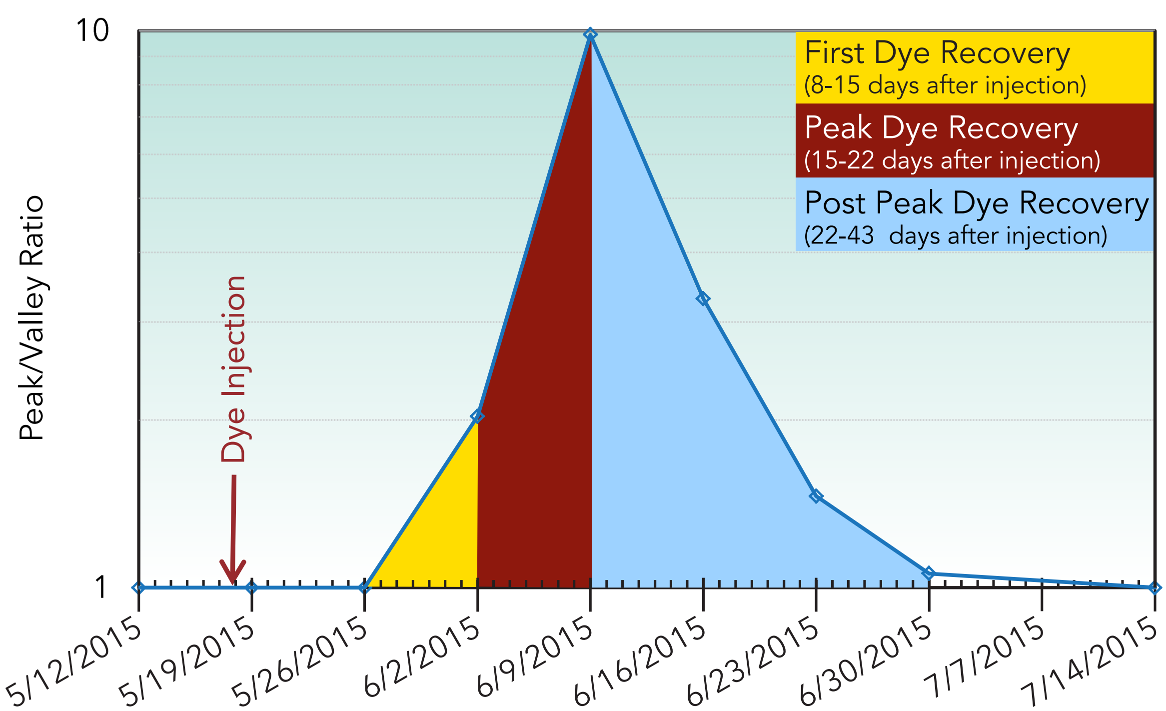


Figure 9. Dye recovery curve interpretation. Nodes on line graph represent carbon packet collection dates with a corresponding PVR value.

Recharge Area Boundary Determinations

As mentioned earlier, accurate water tracing information is essential in determining recharge areas in the Big Four region. Unfortunately, investigators will never complete sufficient traces to remove all doubt as to the exact location of recharge area boundaries. The best locations for dye injections are usually those where water quickly recharges a portion of the aquifer and the water is rapidly flowing through relatively large openings toward a discharge point. There is no infallible way to determine that an injection point will provide those kinds of characteristics based on surface observations.

Because of the relative inaccessibility of many parts of the region, it was difficult to locate more than a small fraction of losing streams which contribute continuous or nearly continuous flow to groundwater. Many streams that lose flow to the subsurface will not be traced directly to major resurgence points since there are literally thousands of springs in the Ozarks, the majority of which are not located on topographic maps or in any database. Given the inherent limitations of existing data and the process of completing new traces, other information must be used to supplement tracing data to determine realistic recharge areas. The following considerations were used in completion of this study. While no set formula was used in applying these factors, each was considered.

Geology

Stratigraphy and structure play major roles in determining where recharge occurs and how water moves through the aquifer system. Low permeability rocks, such as shale or rhyolite, often serve as barriers to rapid groundwater movement. In areas the size of the Big Four Region, one would expect a number of low permeability lithologic units to play an important role in directing water. One factor that makes the Big Four Region somewhat unique is that almost all of the sedimentary rock units exposed at the surface in the region are affected by dissolution to some extent.

The Jefferson City and Cotter dolomites serve as a leaky confining unit in many areas in Missouri. Yet there are a number of places in the Big Four Region where these strata are the uppermost bedrock beneath sinkhole plains and losing streams. They appear to have been greatly impacted by geologic faulting in those settings. There are also upland environments where the Jefferson City and Cotter are relatively unaffected by dissolution, likely due to the absence of persistent faulting and fracturing in those areas. Where they exhibit low permeability at depth, these strata combine to serve as a perched aquifer that supplies small springs and shallow wells. These small perched aquifers are generally not considered in drawing groundwater recharge area boundaries for large springs, except where traces indicate their presence is significant.

Most of the Ozark Aquifer (Ordovician and Cambrian-age) is characterized by karst features. While there are beds of chert and sandstone in the Roubidoux Formation, for example, the area has been impacted by faulting and folding to such a degree that any beds that might normally be characterized by low or moderate permeability have been fractured sufficiently to allow, at least locally, rapid migration of groundwater. The Eminence and Potosi formations are affected by dissolution features but only locally serve as host to major conduits or large springs.

While the St. Francois Confining Unit that is present beneath the Ozark Aquifer is almost certainly impacted by faulting, there is little evidence to suggest that the underlying St. Francois Aquifer provides significant recharge to the Big Four Region springs (see Geohydrology of the Big Four Study Area discussion above).

Precambrian rocks are found to crop out in a small region of the northeast portion of the study area. They are not impacted by solution, nor are they characterized by large zones of interconnected voids as is karst bedrock. Although Precambrian rocks are important in defining the lateral boundaries and the base of sedimentary rocks within the study area, insufficient data exist to use faulting in the Precambrian to determine recharge area boundaries inside the study area.

Losing/Gaining Stream Determinations

Due to budget limitations and access issues, it was not possible to view more than a small percentage of streams in the study area. Nevertheless, by observing stream crossings it is possible to get a reasonable approximation of where losing and gaining stream reaches are present (Figure 10). Large areas in the region are essentially devoid of flowing streams, or even pools of water, during dry periods. Documented gaining stream reaches are much rarer than losing streams within the recharge areas of major springs in the region. Numerous gaining stream reaches are discontinuous and can be observed flowing

Figure 10. Losing stream - Middle Fork of the Eleven Point River downstream of a gaining segment.

into losing segments. Even sizeable springs with discharges of several ft³/s may lose their entire flow to the subsurface within short distances during low flow conditions.

Short gaining streams that flow into losing streams are normally included in the recharge area of the losing stream segment. During large runoff events, even losing streams are limited in their ability to swallow a storm surge. Thus losing streams may discharge a large amount of water to continuous gaining streams that will not enter a spring system. Continuous gaining streams are excluded from recharge areas of springs.

Figure 11. Sinkhole north of Alton once used as a dye injection point (IP4 - Aley, 1972).

Sinkholes

Disseminated sinkholes are found throughout the region (Figure 11). They rarely are provided with a continuous flow of water to carry a tracer significant distances into the subsurface. The largest sinkhole plains in the region are included in recharge areas of springs. However, limited trace information exists with respect to individual sinkholes. In lieu of tracing data, sinkhole locations are of limited value in drawing recharge area boundaries in the Big Four Region.

Potentiometric Maps

In non-karst areas, potentiometric maps are often used to determine groundwater flow directions with some accuracy. Potentiometric maps are constructed by measuring water levels in wells that, ideally, screen the same aquifer. By contouring the water level elevations, one can determine which direction the groundwater is flowing - from higher head to lower head. Potentiometric maps work well in homogeneous aquifers. They can be used in karst regions as well, but only with qualifications.

Karst aquifers are, by definition, not homogeneous. In a region as large as the study area, it is not possible to obtain access to measure water levels in sufficient wells, screened across the same interval, to accurately determine local groundwater flow directions. Potentiometric maps can be used to obtain general flow directions, as shown by Kleeschulte (2000) Mugel et al. (2009) and Imes et al. (2004). In areas where no suitable tracing information was available to delineate groundwater divides with accuracy, potentiometric map data were applied using Missouri Department of Natural Resources (2006A) (Figure 12). This computer generated map depicts data representing multiple years of reported water levels in wells with an emphasis on the uppermost aquifer. Although it is limited in this application, it nevertheless provides a regional approximation of groundwater levels throughout the study area.

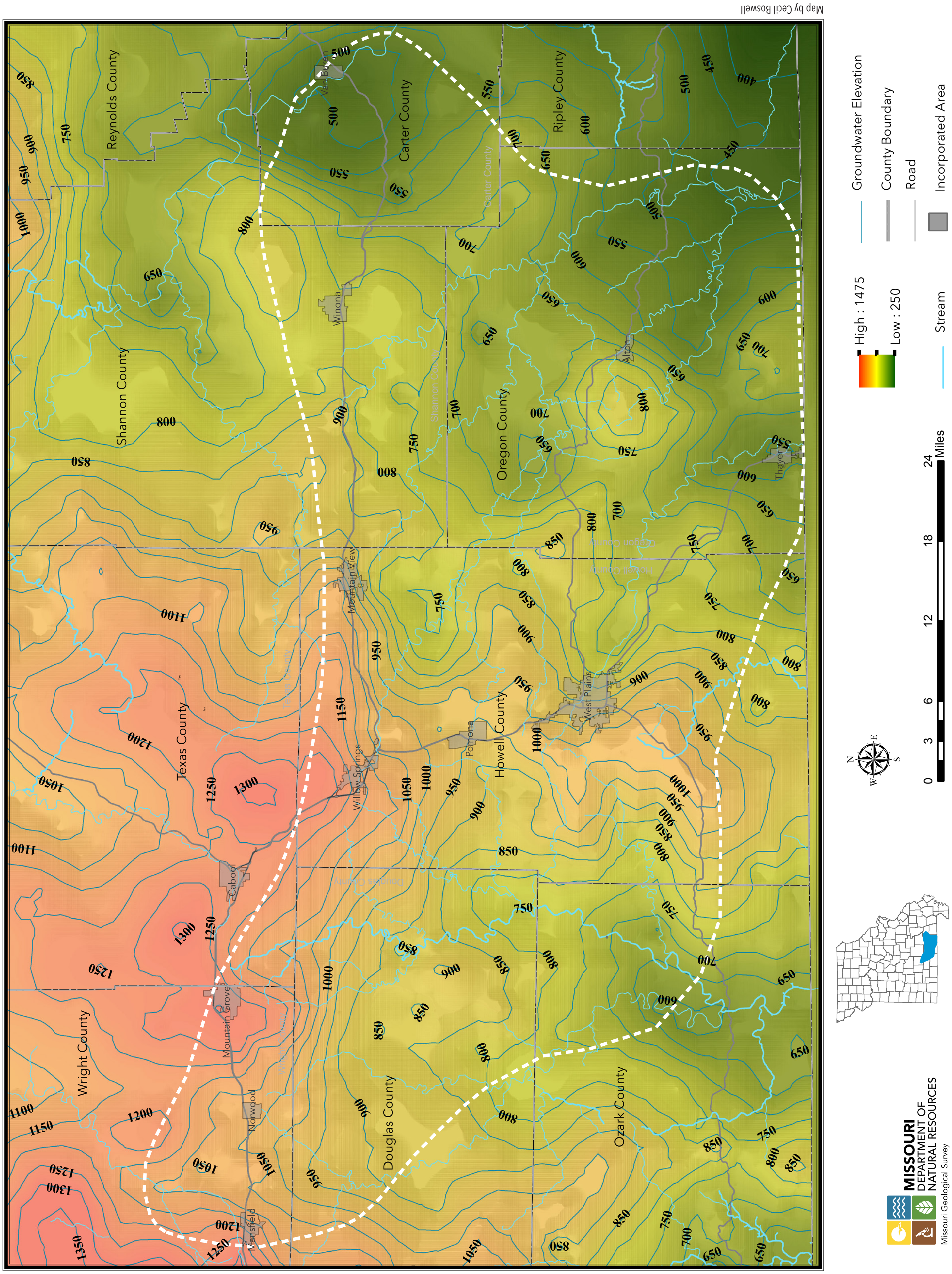


Figure 12. Potentiometric map of the Study Area modified from Missouri Department of Natural Resources (2006A).

Spring Groupings, Spring Descriptions and Traces

Explanation of Spring Groupings and Identification System

The major springs and spring complexes are described in the following sections. Where possible, springs that share recharge areas are grouped in the same section. This allows information about a specific dye injection to be discussed in a single section. Big Spring (Carter County), Big Spring (Douglas County) Warm Fork Spring (Oregon County) and Blue Spring (Ozark County) are described separately. Even though they may share recharge with other springs in the region, existing data suggests that sharing is limited. Some published legacy traces are described briefly along with more detailed descriptions of legacy traces that have not been published or adequately described in prior publications.

Detailed summaries of significant known traces in the region are listed alphabetically by recovery point in Appendix A. Trace numbers are from Missouri Department of Natural Resources (2016A;2016B;2016C), a series of geographic information system water tracing datasets sorted by county of dye recovery. Counties are abbreviated as follows: Carter-Cr, Douglas-Do, Howell-Hl, Oregon-Or and Ozark-Oz. The county designation is followed by a three digit number. Some injections have been recovered at multiple locations which means that multiple traces in Appendix A may stem from the same injection.

Appendix B identifies detailed location information, where available, for monitoring points used in all traces. Monitoring points are listed by watershed. Watersheds are abbreviated and listed in the following order: Gasconade River-GR, Bryant Creek-BC, Eleven Point-EP, Jacks Fork-JF, Spring River-SR, Current River-CR, Bennett Bayou-BB and Beaver Creek-BC.

Appendix C includes locational data for injection points designated by the letters "IP" followed by a one or two digit number. Some injection points have been used multiple times. Again, single dye injections can travel to multiple recovery points.

The spring groupings used for detailed descriptions follow. During the current study at least one trace was completed in each of the groups listed.

A. Blue/Morgan Complex and Boze Mill Spring (Oregon County, Missouri);
B. Blue Spring (Ozark County, Missouri);
C. Greer Spring (Oregon County, Missouri) and Mammoth Spring (Fulton County, Arkansas);
D. Bill Mac Spring, Rookery Tree Complex (Oregon County, Missouri), two unreported Middle Fork springs – one upstream of County Road 3850 and one upstream of County Road 1420 (Howell County, Missouri);
E. Rainbow/North Fork/Hodgson Mill Complex (Ozark County, Missouri);
F. Althea and Wilder springs (Ozark County, Missouri);
G. Big Spring (Carter County, Missouri);
H. Big Spring (Douglas County, Missouri);
I. Warm Fork Spring (Oregon County, Missouri);
J. Dennig Complex, Graveyard Complex and unreported Little Hurricane Creek Spring (Oregon County, Missouri).

Figures 13, 28, 54, 60, 70, 96 and 103 have been inserted near the beginning of selected spring grouping discussions to illustrate selected natural and cultural features of each region. Figures 23, 27, 38, 48, 53, 68, 70, 79, 86, 91, 95, 96 and 104 illustrate traces and other characterization efforts completed in each spring group. All of the traces and interpretations of recharge areas are summarized on Figure 106. While the actual trace paths are unknown, they are generally shown as straight lines. Selected trace paths on Figure 106 are curved to better represent actual recharge areas. Calculated trace lengths in the text, Table 9, Table 10 and Appendix A are all based on the assumption of a straight line connection.

Spring Group A

Blue/Morgan Complex and Boze Mill Spring (Oregon County, Missouri)

Blue/Morgan Complex Description

The Blue/Morgan Complex is associated with a narrow ridge bounded by Frederick Creek on the north and the Eleven Point River on the east and south. This ridge, termed "The Narrows" is managed by the U.S. Forest Service (USFS) and represents a sliver of Jefferson City Dolomite sitting atop the Roubidoux Formation. Blue Spring (Figures 14 and 15) issues from the Roubidoux Formation south of the bedrock bluff that supports the ridge. It can be reached by turning north off of Missouri Route 142 just west of the Eleven Point River at the Narrows. A short walk (approximately 0.1 miles) down an old access road from the Narrows parking area reveals Blue Spring at the bottom of a scenic overlook. Vehicular traffic is not allowed on or beyond the narrowest part of the ridge.

Figure 14. Blue Spring (Oregon County).

Figure 15. Blue Spring (Oregon County) from the overlook at the Narrows.

Morgan Spring can be reached with a more substantial walk down the old access road approximately 0.5 miles past the overlook for Blue Spring. Morgan Spring wells up in the alluvium near the intersection between Frederick Creek and the Eleven Point River. This is the site of the historic Thomason Mill. A concrete and earthen dam still marks the old mill site but the mill is gone (Figure 16).

A third, smaller spring, Sullivan Spring, surfaces south of the ridge and east of Blue Spring, and flows into the Blue Spring Branch less than 100 yards southwest of the Blue Spring orifice. Other small springs nearby are likely part of the system as well, but they were not evaluated systematically during this study. Vineyard and Feder (1974) reported 10 discharge measurements of Blue Spring with a maximum of 100 ft^3/s, a minimum of 52.0 ft^3/s and an average of 72.0 ft^3/s. It is likely that these measurements include the discharge from the above-mentioned smaller spring as well.

Figure 16. Thomason Mill Site at Morgan Spring.

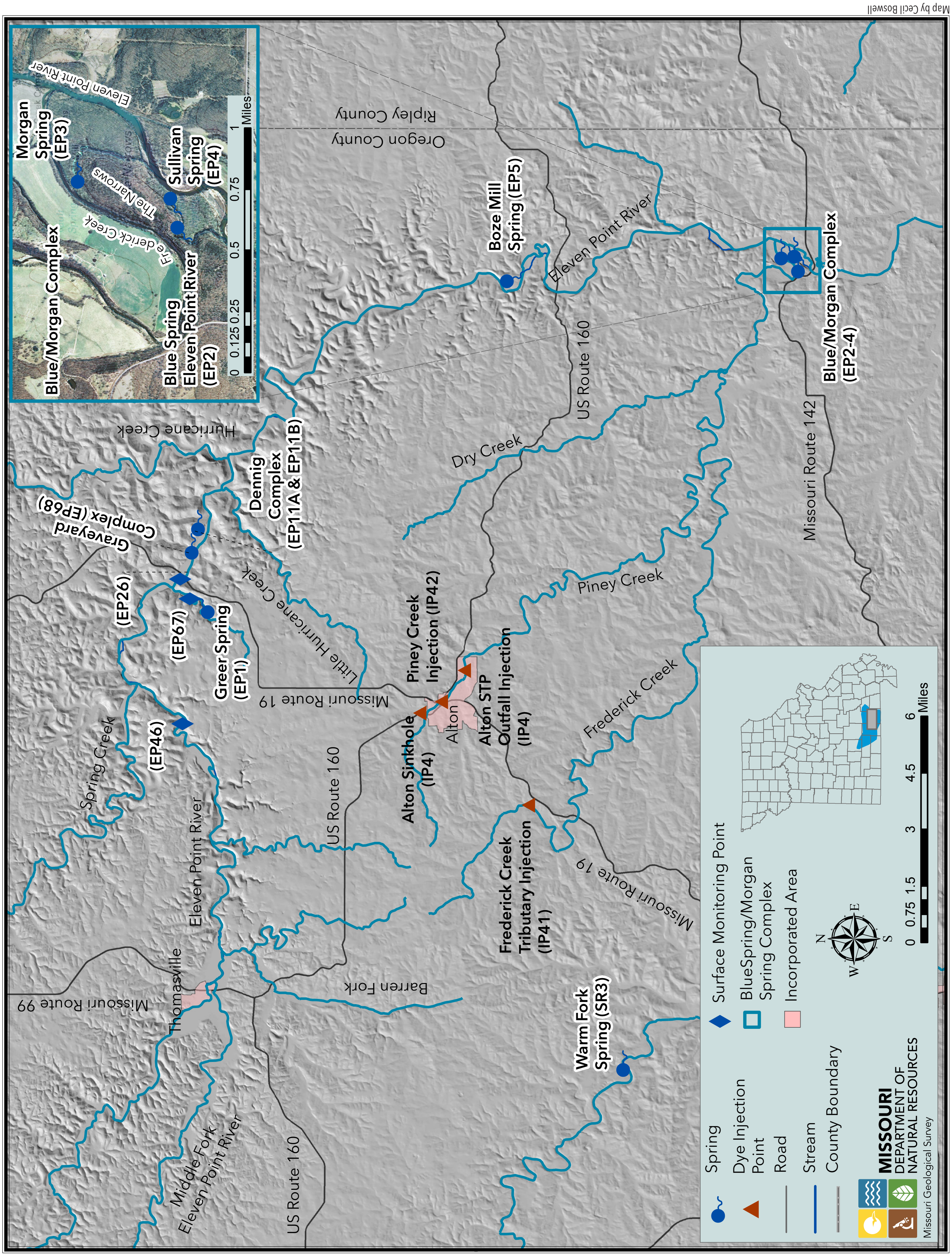


Figure 13. Spring Group A region.

Morgan Spring discharge measurements were also recorded by Vineyard and Feder (1974). Maximum discharge is listed as 58.0 ft^3/s, minimum as 14.0 ft^3/s and the average of 32.0 ft^3/s (12 measurements). MGS staff also measured Morgan Spring on Aug. 19, 2015, at 57.3 ft^3/s. While this measurement was likely taken at a time when flow was slightly above the mean, the long term gages at Big, Greer and Mammoth springs on this date showed that all three springs were within 10 percent of their mean flow as determined by averaging discharge data beginning Feb. 25, 1981, when a long term gage was first installed at Mammoth Spring (U.S. Geological Survey, 2015). The combined flow of the entire complex likely ranges from about 60 to greater than 200 ft^3/s.

Specific conductance measurements collected at sample events during this study indicated that Morgan and Blue springs are likely two orifices for the same conduit. In addition, measurements made during eight sampling events showed that the difference between these springs and Sullivan Spring was negligible. While other springs in the general area showed similar reactions to recharge events and dry periods, there were definite differences in baseline specific conductance values (Figure 17).

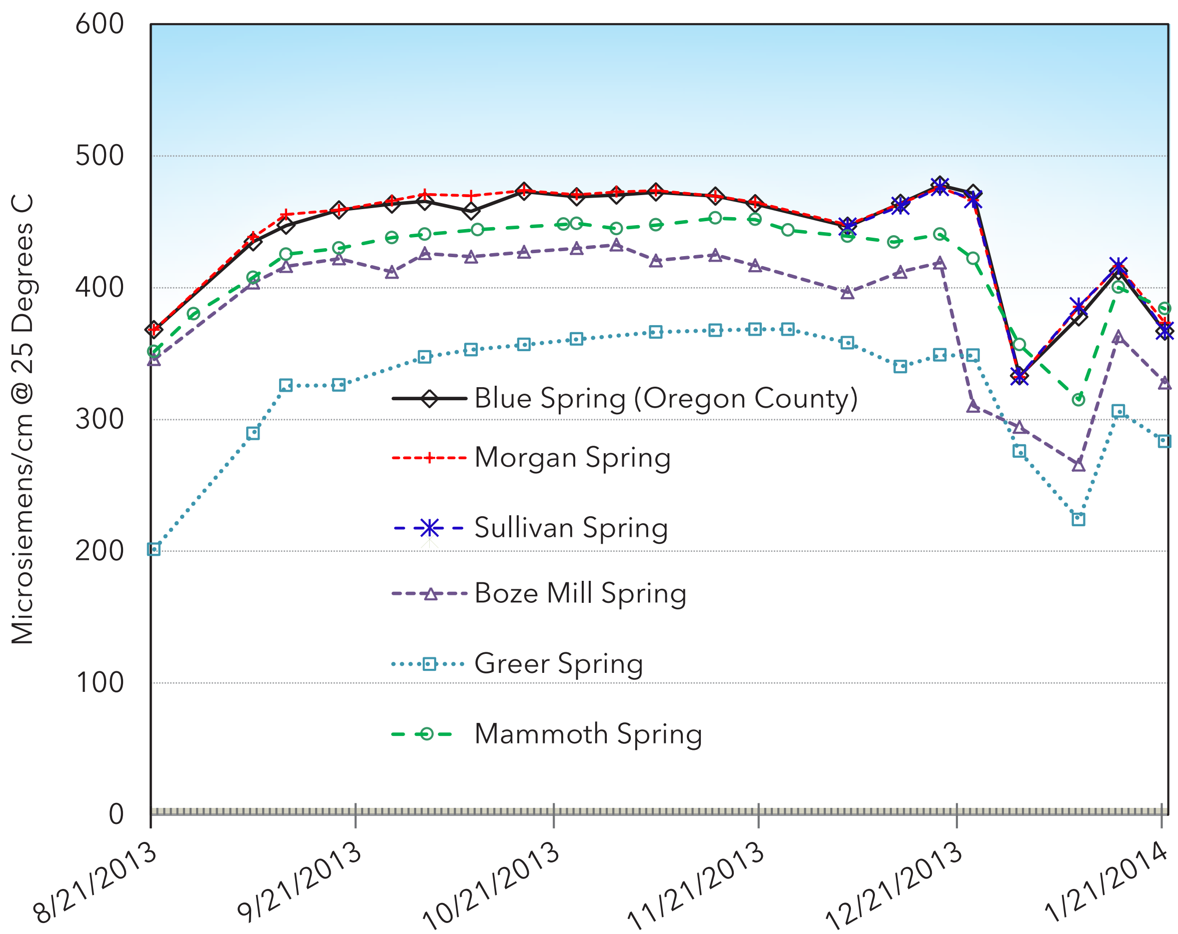


Figure 17: Temporal variance of specific conductance in selected springs in the Big Four Region.

Boze Mill Spring Description

Figure 18. Boze Mill Spring orifice looking downstream.

Boze Mill Spring (Figure 18) issues from a bedrock opening at floodplain elevation on the east side of the Eleven Point River. A rock dam was constructed across the spring branch in the past to provide power to Boze Mill. The mill is gone but some associated machinery remains near the dam (Figure 19). Vineyard and Feder (1974) summarized discharge measurements of Boze Mill as a maximum of 46.0 ft^3/s, a minimum of 13.0 ft^3/s and an average of 23.0 ft^3/s (10 measurements).

An additional 10 unpublished measurements completed after 1974 were obtained from the USFS (Tryon, 1989). These measurements show a maximum discharge of 116.0 ft^3/s, a minimum of 16.1 ft^3/s and an average of 55.1 ft^3/s. Most of the larger discharge measurements were made in March, April and November which are often wet months in the region. MGS staff measured the flow at Boze Mill Spring during a relatively wet period on July 29, 2015 at 74.06 ft^3/s.

Figure 19. Boze Mill dam with associated machinery.

Legacy Traces to Spring Group A

Alton Sinkhole Legacy "Trace"

Prior to this study, only one trace had been reported to the Blue/Morgan Complex. It is not included in the MGS dyetrace database.

It is included here and Appendix A because it is described in a journal article (Aley, 1972). The original "trace" is listed in Table 2 as an example of traces that should be considered for replication.

The injection point, a sinkhole (IP4 – Figure 11), is located just north of Alton, Missouri. It is dry during low precipitation conditions, but ponds water during wetter periods. The sink is about 40 feet deep and is indicated by a copse of trees in the right foreground of Figure 20. Piney Creek, a gaining stream in this reach, flows adjacent to the sink and does not lose significant flow for about 0.6 miles downstream. In dry periods the sink is dry at a level about 20 feet lower than Piney Creek. The USFS reportedly injected 10 pounds of fluorescein into the sinkhole, which was used as a local dump, on May 28, 1969. The first, and only, recovery reported was at Morgan Spring (EP3) from Aug. 11 to Aug. 25, 1969. Dye analysis was by visual means. In addition, no dye was reported at Blue Spring (EP2), even though Blue Spring was monitored as part of the study and we now know that both are part of the same complex. Boze Mill Spring was apparently not monitored.

Photo by Bill Duley.

Figure 20. Panoramic view of upper Piney Creek (left) and Alton sink (obscured by trees at right).

Legacy Traces to Boze Mill Spring (Traces Or 025 and Or 026)

Limited information exists with respect to the recharge area of Boze Mill Spring. Reising (1982) of MGS attempted to determine the resurgence point of water lost from the Alton wastewater treatment facility. In late April 1982, the lagoon in use at that time apparently suffered a rapid loss of liquid waste (Williams, 1982). Fourteen pounds of fluorescein dye were injected into the lagoon (IP29) on April 22 after placement of activated carbon packets in toilet holding tanks associated with six local private wells as well as in Morgan Spring (EP3), "Jones Spring" (presumably a misnomer for Blue Spring, EP2) and Mammoth Spring (SR1). According to Reising (1982), additional packets were later placed at Greer Spring (EP1), Sand Spring (EP24), the Eleven Point River at Missouri Route 142 (EP19) and Frederick Creek at Missouri Route Y (EP18).

Analysis techniques at that time involved elution of packets in 5 percent potassium hydroxide in ethyl alcohol followed by visual analysis. The only recovery reported was in a single well (Duley, 1982A).

Notably, MGS staff did not monitor Boze Mill Spring (EP5) located just east of the Eleven Point River near Riverton. During the same time frame, Everett Chaney of the USFS did report finding a large amount of fluorescein in Boze Mill Spring in a packet he had in place from June 29 to Aug. 8, 1982 (Duley, 1982B). It is likely that Chaney employed similar techniques to those of MGS staff at that time: collecting dye with activated carbon and extracting dye by elution in a basic solution. He analyzed the eluate visually.

This "trace" is not included in Missouri Department of Natural Resources (2016C; 2016D) or Appendix A due to the inconsistencies in monitoring listed above and will not be inserted into the database. It is listed here because the data collected led MGS staff to monitor Boze Mill Spring in later studies that used essentially the same injection point. Ultimately the connection between the Alton wastewater treatment facility and Boze Mill Spring was established.

In traces conducted in 1984 and 1985, Kraft (1985) essentially repeated the Reising injection using Rhodamine WT™ (Or 025 and Or 026). Carbon packets were eluted in a basic alcohol solution, followed by fluorescence spectrometric analysis using protocols described by Duley (1986). Kraft first injected one gallon of Rhodamine WT™ into Piney Creek, a losing stream, just downstream of the city of Alton's wastewater treatment facility, at injection point IP29 on Oct. 30, 1984. Dye was recovered only at Boze Mill Spring (EP5) in the first non-background packet collected on Nov. 15, 1984 (Or 025). Dye traveled the 10.4 mile straight-line distance in fewer than 16 days. This was a small recovery of dye with a maximum PVR of only 1.17.

A second injection was completed in the same vicinity on July 23, 1985, to determine effluent resurgence points during a wetter period than that of the previous trace. Results were consistent with those of the earlier trace. Two gallons of Rhodamine WT™ were injected with dye recovered only at Boze Mill Spring (EP5) in the first non-background packet retrieved on Aug. 9, 1985 (Or 026). Dye traveled to Boze Mill Spring in fewer than 17 days. This trace was also classified as a small recovery of dye with a maximum PVR of 1.34. Kraft (1985) reported monitoring Sibkey Spring (EP7), Blue Spring (Oregon County - EP2) and Morgan Spring (EP3) as well as other points in the area (see Appendix A).

Several causes are suggested for the small dye recoveries at Boze Mill Spring during these traces:

- The instrument and associated methodologies used by MGS staff at the time were not as sensitive as those used today;
- In both cases Rhodamine WT™ was injected into sewage. Rhodamine WT™ has long been known to suffer relatively large adsorption losses in organic-rich environments and to be broken down by chlorine;
- Dye was not injected near the losing point in Piney Creek. Thus there may have been an inordinate amount of degradation, adsorption and dispersal of the dye.

Contemporary Traces Completed to Spring Group A

Two injections that impacted these spring systems during this study were conducted: one in an upper losing reach of Frederick Creek southwest of the city of Alton and a second in an upper reach of Piney Creek within the city of Alton.

Upper Frederick Creek Injection (Traces Or 033, Or 034 and Or 036)

Losing segments of Frederick Creek have long been suggested as one source for water issuing from the Blue /Morgan Complex (EP2 and EP3). The uppermost reaches of Frederick Creek are characterized by shallow water loss into epikarst that feeds numerous small springs. Flow from these springs is subsequently lost to a deeper karst system and does not appear to resurface within the watershed. The lower reaches of Frederick Creek are characterized by long pools of perched water that slowly drain during dry periods. Perennial flow begins where the discharge from Sand Spring enters the main channel about four to five miles from the mouth of Frederick Creek (Jeffrey Crews, MGS, personal communication, 2016).

Carbon packets placed in Blue Spring (EP2), Morgan Spring (EP3), Boze Mill Spring (EP5), Greer Spring (EP1A and EP1B), Mammoth Spring (SR1) and two points in lower reaches of Frederick Creek (EP18 and EP25) were monitored for background beginning in early August 2013. Ten pounds of fluorescein dye were injected in a losing segment of the main stem of Frederick Creek (IP41) at 11:50 a.m. on Aug. 27, 2013. Approximately 10 gpm were flowing into a small pool on this date, with no observable flow downstream for a distance of several miles.

Fluorescein was first recovered from Blue Spring (Or 033) and Morgan Spring (Or 034) in packets in place between Sept. 18, 2013 and Sept. 26, 2013 (about 22 to 30 days after injection). Large amounts of dye were recovered in both springs (maximum PVR of 33.93) and lesser amounts continued to be recovered in packets collected through December 2013. Figure 21 shows the similarity of PVRs for both of these springs throughout the trace.

Fluorescein was also recovered at Boze Mill Spring (EP5) with the first recovery from Sept. 26 to Oct. 1, 2013 (Or 036) 30 to35 days after injection. The maximum PVR of 2.13 indicates a smaller amount of dye was recovered than at Blue or Morgan springs.

Recovery of fluorescein at Boze Mill Spring from the first dye pulse decreased relatively quickly, with the last packet that contained dye at an amount above background in place from Oct. 30 to Nov. 5, 2013. A second pulse of dye may have occurred later, but monitoring ceased on Jan. 21, 2014.

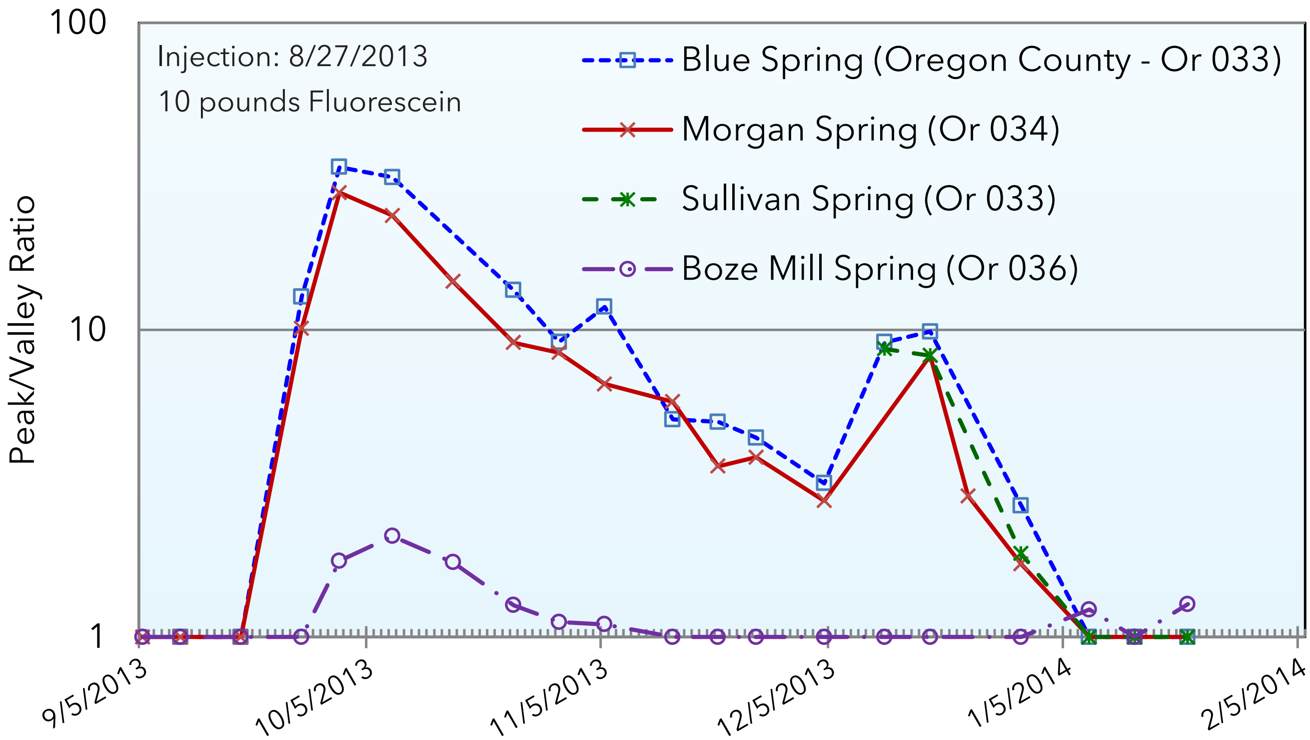


Figure 21. Dye recovery curves (carbon packet eluate) upper Frederick Creek traces (Or 033, Or 034 and Or 036)

The Blue /Morgan Complex is interpreted to represent a single system that is the main recipient of water lost from the upper reach of Frederick Creek where the injection took place. There was no indication that any of the tracer resurfaced in the lower reaches of Frederick Creek upstream of the Complex. Boze Mill Spring apparently received a minor portion of the water from this injection via subsurface flow, but this trace should be considered a secondary connection.

Piney Creek at Alton Injection (Traces Or 030, Or 031 and Or 032)

While it is known that at least a portion of Piney Creek loses water that subsequently resurges at Boze Mill Spring, the earlier trace from the Alton sinkhole dump located immediately north of Piney Creek suggests that water in the Alton area recharges Morgan Spring (Aley, 1969 and 1972). Boze Mill Spring was not listed as a monitoring point. Only one sample interval was recorded to have a dye recovery at Morgan Spring, which was reported to be “Strongly Positive” (Aley, 1969, p.1). It is difficult to reconcile the first recovery between Aug. 11 and Aug. 25, 1969 - nearly three months after the injection with a large dye recovery. In addition, dye was not reported at Blue Spring (part of the same complex) and packets in place at Morgan Spring between Aug. 25 and Sept. 2, 1969, did not contain dye. Thus, MGS staff opted to do an additional injection in the vicinity to better define water movement.

Piney Creek follows the same general pattern observed in other portions of the upper reaches of Frederick Creek: epikarst feeds small springs high in the watershed with subsequent water loss to the regional karst system downstream. The sinkhole used for the earlier injection (Aley, 1969 and 1972) is located adjacent to a gaining segment of Piney Creek even though the base of the sinkhole, which is at a lower elevation than the flow in Piney Creek, is dry most of the time. All flow is lost from Piney Creek during dry periods about 0.6 miles southeast of the sinkhole.

MGS staff opted to inject dye into this losing stream segment instead of the sinkhole for three reasons.

1. Water loss from this reach of Piney Creek is typically rapid with surface flow entering a pool with no surface discharge from the pool during dry periods. The description of the sinkhole response to weather conditions by Aley (1969 and 1972) and MGS staff observations during the current study indicate that water ponded in the sinkhole represents pooling of groundwater in the local karst aquifer during wetter portions of the year.

2. The losing stream injection point on Piney Creek is located between bridges on Missouri Route 19 and US Route 160 and provided direct information with respect to predicting resurgence points for potential future spills near the intersection of these routes.

3. The sinkhole was dry when MGS staff began this trace.

At 2:05 p.m. on Dec. 3, 2013, three gallons of Rhodamine WT™ were injected into a flow of about 15 gpm entering a small pool (IP42). No surface flow was observed downstream at that time. A large precipitation event followed this injection within a week, causing surface flow to wash over the injection point and potentially carrying residual amounts of dye downstream throughout the lower Piney Creek watershed. As a result of this precipitation, water rose in the Alton sinkhole, an apparent response to a rise in the general water table. Water stood at a depth of 10 feet or more in the sinkhole for a period of several weeks. Points monitored during this trace included Blue Spring (Oregon County-EP2), Morgan Spring (EP3), Boze Mill Spring (EP5), Mammoth Spring (SR1) and Greer Spring (EP1).

Dye was detected in large amounts at Boze Mill Spring nine to 15 days after injection with first and peak recoveries in the carbon packet in place between Dec. 12 and Dec. 18, 2013 (Or 030). Dye was recovered at this site continuously until Jan. 21, 2014, when MGS staff ceased monitoring to focus on other areas (Figure 22). A small amount of dye (maximum PVR of 1.34) was also recovered at Blue Spring (EP2), Morgan Spring (EP3) and Sullivan Spring (EP4) with first recovery between Dec. 30, 2013, and Jan. 8, 2014 (traces Or 031 and Or 032).

Interpretation of the Piney Creek trace suggests that the major resurgence point for water loss from Piney Creek between Missouri Route 19 and US Route 160 is Boze Mill Spring. While neither the sinkhole dump trace nor the traces from the Alton sewage facility (Or 025 and Or 026) were replicated directly, the data generated by this study suggests that the middle reaches of Piney Creek recharge Boze Mill Spring. These data corroborate the earlier traces from Piney Creek by MGS staff and the unnumbered “trace” from the Alton Lagoon reported by USFS staff, implying that the Alton sinkhole likely recharges Boze Mill Spring as well. The small amount of dye observed at the Blue/Morgan Complex during this study likely represents a secondary connection caused by surface water runoff into a downstream losing segment of Piney Creek or Frederick Creek, into which Piney Creek discharges (Figure 23). Evidence collected during this study and from other legacy traces suggest the earlier conclusion of a direct subsurface connection between the Alton Sinkhole and Morgan Spring is doubtful.

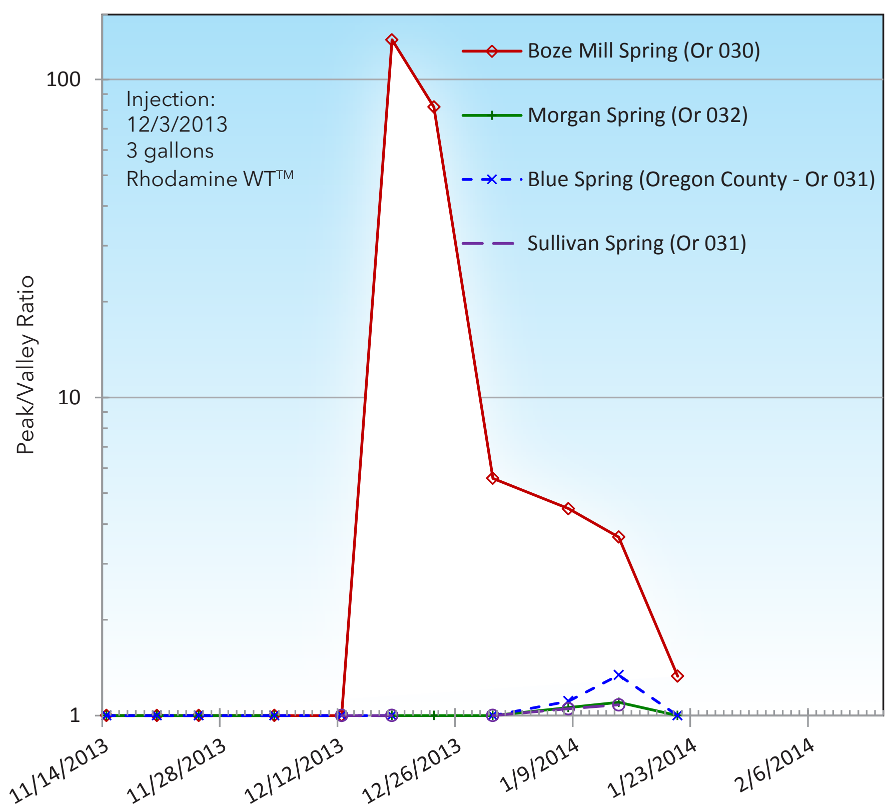


Figure 22. Dye recovery curves (carbon packet eluate) Piney Creek traces (Or 030, Or 031 and Or 032).

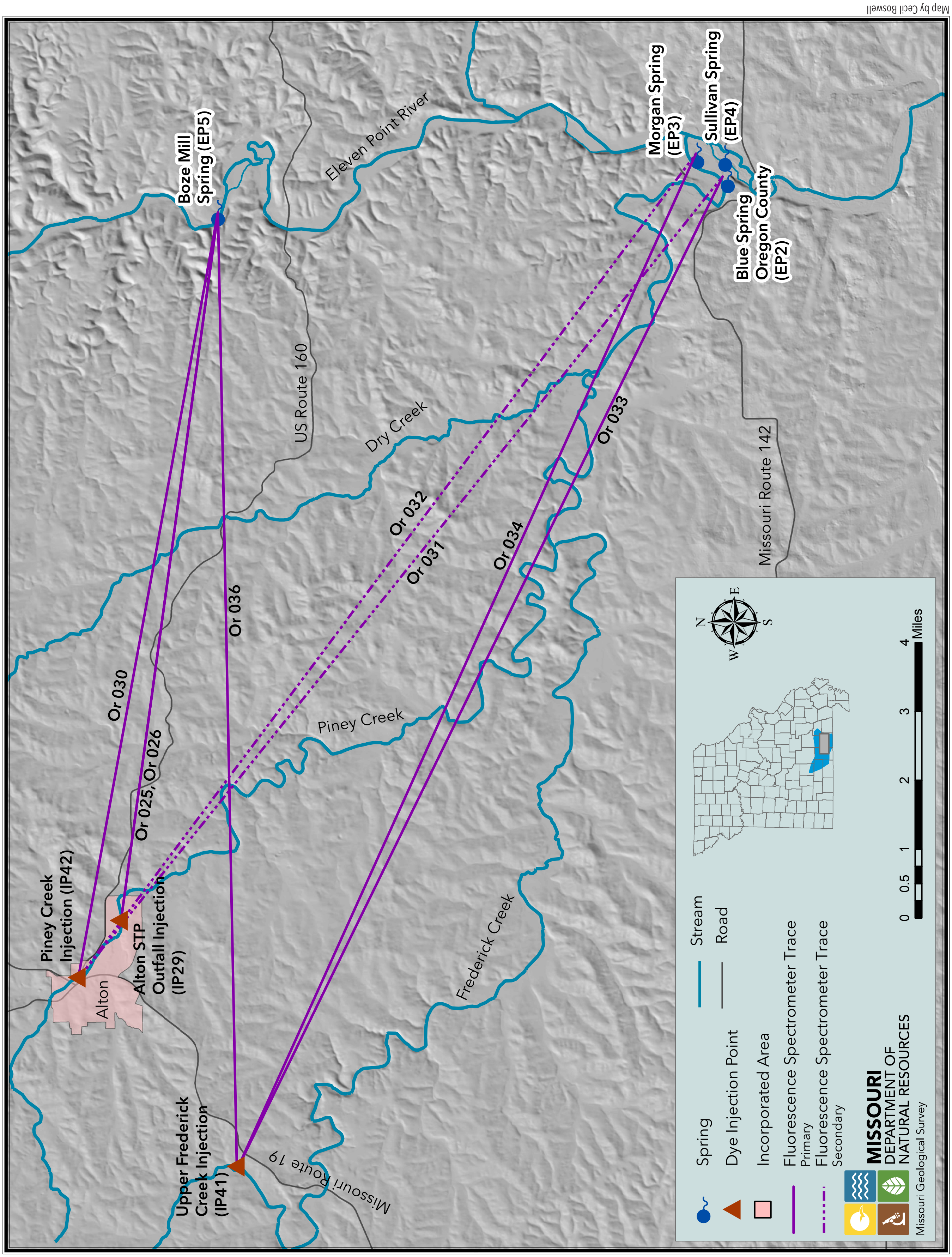


Figure 23. Current interpretation of traces to Blue/Morgan Complex and Boze Mill Spring (Spring Group A).

Spring Group B - Blue Spring (Ozark County, Missouri)

Blue Spring (Ozark County) Description

Blue Spring (Ozark County) is located on the east bank of the North Fork River. It rises in a small boil in a bedrock lined recess in the North Fork River bluff. Blue Spring is an attraction at a USFS day use and camping area located off Missouri Route CC. Hammond Mill, now gone, was once located upstream of Blue Spring on the North Fork. Blue Spring is inundated when the North Fork is in flood, but the spring can still be viewed from a trail and an overlook atop a small bluff just east of the river (Figure 24). Blue Spring issues from the lower part of the Gasconade Dolomite. Six flow measurements ranging between 9.5 and 30 ft^3/s, with most of the measurements in the 10 to 12 ft^3/s range, are recorded in Vineyard and Feder (1974).

Photo by Bill Duley.

Figure 24. Blue Spring (Ozark County) on the North Fork.

Legacy Traces to Blue Spring-Ozark County (Oz 004, Oz 005, Oz 008 and Oz 013)

Prior to this study, traces reported to Blue Spring were from: McGarr Spring Branch (Oz 004, IP18) as reported by Fletcher (1972E), Amber Spring Branch (Oz 005, IP23), The Sinks (Oz 008 , IP24) as reported by Vandike (1979) and Siloam Spring branch (Oz 013, IP86) reported by Tryon (1979). The Sinks trace to Blue Spring must be considered speculative since injection of fluorescein at The Sinks followed the injection of fluorescein at Amber Spring by just 16 days. Reported first recoveries of dye at Blue Spring for the two traces were Aug. 1 to Aug. 15, 1977 and Aug 31, 1977, to Sept. 7, 1977. The injection of fluorescein at The Sinks followed the first recovery period of fluorescein at Blue Spring by only two days.

Contemporary Traces Completed to Spring Group B

Upper Tabor Creek Injection (Trace Oz 034)

Five pounds of fluorescein were injected into an upper reach of Tabor Creek (IP44) to help identify recharge areas on the west side of West Plains (Figure 25). The injection took place at 5:00 p.m. on June 17, 2014. Dye was first recovered in packets in place in Blue Spring (Ozark County) between June 24 and July 8, 2014, (seven to 21 days after injection) with the peak occurring between July 8 and July 15 (Figure 26). Blue Spring is heavily used as a recreational site during this time of year and packets that represented the week of June 24 to June 30 were lost, presumably to visitors who did not know what they were. Straight line distance of the trace is more than 8.6 miles. The trace from upper Tabor Creek is classified as a very large recovery of dye with PVRs ranging up to 246. The amount of dye recovered is indicative of a rapid and direct connection to the injection point. Figure 27 displays the traces completed to Blue Spring on the North Fork during this study along with those reported by previous investigators. A second contemporary trace (Oz 014) to Blue Spring is described in the section on Spring Group C.

Figure 25. Fluorescein injection into upper Tabor Creek.

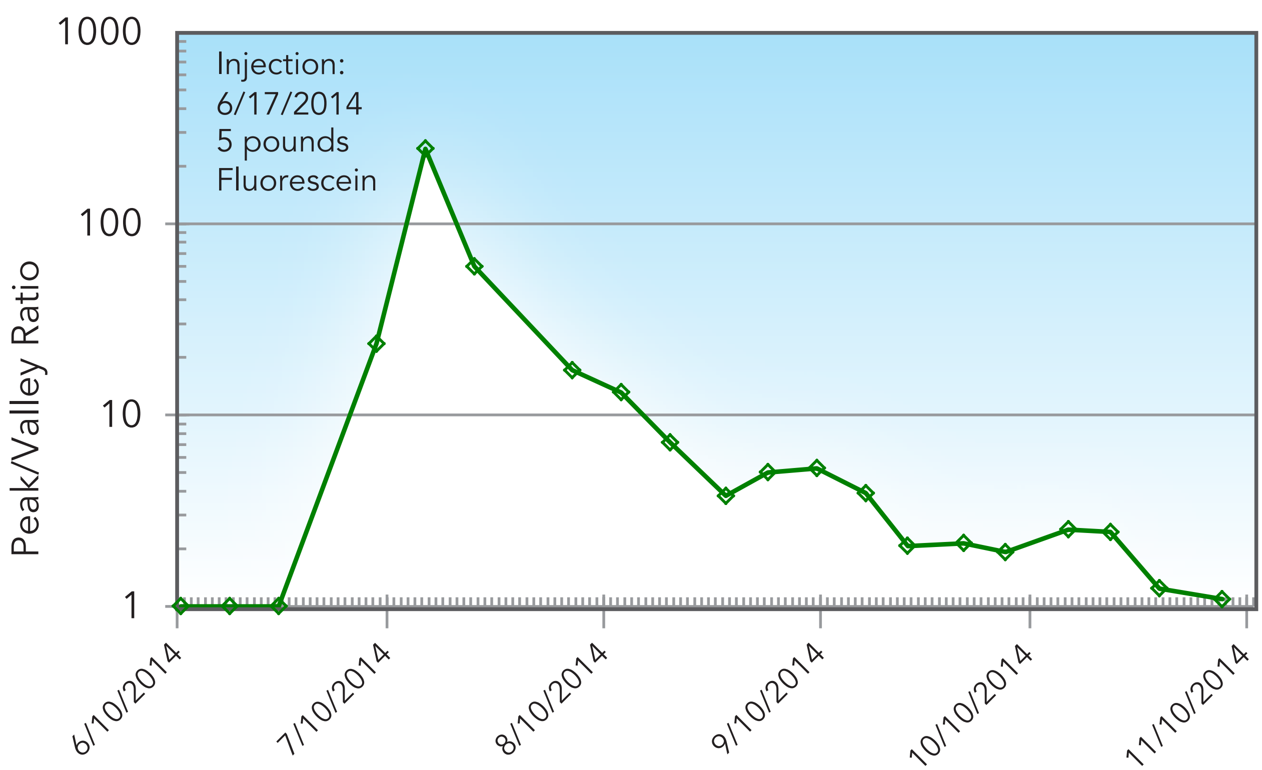


Figure 26. Dye recovery curve (carbon packet eluate) upper Tabor Creek to Blue Spring (Ozark County) trace (Oz 034).

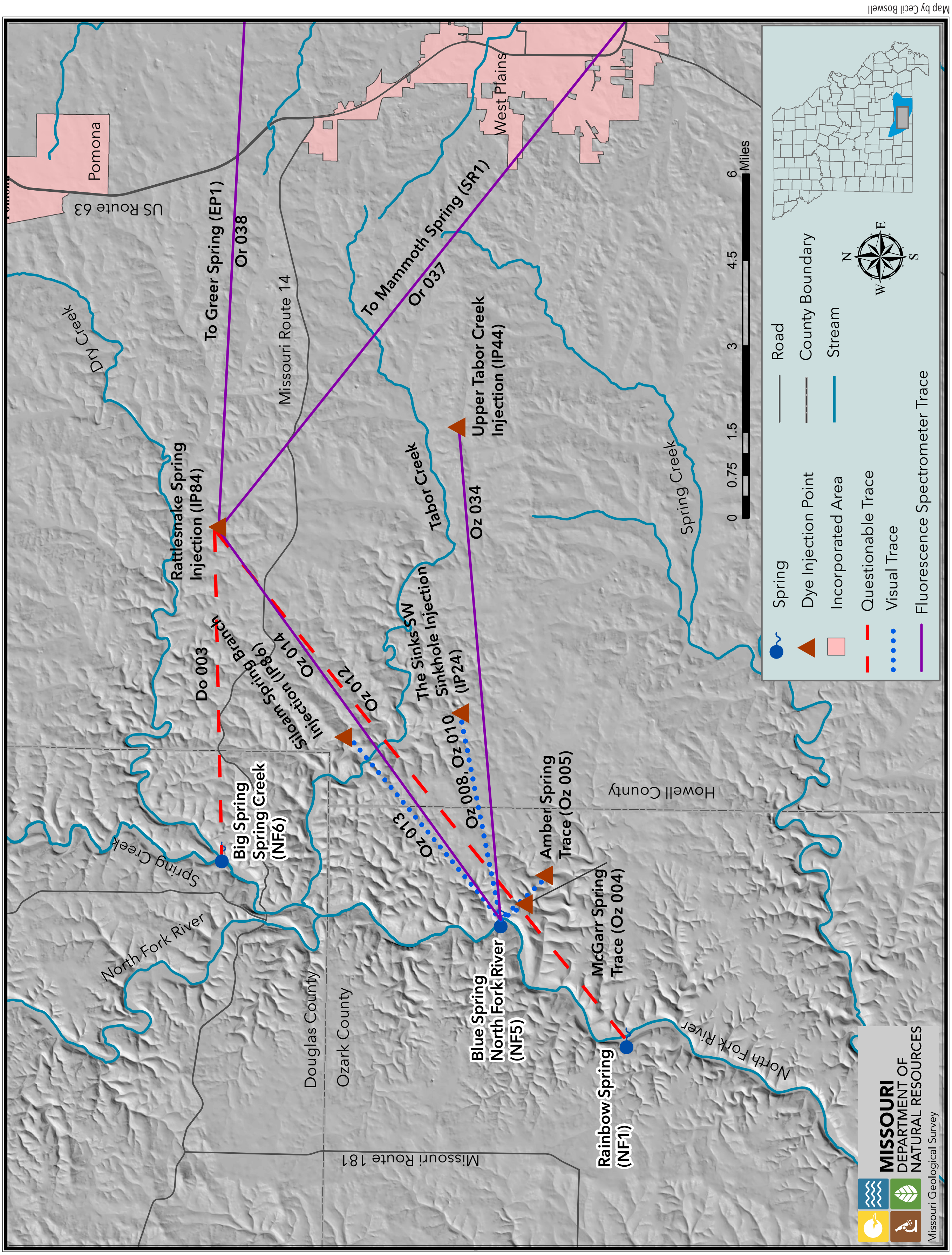


Figure 27: Current interpretation of traces in close proximity to Blue Spring in Ozark County.

Spring Group C - Mammoth Spring (Fulton County, Arkansas) and Greer Spring (Oregon County, Missouri)

Mammoth and Greer springs are the third and second largest springs in the Ozarks, respectively (Figure 28). Though they are located about 22 miles apart, the current study shows they share recharge southeast of Greer Spring and north of Mammoth Spring.

Mammoth Spring is the third largest spring in the Ozarks (U.S. Geological Survey, 2016).

In the 1890s the pioneering speleologist Luella Agnes Owen visited Thayer, Missouri, by train while on her way to visit Grand Gulf and Greer Spring. Her description (Owen, 1898) of the collapsed cave system and associated features that she investigated at Grand Gulf (now a Missouri State Park) has fascinated cave enthusiasts

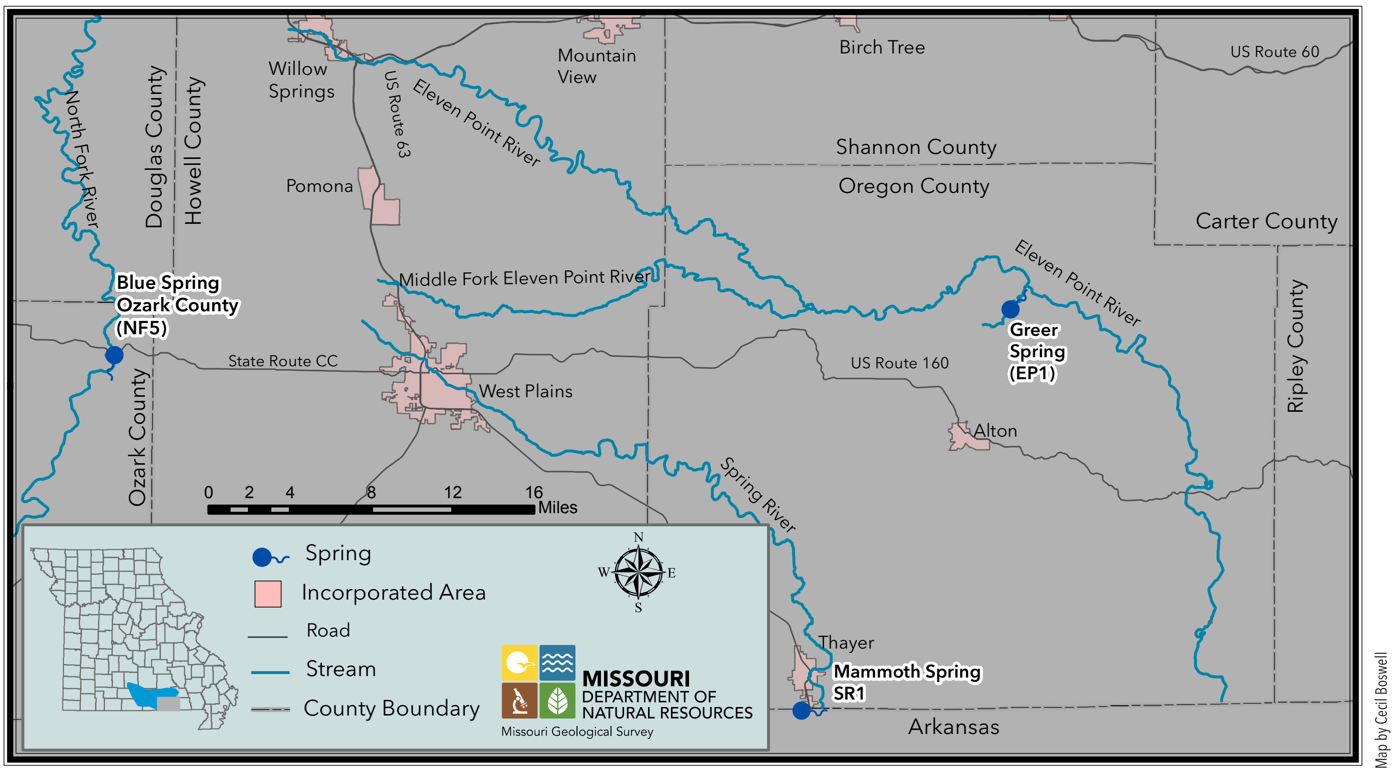


Figure 28. Spring Group C region.

Mammoth Spring Description

Mammoth Spring issues from a single steeply inclined conduit into an artificial reservoir several hundred feet south of the Missouri state line (Figure 29). It is the major feature of Mammoth Spring State Park in Arkansas and is the largest spring in that state. For many years it was considered to be the second largest spring in the Ozarks, having been gaged continuously since 1981 with a mean discharge of approximately 351 ft^3/s over that period. However, a comparison with Greer Spring (water years 1982 to 2015) suggests that Greer Spring is larger (see discussion below). Continuous gaging at Greer Spring and Big Spring (Carter County) in Missouri collected over the same time period shows that

ever since (Figure 30). She described a cave passage that leads to an underground stream populated by abundant numbers of blind cave fish. She reportedly traversed a part of the cave stream in a small boat found in the passage tethered only with "twine" to her companions who were waiting upstream in the cave passage. This passage is no longer accessible from the surface, having been obstructed by sediment and wood debris washed into the cave by flood events in the early 1900s (Vineyard and Feder, 1974). The only spring nearby likely to discharge the large amount of flow described by Owen (1898) is Mammoth Spring. It has long been assumed that the cave stream still exists behind accumulations of sediment and debris.

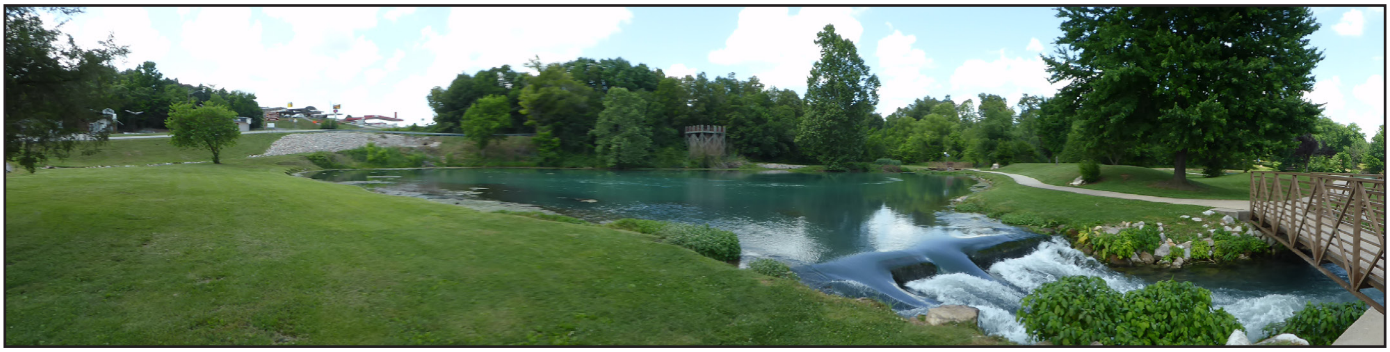


Photo by Bill Duley.

Figure 29. Panoramic view of Mammoth Spring in Mammoth Spring State Park, Arkansas.

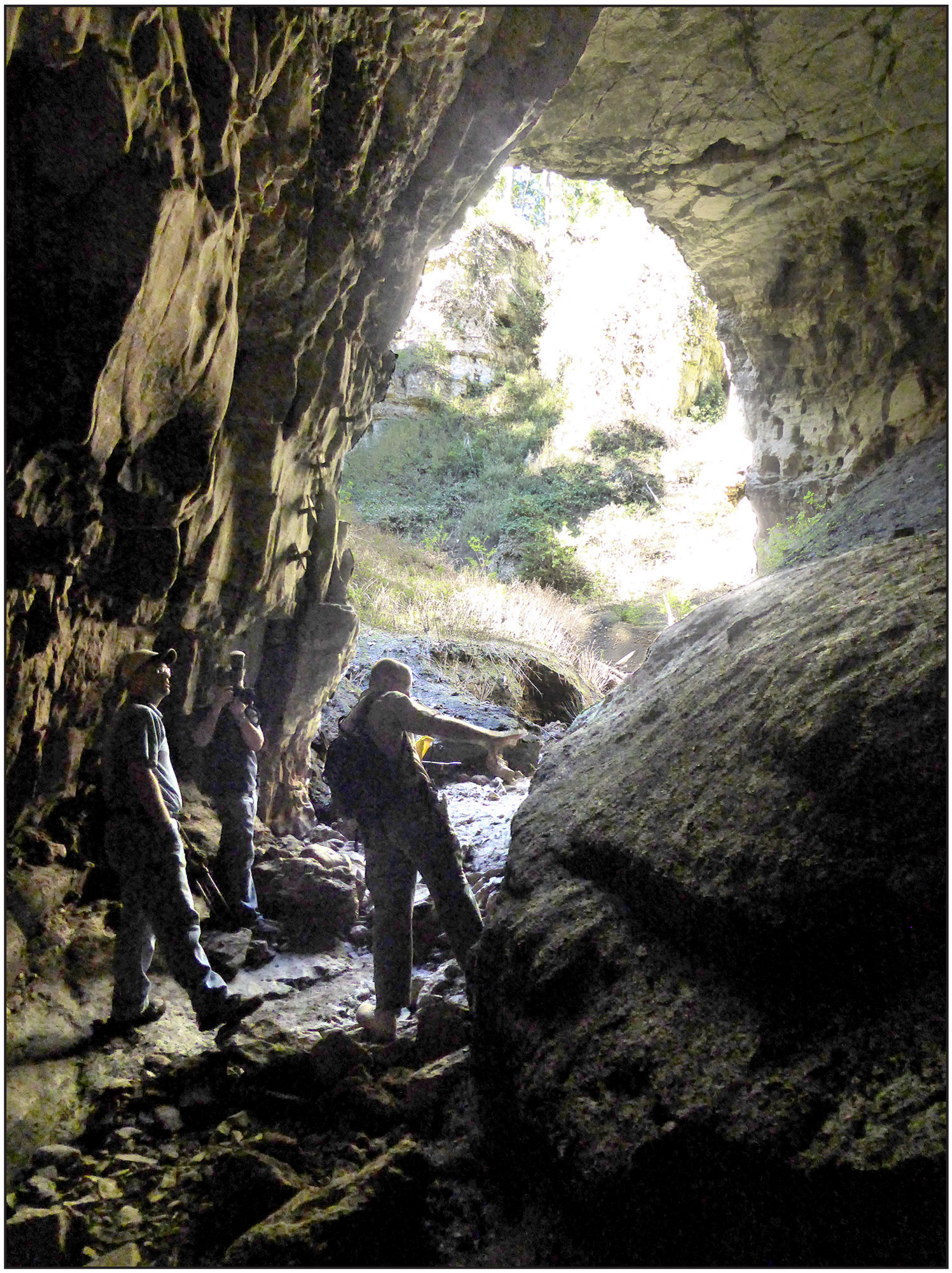


Photo by Bill Duley.

Figure 30. Grand Gulf Cave looking upstream into Grand Gulf Sinkhole.

Photo by Bill Duley/Panorama by Mark Gordon.

Figure 31. Upper Greer Spring.

Greer Spring Description

Greer Spring has two outlets: an upper cave spring (Figure 31) and the main outlet – a lower boil (Figure 32) located about 100 yards downstream. Both outlets are in the Gasconade Dolomite. The upper outlet issues from a cave that is located near the contact between the upper and lower Gasconade, while the lower boil issues from the lower Gasconade Dolomite. Doll (1938) and Jim Vandike (retired MGS, personal correspondence 2016) both report that the cave entrance has been dry during their visits. While there have been no flow measurements recorded for the upper orifice, numerous visual estimates by the authors suggest that normal flow is about 20 to 30 percent of the combined flow of upper and lower outlets.

The combined flow of both outlets has been gaged continuously by the USGS since 1921 at a mean discharge of approximately 349 ft^3/s. In the past it was considered to be the second largest spring in Missouri and the third largest in the Ozarks. Long term gaging for the water years 1982 to 2015 (beginning after a continuous gage was first installed at Mammoth Spring) indicates that Greer Spring has consistently outpaced Arkansas' largest spring with a daily average

Photo by Bill Duley/Panorama by Mark Gorodn.

Figure 32. Panoramic view of lower Greer Spring boil in winter.

flow of approximately 369 ft^3/s as compared to 351 ft^3/s for Mammoth Spring (U.S Geological Survey, 2016). Abnormally high precipitation during this study routinely caused Greer Spring to discharge more water than Mammoth Spring. After some precipitation events, flow at Greer Spring exceeds the flow at both Mammoth Spring and Big Spring (Carter County). Big Spring is characterized by large spikes in flow followed by rapid flow reductions as the flood event subsides. Mammoth and Greer both respond to precipitation and runoff events with a gentler slope on the hydrograph following peak discharge. USGS (2016) continuous monitoring of discharge shows that the time between peak precipitation and peak discharge is similar for Greer, Mammoth and Big springs. Peak discharge normally occurs on the same day for all three.

Water from Greer Spring has been utilized as a power source for wool carding, sawmills, grist mills and flour production. Captain Samuel Greer, who fought for the Confederacy, did not build the original mill located on the spring branch but did own and operate it for a short period (Figures 33-36). Captain Greer reportedly trained oxen to pull a driverless wagon loaded with grain to the mill in the valley and then return the milled product to the top of the ridge (Vineyard and Feder, 1974).

In the 1880s, he built a new mill at the top of the ridge above the spring which was reportedly powered by a series of cables and pulleys that were extended to the ridgetop from the valley below (Morman, 1972). This mill (Figure 37) remains today though it has not been used since the early 1900s. It is under the protection of the USFS. Currently, the spring is in USFS possession where it is maintained in a relatively primitive state, flowing unrestrained for a distance of just over a mile to the Eleven Point River.

The later mill and affiliated dam were associated with a sad historical event related by Morman (1972, pp 614-615).

"A tragedy occurred at the site on March 3. 1884. While working on the dam, Lewis Greer, the twenty-three-year-old son of Captain Greer, was hit by a falling timber and fell into the rocks and swift water below the dam. He was killed instantly. All work on the mill and dam was stopped for about a month. Captain Greer blamed himself for what had happened. Lewis had married Lydia Herrod a short time before this accident. They had planned to leave for Oregon on the Sunday just prior to the accident, however, Captain Greer had talked them into staying with him for awhile, so that Lewis could help with construction of the dam and mill. Lydia was grief-stricken over the loss of her husband and never again went down to the spring. She would often sit at a window in the Greer home listening to the faint roar of the boil-up and cold spring water racing through the large boulders in the ravine."

Figure 33. Upper Greer Spring circa 1870s. Photo courtesy of the Missouri Historical Society.

Figure 34. The old mill circa 1870s. Photo courtesy of the Missouri Historical Society.

Figure 35. The old mill dam at Greer Spring circa 1870s with the lower Greer Spring boil covered by the mill pond. Photo courtesy of Missouri Historical Society.

Figure 36. Above is the old mill and dam at Greer Spring looking downstream circa 1870s. Photo courtesy of the Missouri Historical Society

Figure 37. The "new" Greer Mill built in the early 1880s on the ridgetop currently in restoration phase.

Photo by Bill Duley.

Legacy Traces to Mammoth Spring (Or 024, Or 001, Or 013, Or 012 and Or 007)

A number of legacy traces have been reported to Mammoth Spring (Figure 38). Dean (1978) of MGS injected fluorescein into a sinkhole collapse that developed in the bottom of the West Plains Sewage Lagoon (IP26). While it is likely that this connection (Or 024) is valid, the current study brings data to light that suggests that dye from two separate traces conducted during the same time frame probably overlapped.

The fluorescein injection (Or 024) by Dean on May 18, 1978, apparently overlapped a fluorescein injection by Vandike into Rattlesnake Spring Branch (IP25) on May 7, 1978 (Do 003 and Oz 012). Dean reported his first dye recovery between May 26 and May 30, 1978. At the time, Rattlesnake Spring was thought to recharge groundwater west of the injection in the North Fork watershed. Traces conducted during the current study indicate that this assumption was likely incorrect. The timing of the recovery at Mammoth Spring probably reflects dye from both investigators.

The first documented trace to Mammoth Spring using fluorescent dye was completed by Tony Aide, who was a high school student at the time. He conducted a trace (Or 001) from Grand Gulf (IP1), a large and deep sinkhole complex in Missouri to Mammoth Spring as a science project in conjunction with staff of the Missouri Geological Survey (Aide, 1968). He injected dye into a stream that was flowing into the cave at Grand Gulf. While the larger portion of the cave stream was blocked to human access, the dye was able to pass through small openings into the aquifer.

Both the Dean and Aide traces utilized carbon packets which were eluted in 5 percent potassium hydroxide in ethyl alcohol and analyzed visually. Aide was apparently unable to determine to a degree of certainty if dye was present; consequently the samples were sent to the Missouri Geological Survey where they were analyzed by filter fluorometer. No recent investigator has seriously questioned that Grand Gulf is in the recharge area of Mammoth Spring. However it has long been suggested that analysis of fluorescein in eluate by a filter fluorometer is susceptible to large background fluctuations that may be indiscernible from small amounts of the dye used in this instance.

Trace Or 013, was conducted by staff of the USFS (Aley, 1975) from the upper reaches of Dry Creek (IP17) in the North Fork Basin to Mammoth Spring. The validity of this trace has been questioned due to 1) conflicting potentiometric data, 2) reported recovery of dye in a single sample interval and 3) timing of the injection, which closely followed another fluorescein injection reportedly recovered at Mammoth Spring.

Aley (1975) reported two other traces to Mammoth Spring: one (Or 012) from a sinkhole north of West Plains (IP15) and a second (Or 007) from a losing stream in the Eleven Point watershed near Granny Meyers Spring (IP7). Both traces were considered for replication because of their location near the edge of the supposed recharge area of Mammoth Spring.

Legacy Traces to Greer Spring(Or 022, Or 014, Or 040, Or 041, Or 046 and Or 010)

Six legacy traces to Greer Spring have been reported. USFS traces have indicated that the recharge area extends to the northwest and south of Greer Spring (Figure 38). It has long been speculated that the two traces (Or 022 and Or 014) from the Willow Springs discharge (IP22) and from an area to the east at Nuttle Spring Branch (Or 014 from IP19) occurred through southerly flow west of the gaining segment of the Eleven Point River near Thomasville and thence east to Greer Spring (Tryon, 1975B; Aley, 1975; Miller and Vandike, 1997). However, more recent traces (Or 040, Or 041 and Or 046) conducted by the USGS suggest that there is a direct connection from Spring Creek (IP39 and IP38) several miles northwest of the Eleven Point as well as from Sims Creek at US Route 60 (IP40) to Greer Spring. A fluorescence spectrometer was used to detect dye for these three USGS traces.

The sixth trace, Or 010, from Simpson Pond (IP14) south of Greer has come into question due to the subjective detection methodology used and because the best available potentiometric map does not indicate a northerly groundwater flow direction. Evidence that came to light during this study raised additional questions about the Simpson Pond Trace (see below).

Contemporary Traces Completed to Spring Group C

A number of traces were conducted as part of this study that either added new information about the recharge areas of Mammoth and Greer springs or that confirmed earlier information. While some replication attempts confirmed earlier traces, others changed interpretations in significant ways.

Map by Cecil Boswell

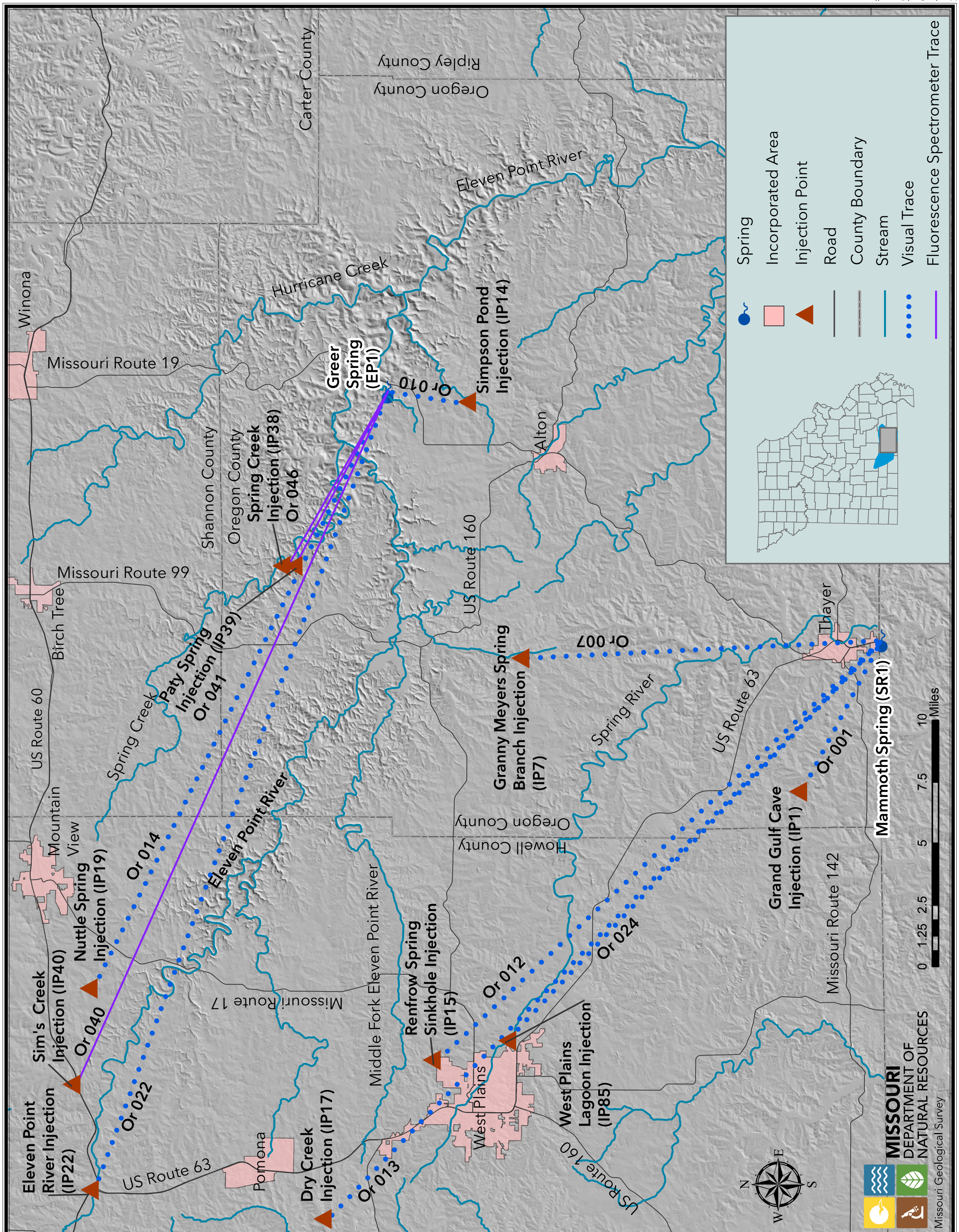


Figure 38. Legacy traces to Mammoth and Greer springs.

Grand Gulf Replication Injection (Trace Or 029)

At 10:50 a.m. on Oct. 9, 2013, 3 gallons of Rhodamine WT™ were injected into a pool known as "the sump" in Grand Gulf Cave which is located at the bottom of Grand Gulf (Figure 39 -IP1). Fluorometric measurements of water at Mammoth Spring, recorded every fifteen minutes, first showed the presence of the dye at about 4 p.m. on Oct. 13, 2013 (Figure 40). The straight line velocity for the first recovery of dye was about 355 ft/hr. Carbon packets confirmed the presence of dye, with the first packets to recover dye in place from Oct. 9 to Oct 16. At its highest, the PVR of eluate from the carbon packets was well over 15, indicating a large amount of dye was present (Figure 41). However, the maximum amount of dye indicated by the fluorometer was only about 1.5 parts per billion (ppb) Rhodamine WT™. Since Rhodamine WT™ is sold as a 20 percent solution, the actual amount of dye in Mammoth Spring peaked at about 7.5 ppb at about 5 a.m. on Oct. 17, 2013. Straight line velocity of the dye peak was approximately 193 ft/hr. Straight line distance for this trace is about 6.8 miles. The velocities calculated analyzing carbon packet eluate using the PVR method yielded similar results with a first recovery in the first seven days after injection with a calculated velocity greater than 210 ft/hr. Peak recovery in packet eluate occurred seven to 13 days after injection with the calculated peak velocity between 115 and 210 ft/hr.


Photo by Bill Duley.

Figure 39. Grand Gulf and Grand Gulf Cave from the overlook.

Use of a fluorometer in large groundwater systems such as Mammoth Spring can yield potential errors. Large increases in turbidity cannot be distinguished from small dye pulses unless a separate recording turbidity meter is used or other corroborative samples collected.

Fluorometers are most effective in conducting time-of-travel determinations in smaller groundwater systems or surface waters wherein dye concentrations can be adjusted to meet the needs of the study. They have limitations in reconnaissance work due to cost and relatively high detection limits as compared to carbon packets. The number of points to be monitored in reconnaissance tracing often makes the cost excessive.

There were no significant differences between this replication and the original trace resurgence point or time of travel reported by Aide (1968). While the original injection had more favorable hydrologic conditions, with significant water flushing into the system, the replication employed more dye and greatly improved detection methodologies.

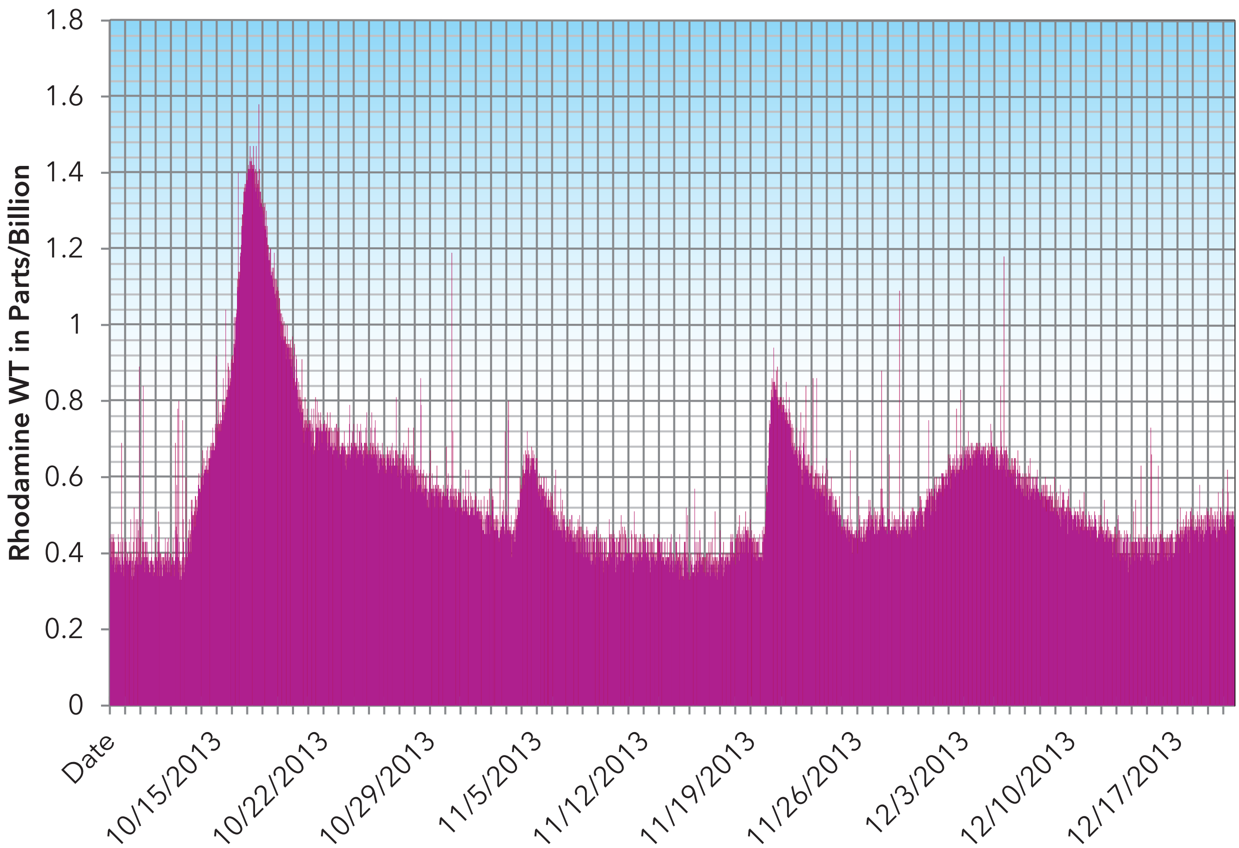


Figure 40. Grand Gulf trace (Or 029) fluorometer readings (15 minute interval) of water at Mammoth Spring.

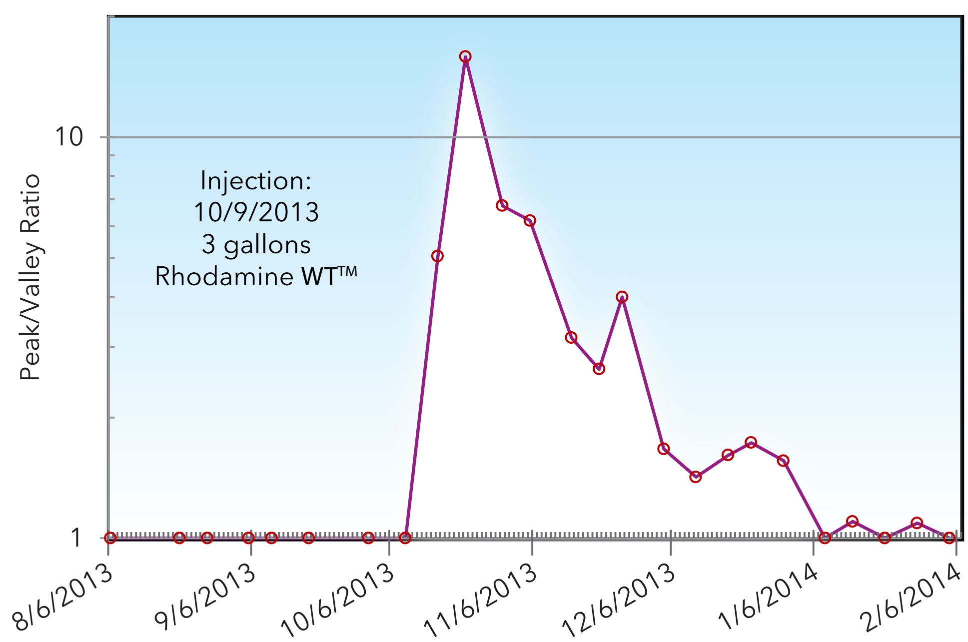


Figure 41. Dye recovery curve (carbon packet eluate) Grand Gulf to Mammoth Spring trace (Or 029).

Mustion Creek Injection (Trace Or 035)

A new injection into an upper reach of Mustion Creek (IP43) was conducted to help determine the western extent of the recharge area of Mammoth Spring. The uppermost reach of this particular branch of Mustion Creek is gaining with about 10 gpm flowing into a small series of pools where all surface flow is lost (Figure 42). Ten pounds of fluorescein were injected just upstream of these pools at 1:00 p.m. on Feb. 14, 2014. No flow was observed in Mustion Creek for more than five miles downstream during the study.


Photo by Bill Duley.

Figure 42. Mustion Creek injection.

A large amount of fluorescein was first recovered from Mammoth Spring in packets in place from Feb. 25 to Mar. 6, 2014 (Figure 43). Peak recovery was detected in packets in place from Mar. 6 through Mar. 11, 2014, 11 to 20 days after injection. Fluorescein levels were well above background from first recovery until packet removal on May 13, 2014. The straight line distance from injection to recovery is 25.3 miles. Points monitored with no dye recovered included Greer Spring (EP1), Althea Spring (NF3), Blue Spring (Ozark County, NF5), Big Spring (Douglas County, NF6), Rainbow Spring (NF1), Hodgson Mill Spring (BC1), and several other selected points on the North Fork River (NF15, NF26), Spring Creek (Douglas County, NF12) and Duncan Ford on Spring Creek (Ozark County, NF13).

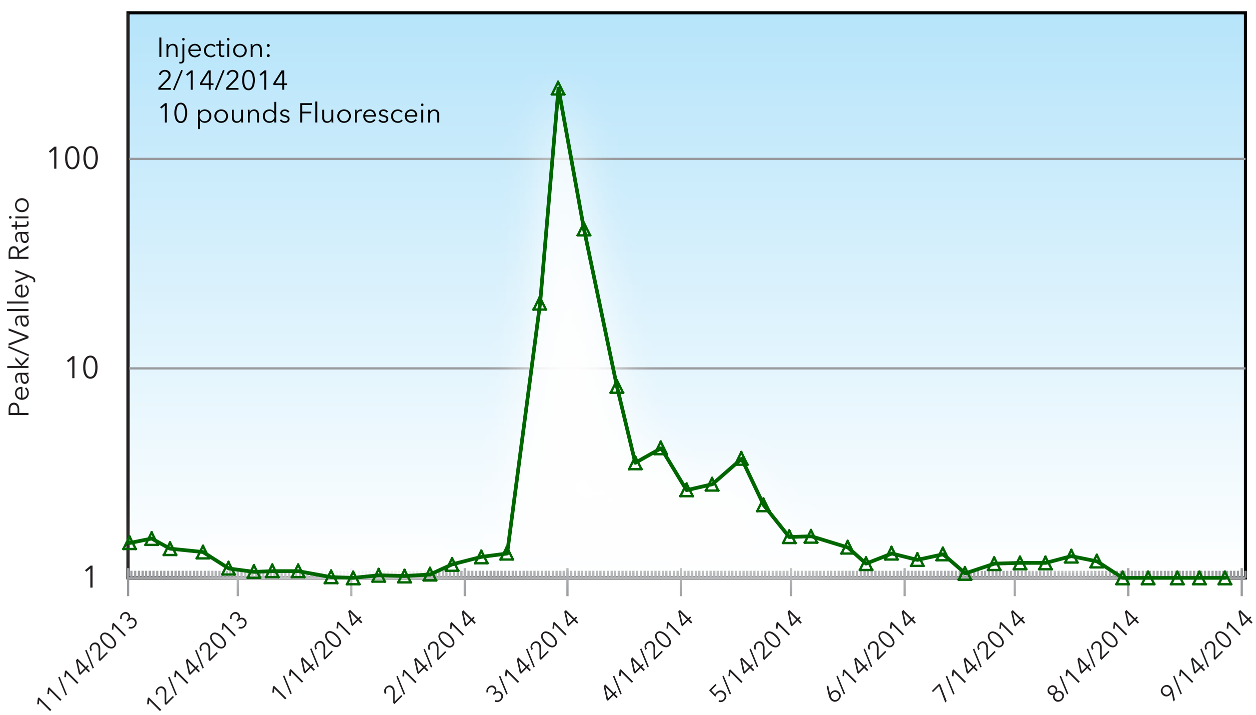


Figure 43. Dye recovery curve (carbon packet eluate) Mustion Creek to Mammoth Spring trace (Or 035).

Figure 44. Rattlesnake Spring with its characteristic "fangs."

Rattlesnake Spring Replication Injection (Traces Or 037, Or 038, and Oz 014)

Rattlesnake Spring is a small spring (IP84) at an altitude of about 990 feet with a normal flow of about 15 gpm (Figure 44). During dry periods all flow is lost from the spring branch within 300 yards downstream. This branch was used as a fluorescein injection site on May 7, 1978. Vandike (1979) reported dye recovery at two locations, Big Spring (Douglas County, NF6) and Rainbow Spring (NF1). Via personal communication, Vandike (retired MGS, 2014) expressed reservations about visual methodologies in general of legacy traces such as this one and specifically about the recovery at Rainbow Spring. He also noted that he did not monitor Mammoth Spring or Greer Spring during the original trace.

During this study, nine pounds of eosine were injected into Rattlesnake Spring Branch (IP84) at 9:00 a.m. Feb. 26, 2014. All flow was lost to the subsurface within about 200 feet of the injection site on that date. First recovery occurred at Mammoth Spring (SR1) and Greer Spring (lower outlet, EP1B) in packets in place from Mar. 18, to Mar. 27, 2014. The maximum concentration of dye appeared at both springs between Mar. 27 and Apr. 1, 2014 (Figure 45).

Dye was not recovered from the upper cave outlet at Greer Spring (EP1A) until the packet representing the period of Mar. 27 to Apr. 1. It is likely that the dye had just begun to issue from the lower Greer outlet earlier on Mar. 27 or late on March 26. The cave outlet for Greer Spring is approximately 10 feet higher than the main Greer outlet but it is unlikely that this difference in head and additional travel distance from the main conduit would have retarded the flow for more than twenty four hours. Time-of-travel to Greer Spring is thus estimated at about 29 days.

Time-of-travel to Mammoth Spring was between 20 and 29 days. Straight line distance from the injection to recovery at Greer Spring is 37.6 miles; to Mammoth Spring it is about 35.2 miles.

A smaller amount of eosine from the Rattlesnake Spring injection was recovered at Blue Spring (Ozark County, NF5) with first recovery between Apr. 8 and Apr. 15. Straight line distance in this case is about 8.4 miles.

Monitoring of Big Spring (Douglas County, NF6), which was presumed to be the likely recovery point never revealed any dye from this injection. Other monitored points at which no dye was recovered include: the Eleven Point watershed at several locations (EP12, EP13, and EP15), Rainbow Spring (NF1), Hodgson Mill Spring (BC1), Althea Spring (NF3) and several other surface points in the North Fork watershed (NF10, NF12, NF13, NF15 and NF22).

Water from Rattlesnake Spring has been traced to three major basins: North Fork River 8 miles to the west, Spring River 35 miles to the southeast and the Eleven Point 37 miles to the east. This is the first known trace that suggests Mammoth Spring and Greer Spring share their recharge areas. It also represents the longest trace conducted to date to either of these springs.

The recovery at Blue Spring was smaller than either Mammoth or Greer springs recoveries and the recession curve quite long (Figure 45). Some might suggest that the precipitation event of March 16, 2014, (1.48 inches as measured at Pomona) flushed eosine from the initial injection site farther downstream into a separate losing reach of the Dry Creek watershed. This could have resulted in a small amount of recharge entering a separate groundwater system. However, the persistent recovery of eosine for four months after first recovery and the later occurrence of the recovery as compared to those at Mammoth and Greer springs suggest a more complex explanation.

The largest peak recorded at Blue Spring occurred 76 to 82 days after the injection, about seven weeks after peak recoveries at both Mammoth and Greer springs. Thus dye required seven weeks longer to travel less than one fourth the distance to either of the main outlets. MGS researchers' interpretation is that dye from the injection entered a distributary system in the Ozark Aquifer characterized by slow flow migrating to the west. Additional investigations will be required to unravel the divide between these three springs.

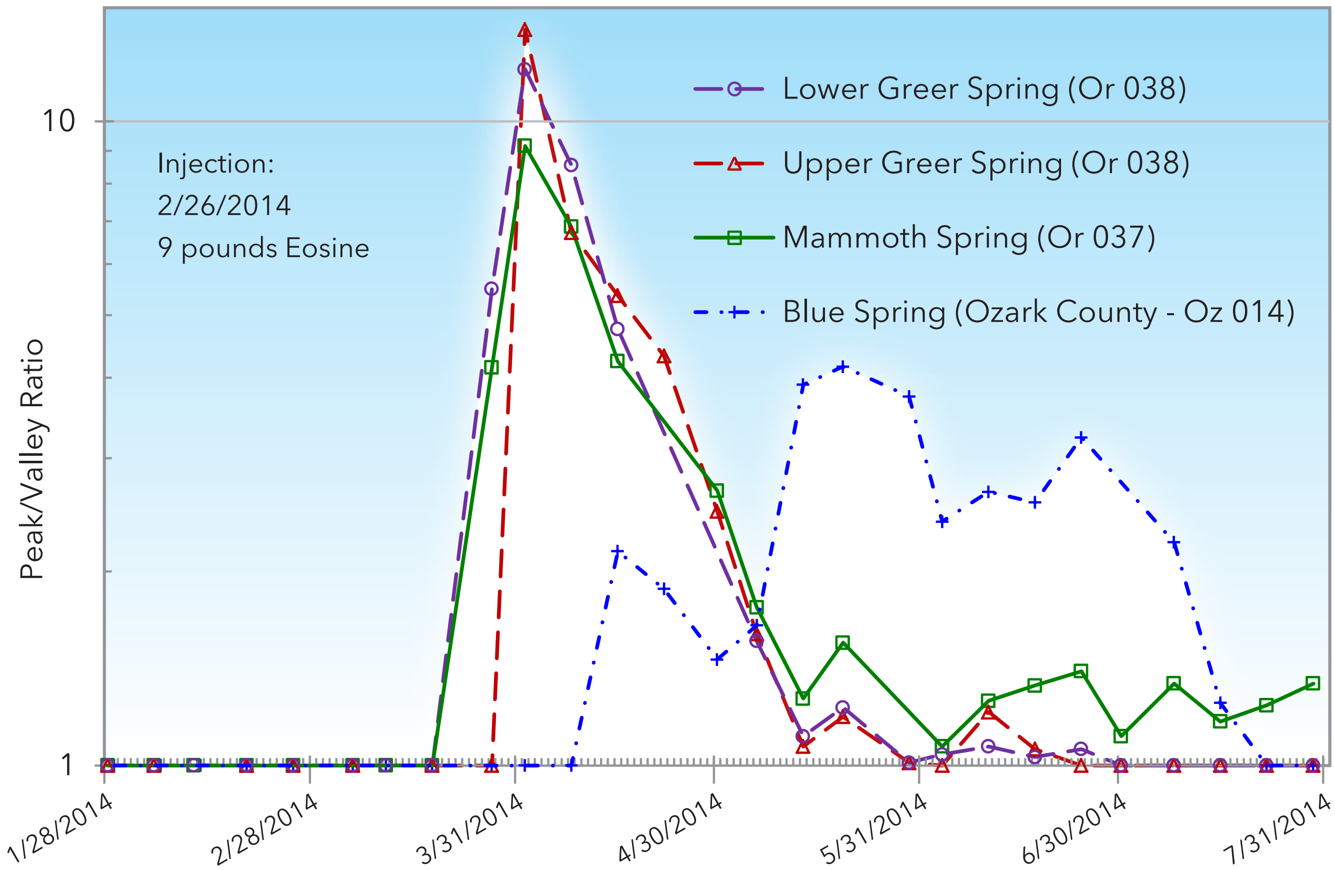


Figure 45. Dye recovery curves (carbon packet eluate) Rattlesnake Spring traces (Or 037, Or 038 and Oz 014).

Upper Dry Creek (Howell County) Injections (Traces Or 027 and Or 028)

Dry Creek is largely a losing stream from its upper to lower reaches with notable exceptions. Small springs are present locally that flow on the surface for a short distance and then sink into the bedrock - Jefferson City Dolomite in the uppermost reaches, and Roubidoux Formation throughout the lower. This injection was an attempt to replicate a legacy trace (Or 013) to Mammoth Spring (Aley, 1975).

At 1:05 p.m. on Mar. 26, 2014, three gallons of Rhodamine WT™ were injected into a flow of about 15 gpm that was lost to the subsurface in a small pool (IP17). On that date, the Aley (1975) injection point and presumed losing point appeared to be several hundred feet upstream of the current study injection, perhaps due to wetter conditions during the MGS trace or other changes that may have reduced permeability of the stream channel in the intervening decades since the earlier injection.

First recovery and maximum recovery were from April 15 to April 22, 2014, (20 to 27 days after injection) at both Greer and Mammoth springs (Figure 46). One connection of the legacy trace was confirmed but a second connection was established that essentially confirms one of the Rattlesnake Spring traces described above. Points monitored without dye recovery were: Blue Spring (Ozark County, NF5), North Fork River, upstream from Blue Spring (NF15), Althea Spring (NF3), Duncan Ford on Spring Creek (Ozark County, NF13), Spring Creek in (Douglas County, NF12) and at Blair Bridge on the North Fork (NF14).

One small peak of dye was recovered at Big Spring on Spring Creek (Douglas County, NF6). Because only one sample contained a minimal amount of dye (PVR of 1.14) shortly after a sizable Apr. 13 precipitation event of 1.55 inches as measured at Pomona, it is assumed that dye was flushed downstream into a lower losing segment of Dry Creek that recharges Big Spring. This theory is consistent with the findings of Vandike (1979) who conducted a short trace from a lower reach of Dry Creek to Big Spring. It is interesting that a similar rainfall event did not flush eosine into Big Spring from the nearby Rattlesnake Spring injection. More work is needed to

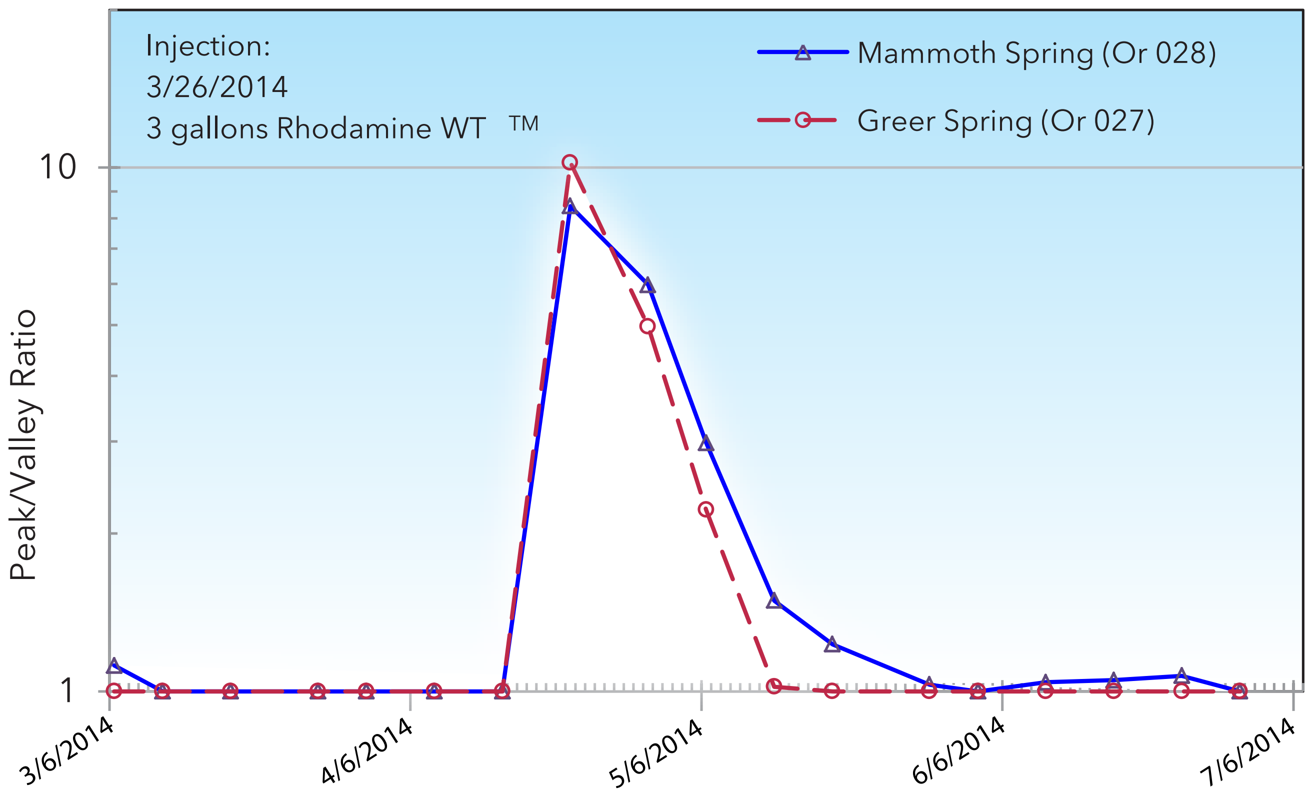


Figure 46. Dye recovery curves (carbon packet eluate) upper Dry Creek traces (Or 028 and Or 029).

determine the interrelationships of water loss in the downstream reaches of Dry Creek. Straight line distance from the injection to Mammoth Spring is 32.7 miles, and to Greer Spring is just under 34 miles.

Granny Meyers Spring Replication Injection (Trace Or 039)

As MGS staff began to evaluate the recharge area boundaries of Mammoth Spring, Greer Spring and the Blue/Morgan Complex, it quickly became obvious that one legacy trace in particular was critical in the process - Granny Meyers Spring to Mammoth Spring (Or 007).

At 3:56 p.m., on July 23, 2014, five pounds of eosine were injected into the losing stream just downstream from Granny Meyers Spring (IP7) in order to verify or improve upon the legacy trace.

Packets in place at Mammoth Spring from Aug. 5 to Aug 12, 2014 contained eosine at levels significantly above background, 13 to 20 days after dye injection. Eosine peaked in the packets in place from Aug. 12 to Aug. 19, 2014, with a maximum PVR of more than 23 (Figure 47).

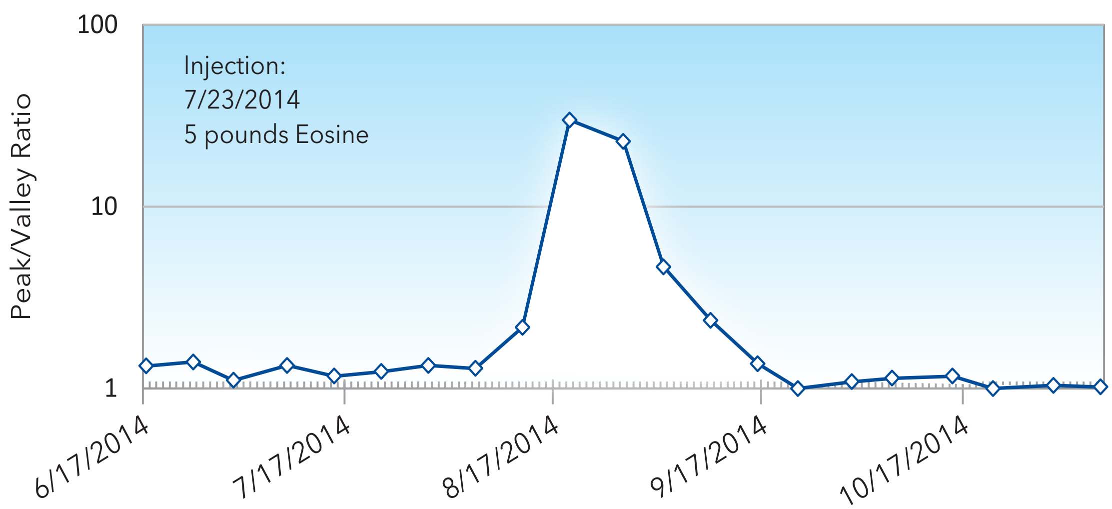


Figure 47. Dye recovery curve (carbon packet eluate) Granny Meyers Spring to Mammoth Spring trace (Or 039).

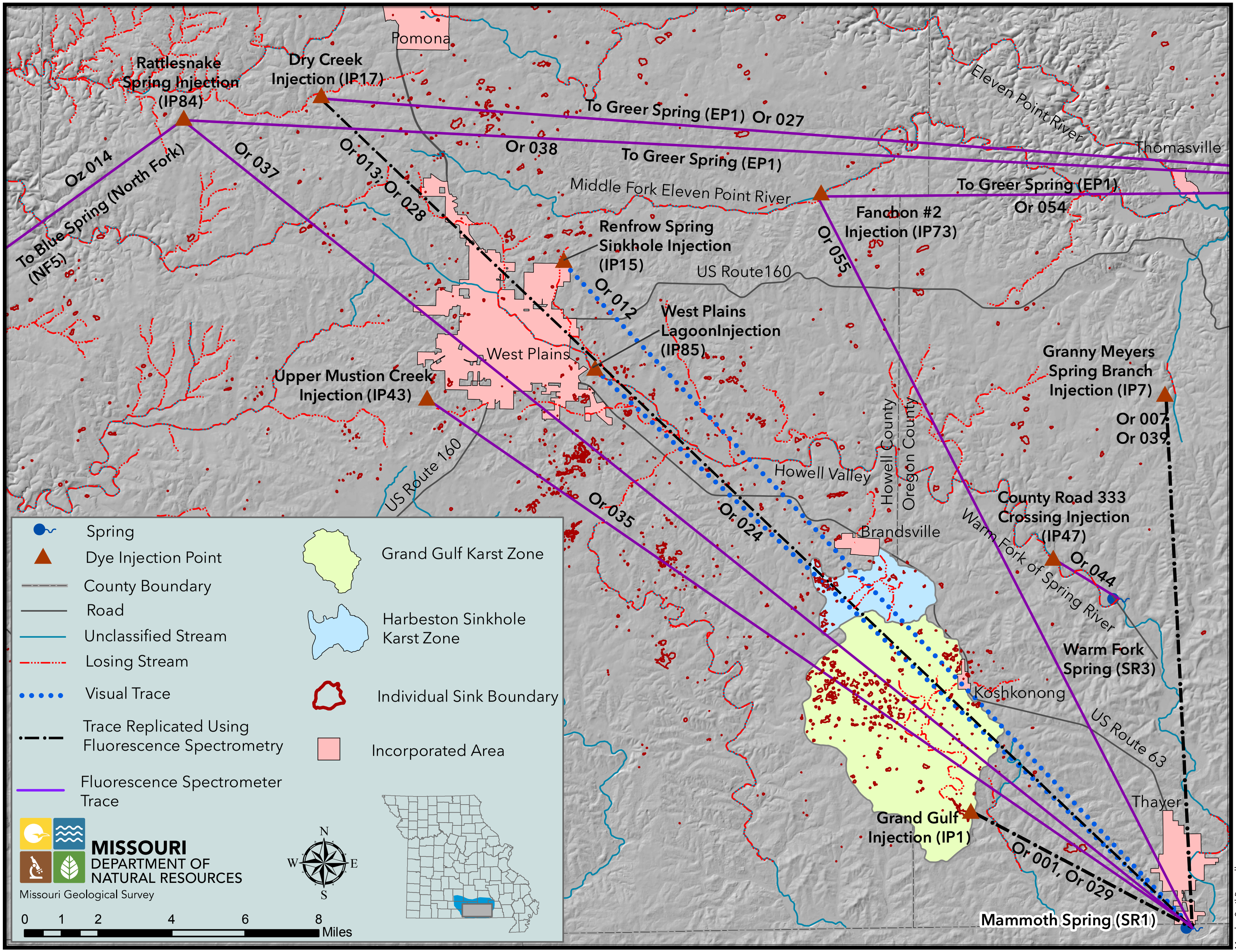


Figure 48. Current interpretation of traces in the vicinity of Mammoth Spring.

Verification of this trace raised questions about earlier assumptions. It had long been assumed that injections east of Willow Spring and Nuttle Spring Branch flowed south to a point west of Thomasville and then east to Greer Spring. There is a narrow window between the losing segment of Barren Fork downstream of Granny Meyers Spring and the gaining reach downstream that flows into the Eleven Point River.

While it is possible that a conduit or fracture zone that leads to Greer Spring could pass through this area (see Figure 48) or beneath a gaining reach, it is notable that the only trace ever reported to Greer Spring from the south side of the Eleven Point River is from the upland area just south of the town of Greer. That trace (Or 010) from Simpson pond (IP14), was completed in 1972 using visual methods and was reported as the "first successful subsurface water trace to Greer Spring in a series of attempts" (Fletcher, 1972D, p.2), implying other attempts to find the recharge area of Greer Spring were ongoing at that time. It is possible that the Or 010 recovery was from an earlier unrecorded injection.

Lost Hill Injection (Trace Or 042)

Much of the upper Eleven Point River in Howell County loses water to the subsurface. One of the uppermost water loss reaches is just downstream of Willow Springs. This water, in the vicinity of US Route 63 (IP22) has been traced (Or 022) to Greer Spring (Tryon, 1975C). Other reaches of the Eleven Point lose flow as well. One water loss reach is downstream of Missouri Route W in Oregon County. MGS staff used this losing reach as an injection point to determine whether this reach is consistent with the upstream water loss in resurging at Greer Spring or at other points.

Five pounds of eosine were injected into the losing reach of the Eleven Point River channel about three miles downstream of Missouri Route W (IP46). The injection was conducted by MGS staff at 5:00 p.m. on Oct. 28, 2014, into a moderate sized pool about 150 feet long by 10 feet wide and two to three feet deep. Flow into the pool on the date of injection was estimated at 50 gpm with no significant surface flow occurring downstream for at least a mile. When the injection site was revisited on Nov. 4, 2015, this pool was completely dry and the water loss point had migrated upstream about 100 yards (Figure 49).

The first recovery of dye was at Greer Spring (both outlets-EP1A and EP1B) between Nov. 3 and Nov. 13, 2014, six to 16 days after the injection; this was also the peak recovery (Figure 50). A second but less intense peak occurred approximately five weeks later apparently in response to two pulses of surface flow through the injection

Photo by Bill Duley.

Figure 49. Eleven Point River at Lost Hill injection pool one week after the injection.

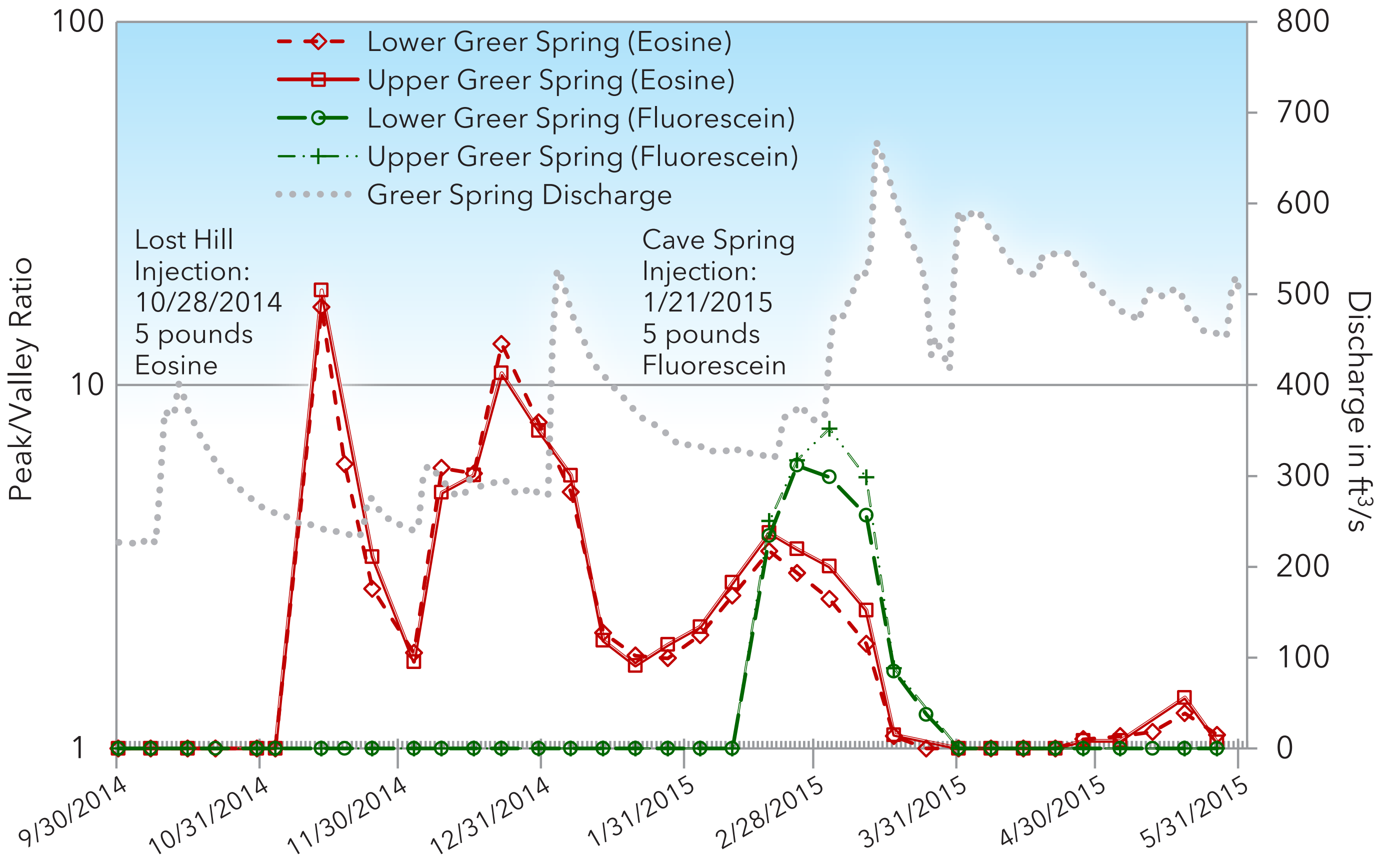


Figure 50. Dye recovery curves (carbon packet eluate) at upper and lower Greer springs during the Lost Hill and Cave Spring traces (Or 042 and Or 045).

pool in early December. A third, still smaller, pulse was observed to peak between Feb. 10 and Feb. 18, 2015. The third pulse may be the result of a large runoff event (documented by the continuous gage at Greer Spring) that temporarily diluted dye from the second pulse. This may have been caused by preferential flow with increased head in one part of the system retarding flow through the Lost Hill part of the system. A small fourth peak was also observed beginning about six months after the injection. This clear documentation of multiple peaks from a single injection, strung out over a long period of time raises concerns about many legacy traces. In the past, dye was often injected within one or two months of previous injections in areas where overlap could occur. Dye was not recovered downstream in the Eleven Point River at Bill Mac Spring (EP6) or at any other points monitored downstream in the main channel throughout this study (EP12, EP42, EP46 and EP60), nor was dye recovered at Big Spring (Carter County, CR1). Straight line distance of the trace is over 16 miles.

Cave Spring on Spring Creek Injection (Trace Or 045)

At 10:25 a.m. on Jan. 21, 2015, five pounds of fluorescein powder were injected into the bed of Spring Creek (Shannon County) immediately downstream of Cave Spring (IP49). On this date flow of about five gpm entered some small pools containing less than 1,000 gallons of water before flowing into the subsurface. First recovery of fluorescein was at Greer Spring (EP1) about 11 miles to the southeast in packets that were in place Feb. 10 to Feb. 18, 2015, 20 to 28 days after the injection. Peak recoveries occurred between Feb. 18 and Feb. 24 at the Greer lower outlet with the peak occurring between Feb. 24 and March 3, 2015 at the upper (cave) outlet. Recovery curve data (Figure 50) suggest that the dye peak likely occurred about Feb. 24 at the lower boil and about Feb. 25 at the cave outlet.

Kenaga Hollow Injection (Trace Or 047)

Much of the work done by MGS staff during this study was intended to better delineate the eastern boundary of the Greer Spring recharge area. Previous USGS traces that were unpublished or not widely distributed indicate that the boundary is farther east than previously thought. While there is solid evidence that much of Mountain View, which drains to Jam-Up Creek, is in the recharge area of Big Spring (Carter County), new evidence has shown that Mountain View is near the groundwater divide.

USGS traces from lower Spring Creek (Or 046) and Sims Creek (Or 040) to Greer Spring clearly demonstrate that Greer is receiving most of the water loss that occurs in areas between the east side of Willow Spring to the areas west of Mountain View. The MGS Kenaga Hollow Trace further demonstrated this fact.

At 11:19 a.m. on May 18, 2015, MGS staff injected 2 gallons of Rhodamine WT™ into a trickle flow of about 5 gpm in the upper reaches of Kenaga Hollow (IP65). There was no observable flow downstream at the Howell County Road 3370 crossing and no evidence of recent runoff despite the fact that the dye was injected during a relatively wet period. The dye was first recovered at both upper and lower Greer outlets eight to 15 days after the injection in packets that had been in place from May 26 to June 2, 2015 (Figure 51). Peak recovery occurred between June 2 and June 9, 2015. Dye was not recovered at other monitored locations, including Big Spring (CR1). Thus the recharge area of Greer Spring extends at least within two miles of Mountain View and may include part of the city. Straight line distance of the trace is just over 24 miles.

Dean Davis Conservation Area Injection (Trace Or 048)

Dean Davis Conservation Area (CA) is located just north of Pomona. It was originally intended to be a large lake. A dam constructed in 1956 and 1957 would have been suitable for an 85 acre lake if the site had successfully impounded water (Reitz, 1960). A large runoff event in early 1957 began to fill the impoundment but a sinkhole developed in the lake bottom about 400 feet from the spillway catastrophically draining the facility. According to Reitz (1960, p.1), water impoundment after the sinkhole collapse and subsequent repair “seldom exceeded 10 acres” with leakage causing about an inch per day loss in water levels after precipitation events.

MGS staff injected 10 pounds of fluorescein into a losing stream in the upper end of the intended reservoir (IP66)

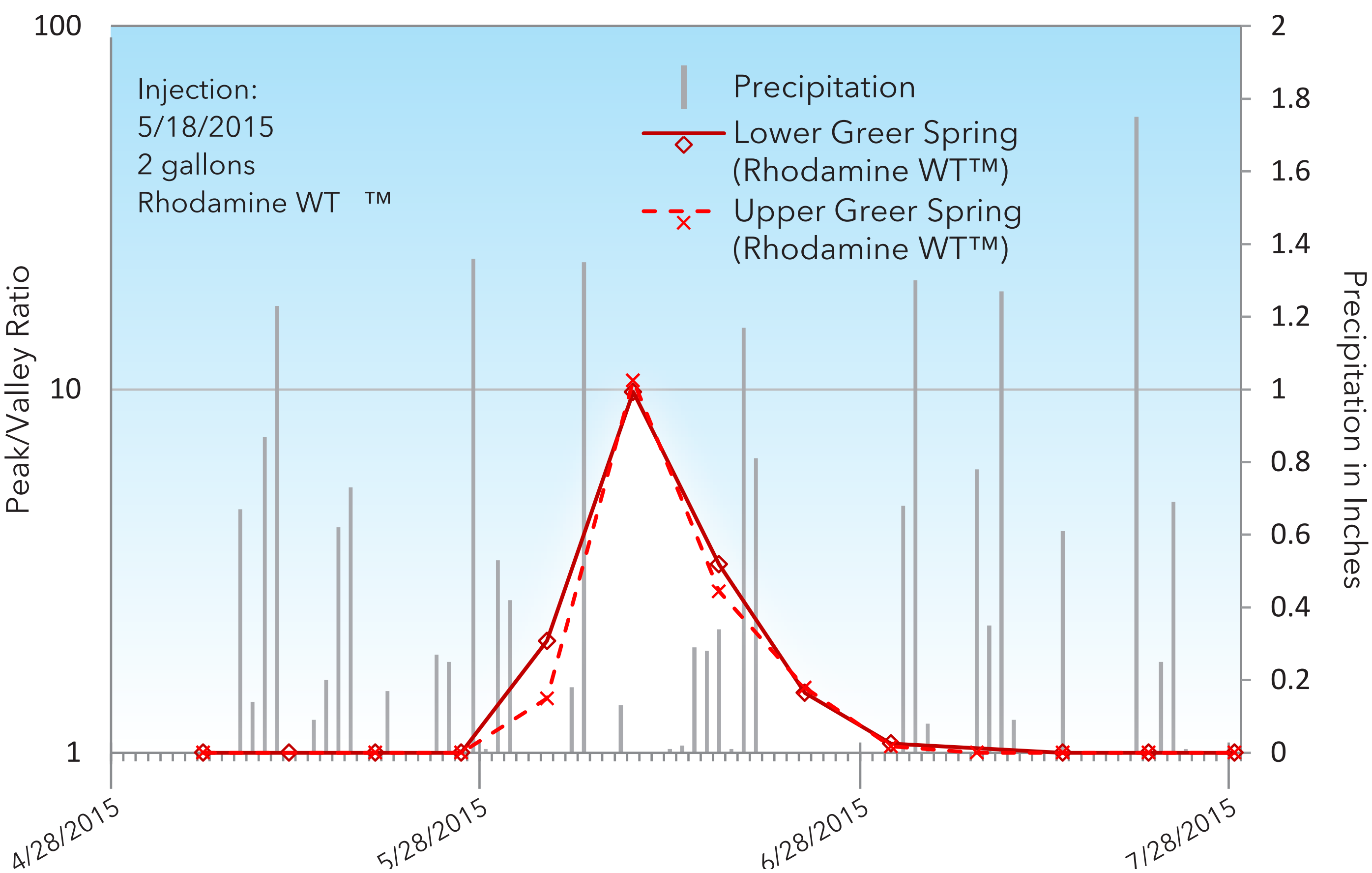


Figure 51. Dye recovery curves (carbon packet eluate) Kenaga Hollow trace (Or 047) and daily precipitation at Pomona.

at 12:12 p.m. on June 18, 2015. Flow on this date was about 3 gpm at the injection site with all flow lost to the subsurface in a distance of 50 feet downstream of the injection. Including the injection date, 2.12 inches of precipitation was recorded at Pomona during the week preceding the injection and another 0.81 inch followed in the next 24 hours. Locations monitored included Bill Mac Spring (EP6), the Eleven Point River at three locations (EP12, EP42 and EP43), Middle Fork of the Eleven Point River at two locations (EP14 and EP48), Mammoth Spring (SR1), Hodgson Mill Spring (BC1), Rainbow Spring (NF1) and four other locations on the North Fork: Big Spring (Douglas County, NF6), Blue Spring (Ozark County, NF5) and two other North Fork mainstem sites (NF15 and NF22).

Fluorescein was only recovered at Greer Spring (both upper and lower outlets) nearly 32.5 miles to the southeast of the injection. The first slight increase in fluorescein occurred between June 23 and June 30 but the first significant increase over background levels occurred in the packet representing June 30 to Jul. 7 (12 to 19 days after injection) at the upper Greer Spring location (Figure 52). Unfortunately, the lower Greer Spring packet was missing at that collection. Peak dye recovery likely occurred between July 7 and July 14 at both upper and lower Greer Spring. A second dye peak occurred between Sept. 22 and Sept. 29 and could be a second recovery from Dean Davis CA, but precipitation data suggests that is not the case. The secondary peak likely represents a short term recovery from an injection in the Middle Fork of the Eleven Point River that occurred immediately prior. The main recovery point for that injection was Bill Mac Spring. However, the Eleven Point River loses flow within a mile downstream of Bill Mac Spring and it is possible that dye issuing from Bill Mac Spring could have flowed underground to resurface at Greer Spring. Additional work is needed to clarify this issue. It is the authors' conclusion that the Eleven Point River downstream of Bill Mac Spring is also supplying recharge to Greer Spring (see Or 060); this should be verified during a low flow period with a dye injection in the losing reach (see discussion below).

All known traces to Greer Spring are shown in Figure 53.

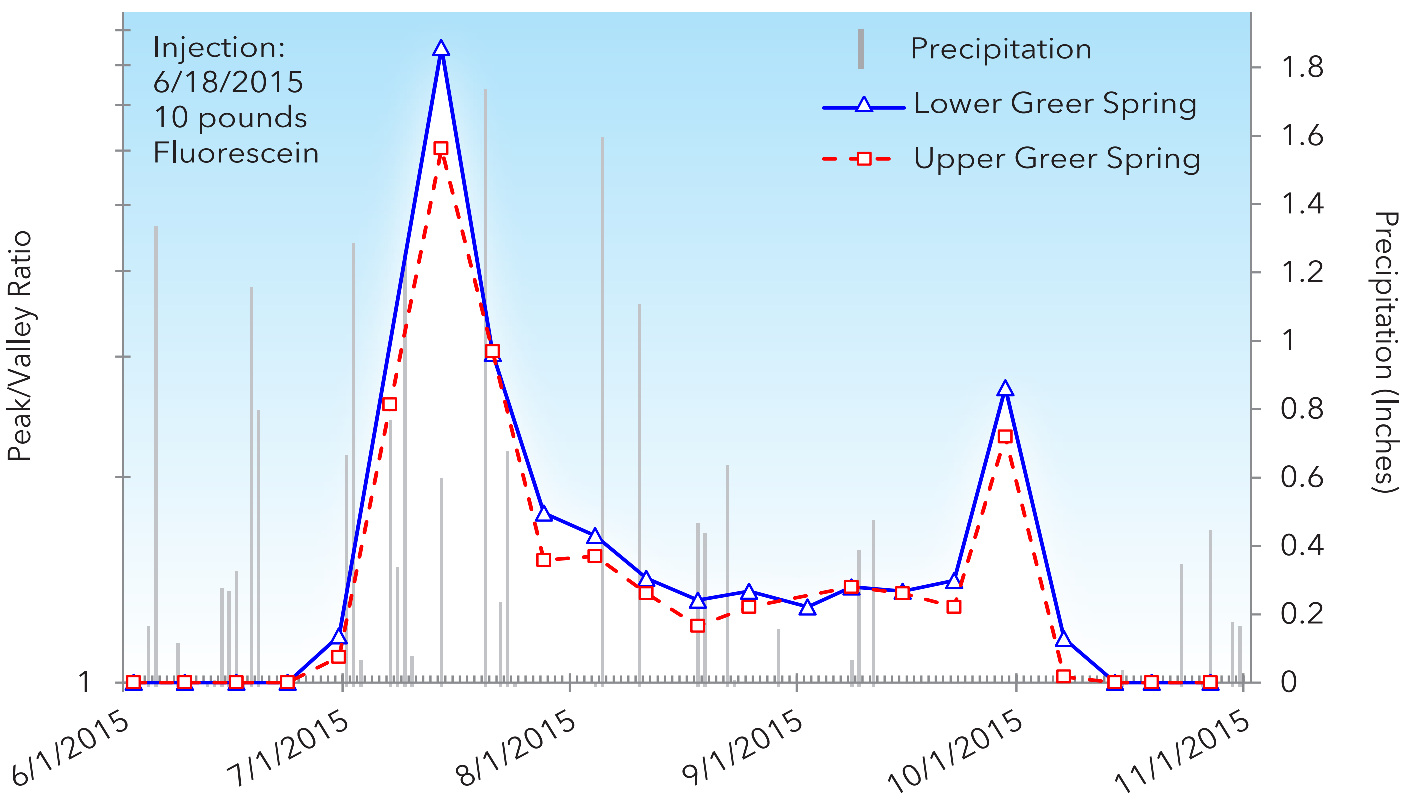


Figure 52. Dye recovery curves (carbon packet eluate) Dean Davis Conservation Area trace (Or 048). Bar graph (right axis) shows daily precipitation at Pomona.

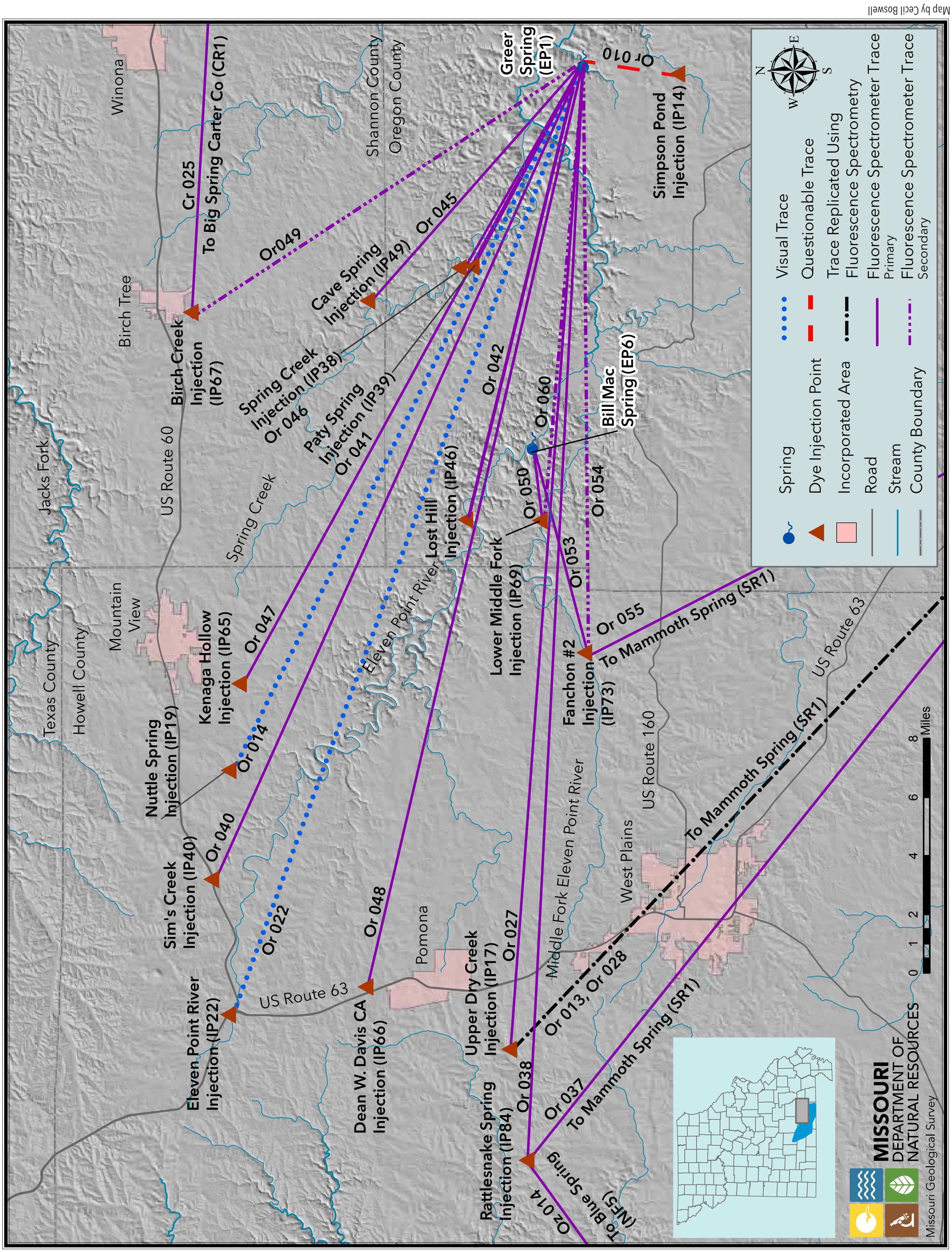


Figure 53. Current interpretation of traces in the vicinity of Greer Spring.

Spring Group D - Bill Mac Spring, Rookery Tree Complex, unreported spring (all in Oregon County, Missouri) and an unreported spring (Howell County, Missouri)

Bill Mac Spring and the Rookery Tree Complex are the major components of Spring Group D (Figure 54). Though both systems are located above losing reaches, they play a significant role in shallow water movement in the Middle Fork and main stem of the Eleven Point River.

Bill Mac Spring Description

Bill Mac Spring is normally the largest spring in the Eleven Point River upstream of Thomasville. It issues from a pile of huge boulders at the base of a sandstone and dolomite bluff of the Roubidoux Formation and flows directly into the Eleven Point (Figure 55). During dry periods, the Eleven Point River displays no flow just upstream of the spring despite the fact that the Eleven Point watershed drains more than 300 square miles at this point and contains several perennial springs. It is interesting to note that all of the tracing to date has shown that the upper Eleven Point recharges Greer Spring - not Bill Mac Spring.

Photo by Bill Duley.

Figure 55. Most of the flow of Bill Mac Spring rises in a pool of the Eleven Point River, but numerous outlets can be observed at or below river level during high spring-flow events,.

Limited discharge data have been published for Bill Mac Spring (Table 4). The first measurement, in 1969, is reported by Tryon (1989). Kleeschulte (2000) conducted a seepage run on this section of the Eleven Point River and recorded measurements showing that the river lost about 6.1 ft³/s in the seven miles upstream of Bill Mac Spring just as Bill Mac was discharging about 11.1 ft³/s. It would be reasonable to assume that this water loss resurfaces at Bill Mac Spring, but that is apparently not the case. Observations during this study, supported by descriptions of local residents, indicate that the flow of Bill Mac Spring is quite variable and does not correlate well with precipitation events in the Eleven Point watershed. The spring has been reported to cease flow during extreme drought conditions. No flow measurements have been recorded for extreme runoff events.

Date (Source)	Eleven Point River above Bill Mac Spring	Bill Mac Spring	Eleven Point River below Bill Mac Spring	Eleven Point River 1.5 miles below Bill Mac Spring
Aug. 6, 1969 (Tryon, 1989)		11.9 ft³/s		
Aug. 16, 1995 (Kleeschulte, 2000)	6.5 ft³/s	11.7 ft³/s	18.2 ft³/s	18.2 ft³/s (avg. of 3)
Sept. 30, 2014	0 ft³/s	5 ft³/s estimated		0 ft³/s
July 28, 2015	69.31 ft³/s	20.28 ft³/s	96.9 ft³/s	
Oct. 7, 2015	<0.1ft³/s (estimated)	7.99 ft³/s		5.9 ft³/s

Table 4. Available discharge data at selected points near Bill Mac Spring

Not all large springs in the region display the same degree of limited seasonal temperature variation as Greer and Mammoth. Hodgson Mill and Rainbow springs are examples of large springs with greater temperature fluctuation, but temperatures at those springs do not vary as much as Bill Mac Spring. Water temperature at Bill Mac Spring shows relatively large seasonal and short-term fluctuations as compared to other large springs of the region (Figure 56).

The temperature curve of Bill Mac Spring displays a muted version of surface water temperature. The authors' interpretation is that water resurging from this spring is not underground long enough to achieve temperature equilibrium with surrounding bedrock. Thus, Bill Mac Spring is considered to be a hybrid between surface water and the higher residence-time groundwater represented by Greer and Mammoth springs.

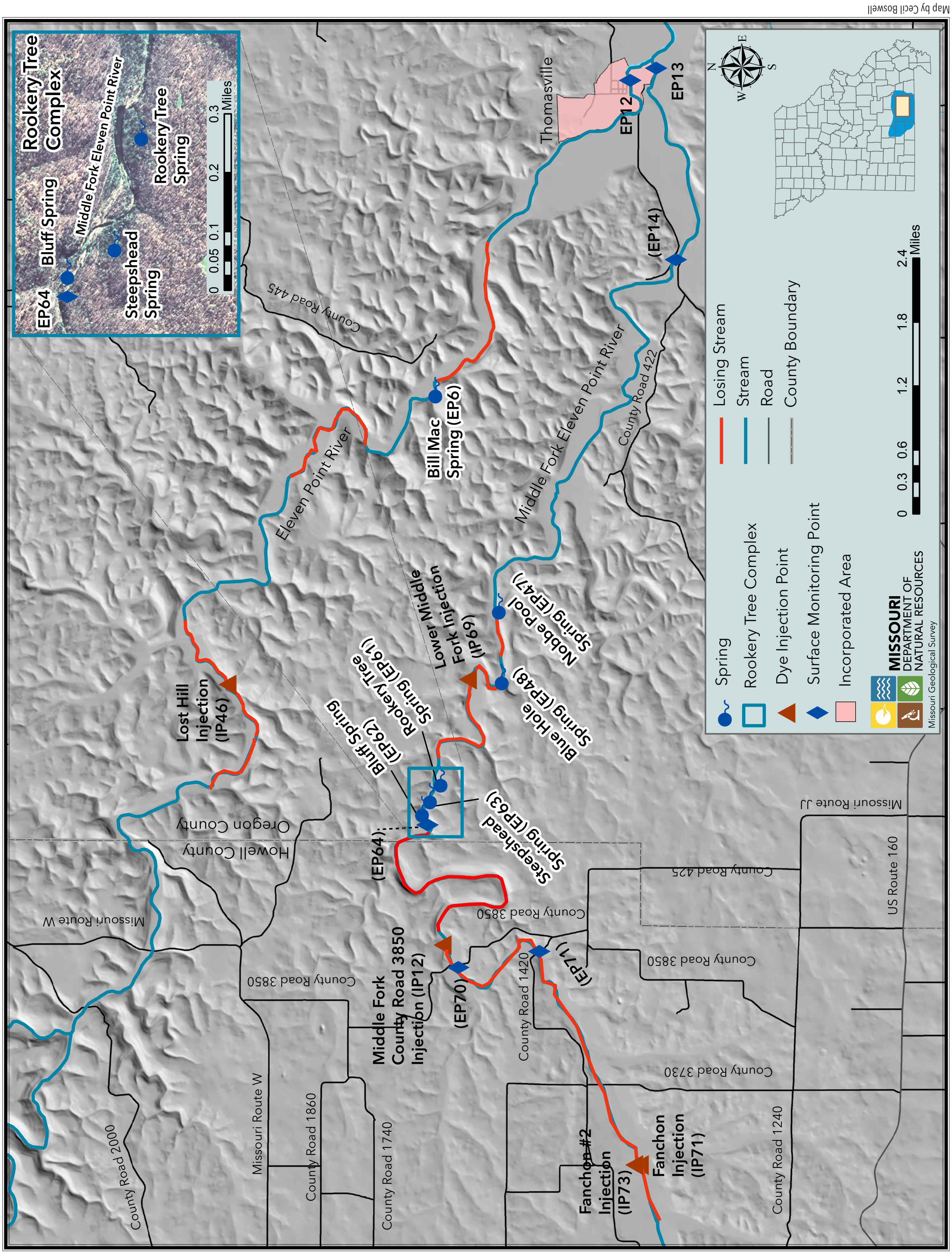


Figure 54. Spring Group D area.

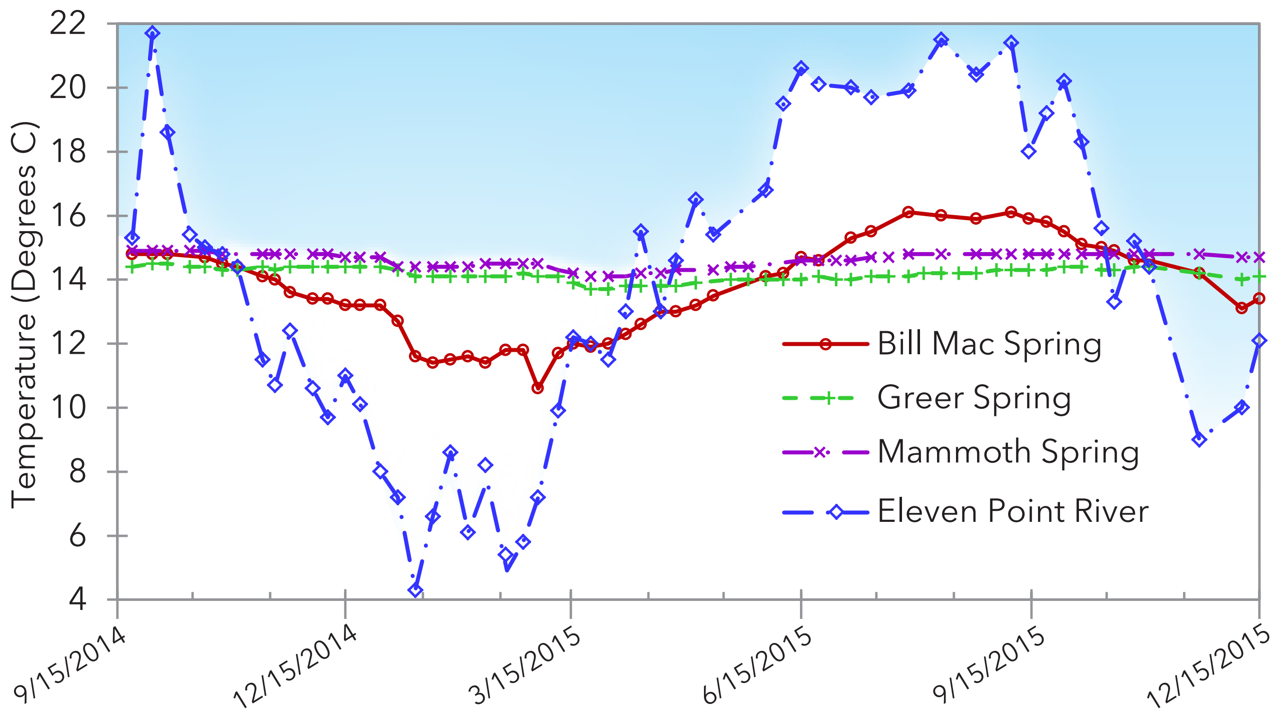


Figure 56. Temporal variations in spring- and surface- water temperature at selected monitoring points.

Rookery Tree Complex Description

Rookery Tree Complex is a group of springs on the Middle Fork of the Eleven Point River that have not been thoroughly evaluated. During this study, three springs (Rookery Tree, Steepshead and Bluff: Figures 57-59) were observed to issue from the Roubidoux Formation on a large tract of privately owned land. At least one other spring is present upstream that has not been observed by the authors (Figure 60).

Figure 57. Rookery Tree Spring.

Little is known about the discharge for any of the springs. The Middle Fork of the Eleven Point River was measured on one occasion during the current study at a point less than 0.2 miles downstream of the complex on Aug. 26, 2015 as having a flow of 8.68 ft^3/s. On that date, stream measurements showed substantial decreases in flow in the Middle Fork downstream of the complex; nearly 4 ft^3/s was lost within a mile and at least 6 ft^3/s within 1.5 miles (Figure 60).

Rookery Tree Spring had no flow on Nov. 2, 2015 while both Steepshead and Bluff springs had small flows (estimated at 0.25 ft^3/s each) on that date. Upstream of Bluff Spring, the Middle Fork also had no flow on that date, which suggests that either the other upstream spring is a wet weather spring like Rookery Tree, or the Middle Fork has another losing reach upstream from the main part of the complex.

Photo by Bill Duley.

Figure 58. Steepshead Spring.

Photo by Bill Duley.

Figure 59. Bluff Spring.

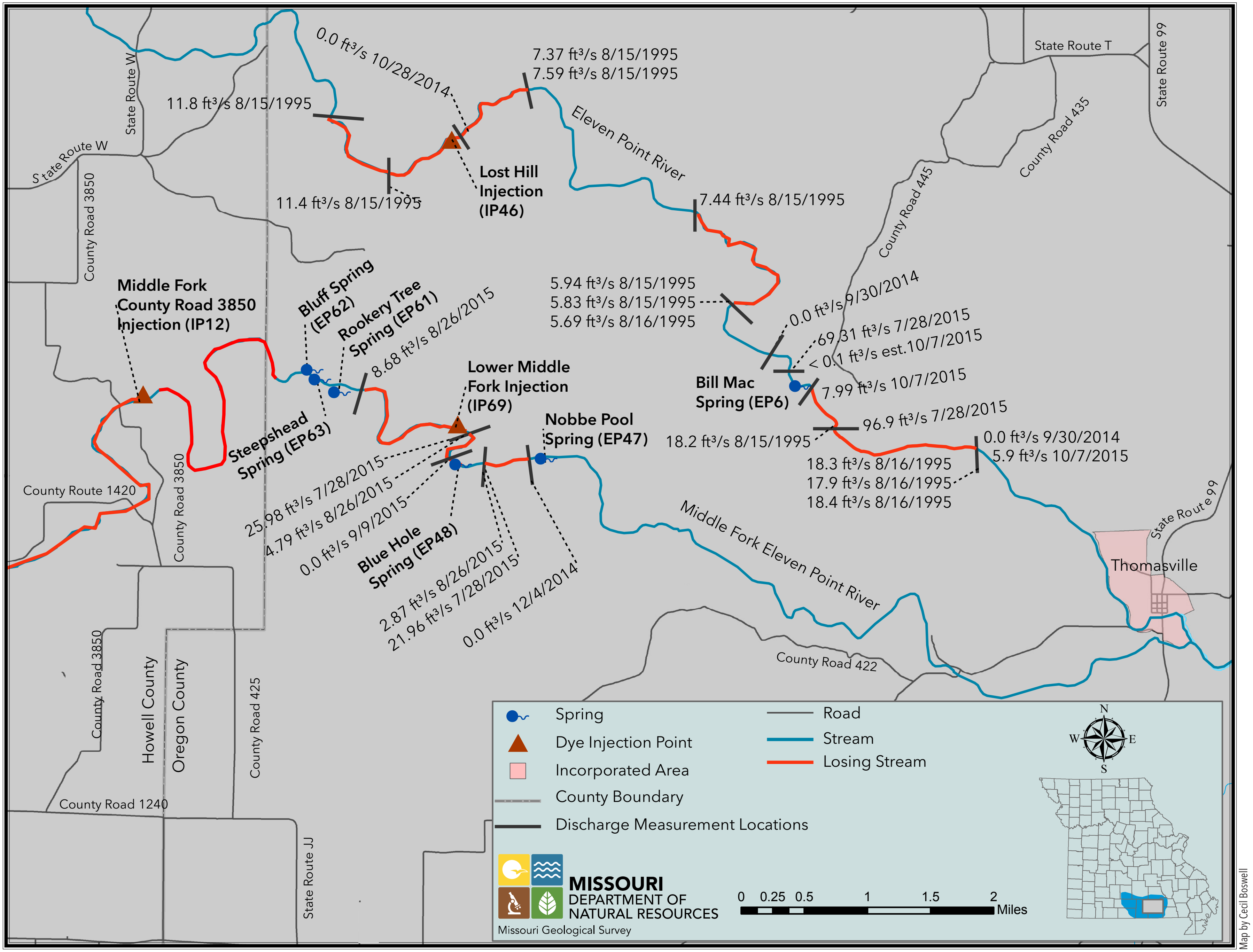


Figure 60. Flow measurements in Spring Group D area.

Middle Fork County Road 3850 (Trace Or 043)

The Middle Fork of the Eleven Point River has several losing reaches. During wet conditions, surface flow may be continuous throughout the entire stream and may continue for a period of days, weeks or even months. As surface flow decreases, dry reaches begin to appear downstream of flowing reaches. During prolonged periods of limited precipitation, flowing reaches in losing segments, downstream of gaining segments, retreat upstream. The pattern is one of water, mostly discharging from springs in small perched zones, flowing a short distance during low flow conditions before recharging deeper groundwater. It was from these losing segments that MGS staff attempted several traces during the current study.

MGS staff attempted to replicate two traces reported by Aley (1975) in the area just downstream from Howell County Road 3850 (Cr 009 and Cr 010). He reported a replicated connection between the small spring and losing reach downstream to Big Spring in Carter County. The first replication attempt by MGS staff involved injection of 10 pounds of fluorescein at the same site (IP12) on Dec. 3, 2013. Monitoring was conducted at Big Spring (Carter County, CR1), Greer Spring (EP1), Mammoth Spring (SR1), Blue Spring (Oregon County, EP2), Morgan Spring (EP3), Middle Fork of the Eleven Point River at Thomasville (EP13), Eleven Point River at Thomasville (EP12), and the Barren Fork at US Route 160 (EP15). No fluorescein was recovered at any point monitored through February, 2014, despite significant precipitation and runoff events that occurred during this time. One precipitation and snow melt event caused the Current River to flood Big Spring from middle to late December 2013, presenting the possibility that the injected dye was flushed through the system during this time and was undetectable due to dilution.

A second attempt was made to replicate this trace with another ten pound injection of fluorescein at the same location on Feb. 26, 2014. Though additional monitoring points were added at the Missouri Route W crossing of the Eleven Point River in Howell County (EP43), Cane Bluff on the Eleven Point (EP46), and Greer Crossing on the Eleven Point (EP26), dye was not recovered throughout the following summer in spite of numerous precipitation events.

Given the failure of the first two replication attempts, on the third attempt MGS staff used additional monitoring points in conjunction with a dye less susceptible to photo-decay. In the latter part of 2014, permission was obtained to monitor Bill Mac Spring on the Eleven Point River (EP6) as well as Blue Hole (EP48) and Nobbe (EP47) springs, which are both located downstream of the Middle Fork injection site. The Middle Fork monitoring point near Thomasville was moved upstream (EP14).

Bill Mac Spring issues from an opening or group of openings at or below the level of a large pool in the Eleven Point River at that location (Figure 61). Blue Hole and Nobbe springs are both located at the bottom of pools in the Middle Fork channel. Three gallons of Rhodamine WT™ were then injected into the same pool used in the earlier trace attempts (IP12) at 11:45 a.m. on Dec. 11, 2014.

Photo by Bill Duley/Panoramic by Mark Gordon.

Figure 61: Bill Mac Spring occupies the middle half of this panorama in the boulders at the base of the bluff.

No dye was recovered from the third injection until a large runoff event just prior to the Jan. 6, 2015, sampling event. At that time, water levels clearly raised significantly in the reaches of the Middle Fork upstream of Thomasville, indicating a large flood surge down the valley. At the same time, flow in the Eleven Point River upstream of Bill Mac Spring increased somewhat, but with no evidence of a significant flood event. Flow from Bill Mac Spring increased significantly, with water observed coming out of numerous outlets along the south side of the Eleven Point River in the area of the spring.

The packets removed from Nobbe Spring (EP47), the Middle Fork upstream of Thomasville (EP14) and Bill Mac Spring (EP6) on Jan. 6 all contained dye. Dye arrived at Bill Mac Spring 19 to 26 days after injection. The packet from Blue Hole Spring was lost in the flood surge. However dye was found in the next packet recovered at Blue Hole Spring on Jan. 13. The dye peak passed through Bill Mac Spring 44 to 61 days after injection between Jan. 13 and Jan. 20, 2015 with a peak PVR of 5.04 (Figure 62). Dye from this injection was not recovered at Big Spring (Carter County-CR1).

While it is possible that the dye had resurfaced at Blue Hole or Nobbe springs, the dye recovery curves suggest that surface water was the dye source at both of these monitoring points, which were located in the channel of the Middle Fork. Dye was present at these locations for just a few weeks and quickly returned to background levels as surface flow decreased. While dye recovery at Bill Mac Spring was clearly the result of subsurface flow, the route the dye traveled is uncertain. Dye may have flowed into an underground conduit system through which flow is relatively slow or water loss from this particular reach of the Middle Fork may go into short-term aquifer storage. In either case it appears that the flood event washed dye downstream, either on the surface or through the subsurface, into a lower losing reach of the Middle Fork. The inability to detect dye in previous fluorescein injection attempts suggests that surface flow is likely a large component of the flow downstream in the Middle Fork since fluorescein is more susceptible to photo-degradation than Rhodamine WT™.

Additional data were collected to supplement this trace. MGS staff observed and measured several points in the Middle Fork and Eleven Point River watersheds in an effort to determine where and how much flow was lost from both watersheds (Figure 60).

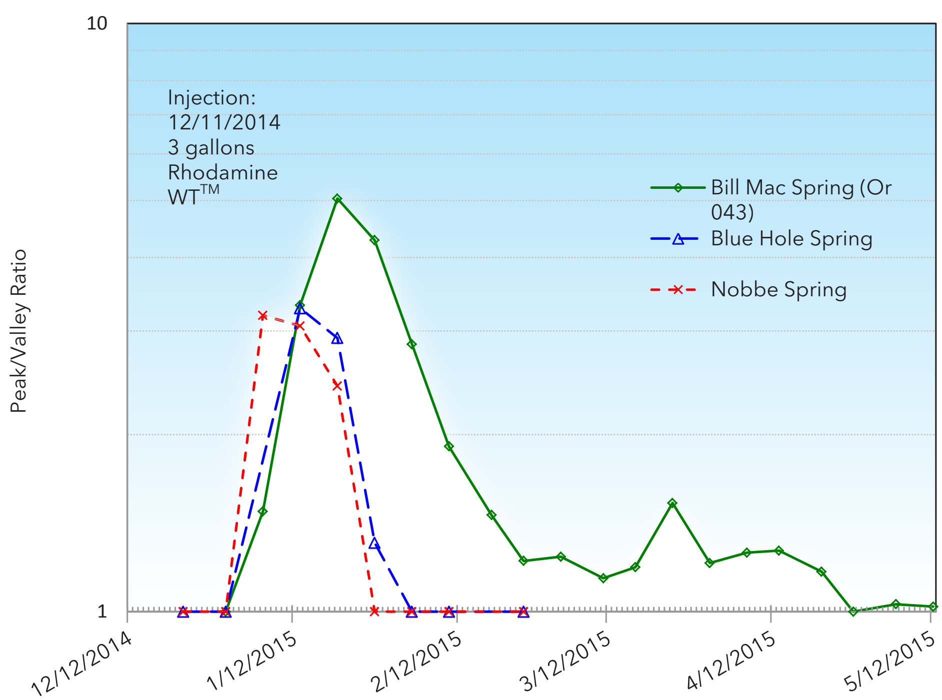


Figure 62. Dye recovery curves (carbon packet eluate) Middle Fork Eleven Point River downstream of County Road 3850 to Bill Mac Spring trace (Or 043).

Lower Middle Fork Injection (Traces Or 050 and Or 060)

Because the Howell County Road 3850 trace did not precisely delineate which reach of the Middle Fork contributes recharge to Bill Mac Spring, a second trace was undertaken. At 11:45 a.m on Sept. 9, 2015, two pounds of fluorescein were injected into the Middle Fork at IP69 about 0.25 mile upstream of Blue Hole Spring on private property after a precipitation event. On the day of injection, significant flow loss, estimated at 3 ft^3/sec, was occurring from the Middle Fork immediately upstream of Blue Hole Spring.

Figure 63 shows the pertinent PVRs for the Lower Middle Fork trace. Large PVRs are associated with the packets collected Sept. 15, 2015, at Bill Mac Spring and other points monitored in the Eleven Point downstream to Thomasville. Thus, a large dye pulse passed from the Middle Fork to surface at Bill Mac Spring (EP6) in less than six days. Notably, dye was not recovered downstream of the injection at Blue Hole Spring (EP48), Nobbe Spring (EP47) or the Middle Fork at Oregon County Road 422 west of Thomasville (EP14). The elevation difference from the point at which all flow was lost on the Middle Fork to Bill Mac Spring is about 80 feet. Other losing reaches downstream of Blue Hole Spring may provide flow to Bill Mac or other local springs, but those reaches were not isolated during this study.

Greer Spring PVRs also illustrate the likely connection between the Middle Fork and Greer Spring. The dye recovered in late June and July at Greer Spring was associated with the Dean Davis CA trace. It is the authors' interpretation that the smaller recoveries from both Greer Spring locations between Sept. 22 and Sept. 29 were the result of dyed water issuing from Bill Mac Spring being lost from the Eleven Point River immediately downstream of Bill Mac Spring (Figure 65). Just such a losing reach was documented by MGS during relatively low-flow conditions (Figure 60). However, because of the timing of this recovery it is not possible to rule out a flushing event at Dean Davis CA as the cause of this second peak. Unfortunately the timing and intensity of the later peak is consistent with either interpretation. Additional work done in the area helped to clarify this issue (See Or 054 and Or 060). Unless and until a primary trace is conducted from the Eleven Point River downstream of Bill Mac Spring, this connection should be considered tentative.

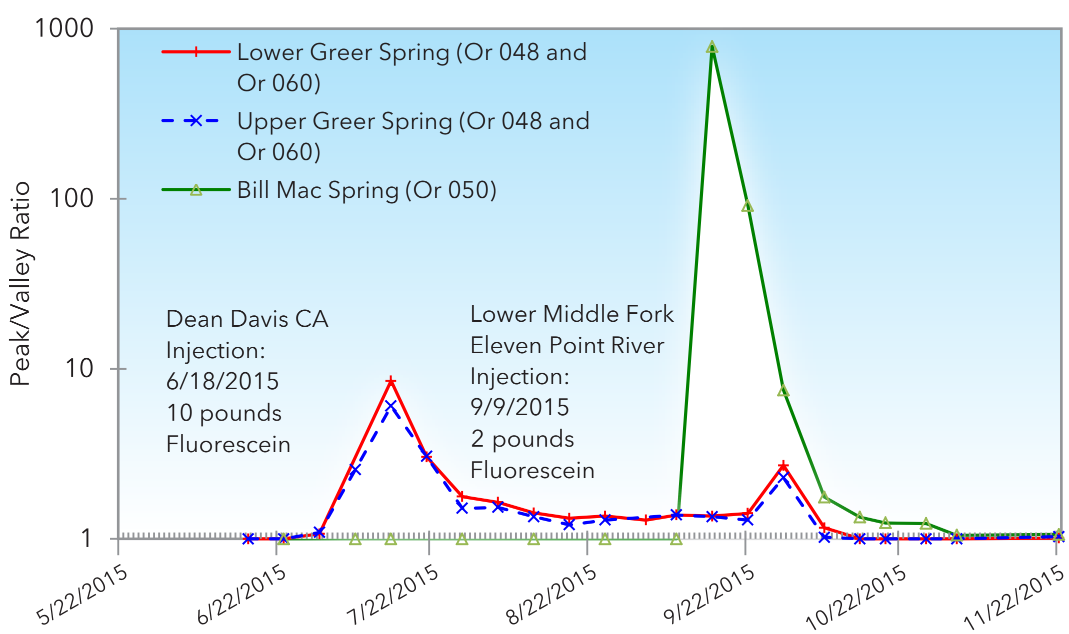


Figure 63. Dye recovery curves (carbon packet eluate) Dean Davis CA trace (Or 048) and lower Middle Fork Eleven Point River traces (Or 050 and Or 060).

Initial Fanchon Injection (Traces Or 051 and Or 052)

Another losing segment is present in the Middle Fork upstream of the small community of Fanchon. At about 10:20 a.m. on Sept. 9, 2015, two gallons of Rhodamine WT™ were injected into an estimated water loss of about 15 gpm that was occurring in the main channel at IP71. Some of the points monitored included: Greer Spring (EP1), Mammoth Spring (SR1), Bill Mac Spring (EP6), Nobbe Spring (EP47), Blue Hole Spring (EP48), the Eleven Point River at Missouri Route W (EP43), the Eleven Point upstream (EP42) and downstream of Bill Mac Spring (EP60), the Eleven Point at Thomasville (EP12), the Eleven Point at Greer Crossing (EP26) and Big Spring (Carter County-CR1).

Dye was first recovered at Bill Mac Spring and downstream in packets in place Oct. 7 to Oct. 14, 2015. The small recovery is shown on Figure 64 along with the earlier recovery (January through April) from the replication injection downstream in the Middle Fork (Or 043). Due to the small size of the recovery, additional investigations were undertaken to help determine whether the recovery was a result of the Sept. 9 injection or a second pulse of the first injection (Dec. 11, 2014). Additional points were monitored in the reach of the Middle Fork upstream of Blue Hole Spring where four springs are located - Rookery Tree (EP61), Bluff (EP62), Steepshead (EP63) and monitoring point (EP64) which likely represents an unreported spring in the Middle Fork of the Eleven Point River upstream of Bluff Spring.

Beginning with the first packets removed from these locations, degraded Rhodamine WT™ was found at all four of these monitoring points. Degraded Rhodamine WT™ was also recovered at Bill Mac Spring in packets in place during approximately the same time period (Dec. 9 to Dec. 16, 2015).

The timing and levels of degraded Rhodamine WT™ found at all of these locations suggest a connection to the Fanchon injection, though the possibility of surface water flushing old dye from the earlier Middle Fork Trace could not be ruled out without additional investigation. Larger recoveries of degraded Rhodamine WT™ followed large precipitation events in November 2015.

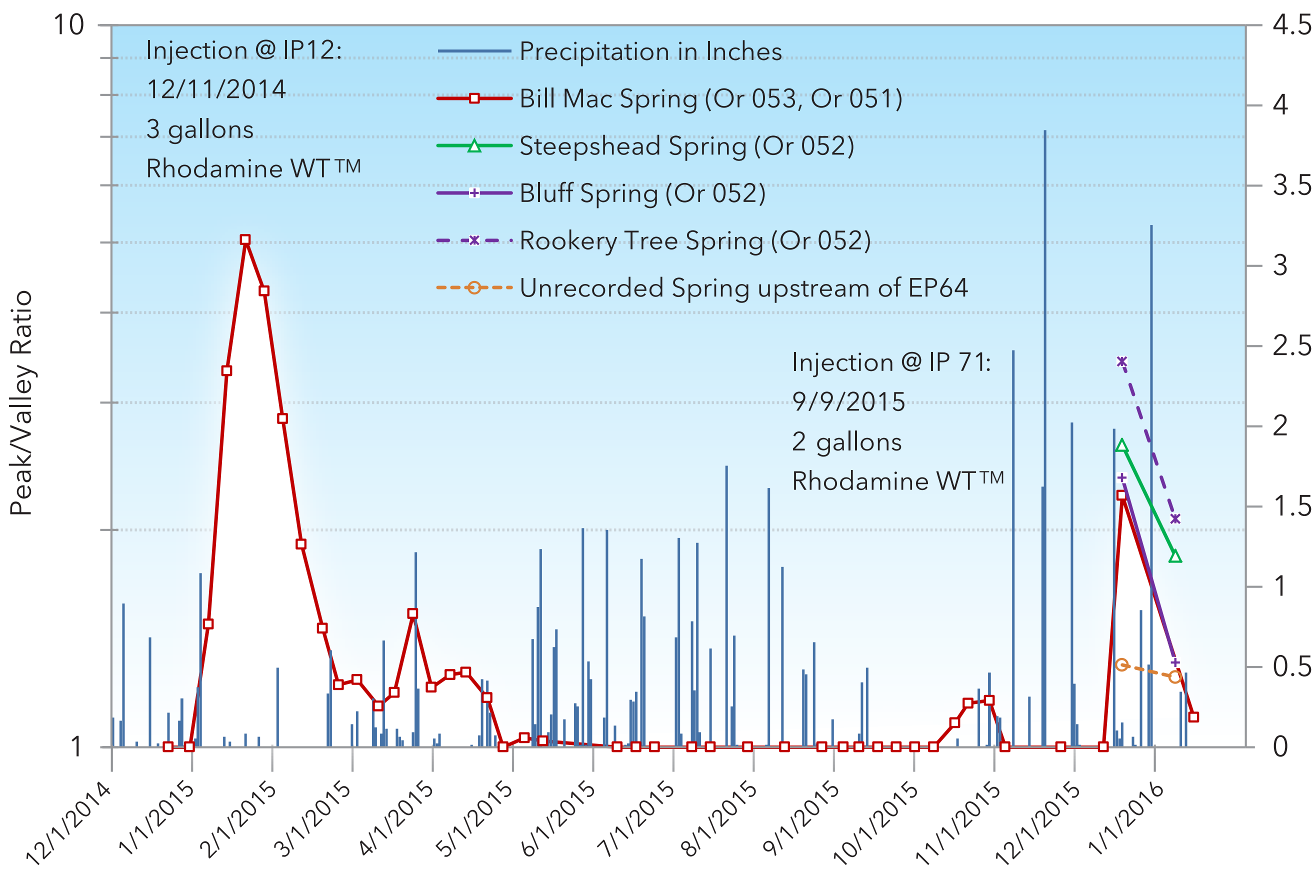


Figure 64. Dye recovery curves (carbon packet eluate) upper Middle Fork Rhodamine WT™ traces (Or 043, Or 051 and Or 052) and precipitation at Pomona.

Photos by Bill Duley.

Figure 65. Three views of the Eleven Point River on October 7, 2015-Top to Bottom: 1. Upstream of Bill Mac Spring (Note: 27 inch machete for scale). 2. Measuring stream flow downstream of Bill Mac Spring and 3. Below the losing segment.

Fanchon Replication Injection (Traces Or 053, Or 054,Or 055, Or 056, Or 057 and Hl 001)

Because of questions raised during earlier work, MGS staff injected 10 pounds of eosine into the Middle Fork losing segment upstream of Fanchon (IP73) at 4 p.m. on Feb. 9, 2016. Due to greater flow in the Middle Fork of the Eleven Point River, than was the case during the previous injection, the new injection point was moved downstream several hundred feet. About 0.25 ft^3/sec was lost to the subsurface within 0.25 mile of the injection on that date (Figure 66).

This dye was recovered in the first sampling eight days after injection on Feb. 17 at a number of locations, beginning with Rookery Tree Complex (Trace Or 057 at EP61 through EP63) and the Middle Fork of the Eleven Point River just upstream of Bluff Spring (Trace Or 056 at EP64). Dye was not recovered in the Middle Fork at Howell County roads 1420 (EP71) or 3850 (EP70) on that date, showing that a significant part of the trace was through the subsurface. Thus, there is at least one other spring upstream of the Rookery Tree Complex and downstream of County Road 3850. Because this reach of the Middle Fork has been observed to dry up during lower flows, this spring or springs group is either intermittent, flows into a losing segment of the Middle Fork, or both. Dye was recovered at Bill Mac Spring (Trace Or 053 at EP6) and at other points downstream in the Eleven Point River downstream to Thomasville in the next sampling event (February 29). These recoveries are all consistent with the lower Middle Fork trace and the first Fanchon traces.

The March 14 packets at Mammoth Spring (Trace Or 055 at SR1) and Howell County Road 3850 (Trace Hl 001 at EP70) also showed a moderate amount of eosine. The dye at EP70 appears to have issued from a previously unrecorded spring (or springs group) in the Middle Fork upstream of Howell County Road 3850 and downstream of Howell County Road 1420 (EP71). The authors have not observed the spring, which is on private property. Since flow at County Road 3850, the downstream crossing, is intermittent, either the spring is intermittent or the Middle Fork loses flow to the subsurface in the reach upstream of County Road 3850 and downstream of the unrecorded spring.

The recovery at Mammoth Spring is yet another indication of the complexity of the karst around the borders of the recharge areas of the Big Four systems.

The earlier trace from Fanchon was not recovered at Mammoth Spring in any definite manner. Mammoth Spring typically displays a fluctuating background with small intermittent peaks in the same general spectral region as fluorescein and Rhodamine WT™. A small recovery of Rhodamine WT™ would have been difficult to detect with any degree of certainty due to the background. However, the authors did note a slight shift in the background peak toward the normal Rhodamine WT™ peak wavelength during the earlier trace.

Also, beginning with the March 14 packets, eosine was recovered in small amounts at Greer Spring (EP67). Dye recovery curves are shown for all of the second Fanchon injection traces on Figure 67. Figure 68 shows the location of these traces.

Figure 66. Second injection upstream of Fanchon at IP73.

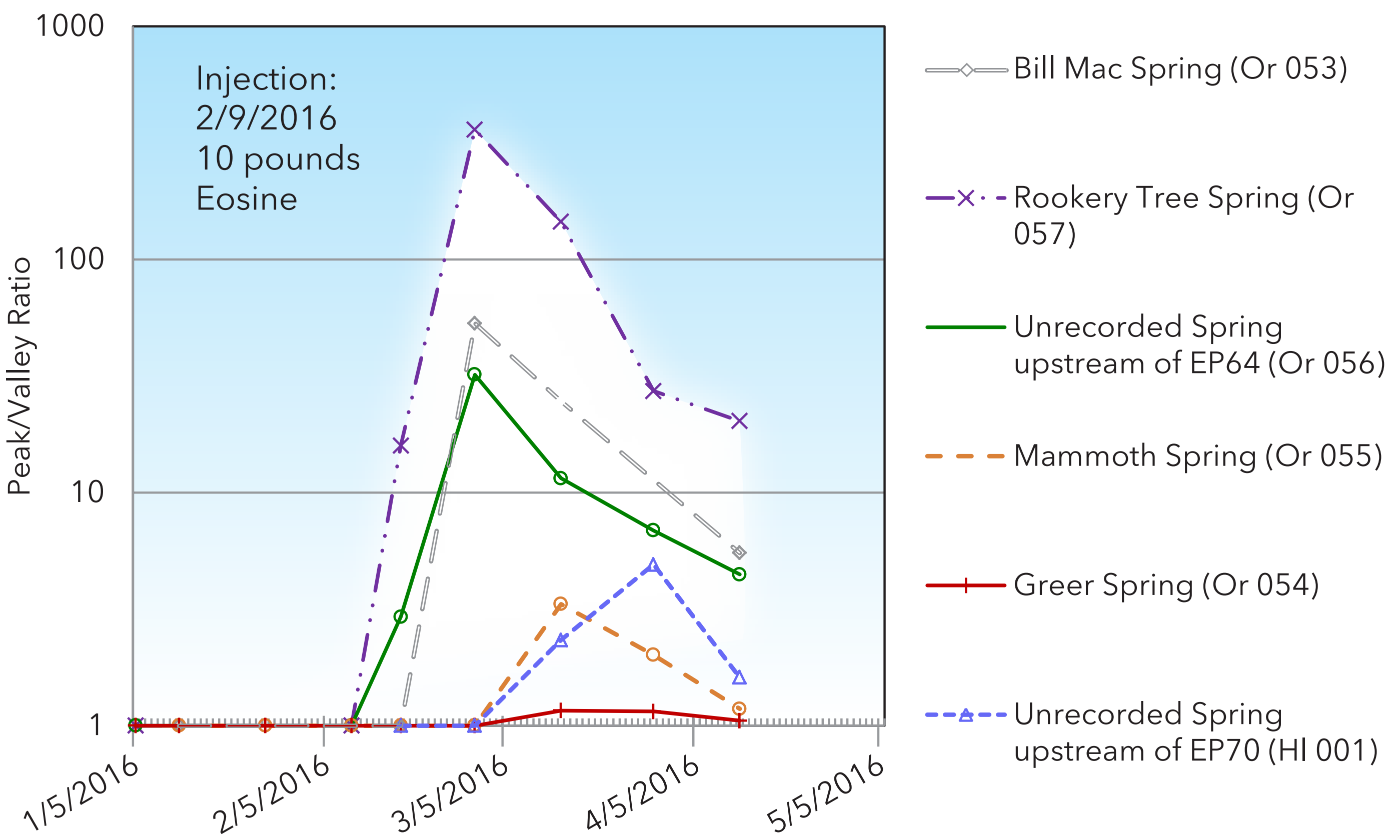


Figure 67. Dye recovery curves (carbon jacket eluate) Fanchon replication injection Middle Fork Eleven Point River traces (Or 053, Or 057, Or 056 Or 055, Or 054 and H1 001).

Interpretation of the Middle Fork Traces

The data collected suggest that all injection points used in the Middle Fork of the Eleven Point River (IP12, IP69, IP71 and IP73) are hydrologically connected to Bill Mac Spring on the Eleven Point River and other points downstream in the Middle Fork. The surface connection is intermittent, as water goes into shallow aquifer storage and flushes from storage during runoff events.

A number of springs are located downstream of the uppermost injection sites and upstream of losing reaches that supply water to Bill Mac Spring. When a large precipitation and runoff event occurs, water apparently floods the shallow karst system and causes groundwater to surface at a series of springs downstream in the Middle Fork. Rookery Tree, Bluff and Steepshead springs represent three of these resurgences, but at least two others exist farther upstream. MGS recorded dye surfacing upstream of County Road 3850 as well as between County Road 3850 and Bluff Spring.

At least three distinct losing reaches in the Middle Fork feed Bill Mac Spring. Others likely exist that were not documented due to limited access and insufficient resources to conduct losing stream investigations during this study. The three losing reaches documented during this study are listed below:

1. The Middle Fork just upstream of Fanchon exhibited no flow at Howell County Road 3730 except in abnormally wet periods, even though significant flow was observed immediately upstream;
2. The Middle Fork downstream of County Road 3850 and upstream of the Rookery Tree Complex normally loses flow about 200 yards downstream of the road crossing;
3. Downstream of the Rookery Tree Complex and upstream of Blue Hole Spring significant flow loss was observed in the area immediately upstream of Blue Hole Spring during wet periods.

Water lost from the first reach clearly resurfaces downstream at the Rookery Tree Complex and the unnamed spring upstream first. It appears that the Fanchon losing reach feeds Mammoth Spring during wetter periods. The conclusion is that water from losing reaches 1 and 2 does not travel significant lateral distances in any direction until precipitation events saturate the local aquifer. When significant precipitation and runoff does occur, water in shallow storage is flushed into conduits in the karst aquifer. Some of this water flows south to Mammoth Spring while some remains in the Middle Fork valley resurging at a number of springs downstream including the Rookery Tree Complex.

Rookery Tree Spring is intermittent in nature; it has been observed to be essentially dry during a relatively brief hiatus in precipitation, while Bluff Spring and Steepshead Spring both continued to discharge. Insufficient data have been collected by the authors to determine if any of the springs in this area are perennial during prolonged drought. Discussions with the landowner suggest that all of the Rookery Tree Complex springs are intermittent.

Water discharged downstream of Howell County Road 3850 and upstream of Blue Hole Spring flows through a series of large surface pools in the Middle Fork. Some of this water is lost to the subsurface from the third reach and resurges at Bill Mac Spring.

During high flow events, a significant amount of flow passes all of these losing reaches and continues down the Middle Fork and ultimately into the gaining portion of the Eleven Point River. At least two other losing reaches downstream of Blue Hole Spring could potentially recharge Bill Mac Spring but additional work is needed to determine their actual resurgence points.

Once flow emerges at Bill Mac Spring it enters another losing stream segment. The authors conclude that this water resurfaces at Greer Spring. Small to moderate recoveries of dye on two separate occasions indicate that water loss in this reach is not a major component of flow at Greer. It is surprising that any dye was recovered there given the large amount of dilution that occurred in the system. Only a small percentage of the flow downstream of Bill Mac Spring is lost to the subsurface during large runoff events such as those that flushed dye to Greer Spring during the study.

Since the traces completed at this location have not used this reach as a primary dye injection site, the authors can only estimate time-of-travel from the Eleven Point River downstream of Bill Mac Spring to Greer Spring. Since dye from the last Fanchon injection on Feb. 9 resurfaced at the Rookery Tree Complex between Feb. 9 and Feb. 16 and then resurged at Bill Mac Spring between Feb. 16 and Feb. 29 while first recovery of dye at Greer was between Feb. 29 and March 14, it is likely that it took two to four weeks for the dye to travel from the Eleven Point River downstream of Bill Mac Spring to Greer Spring.

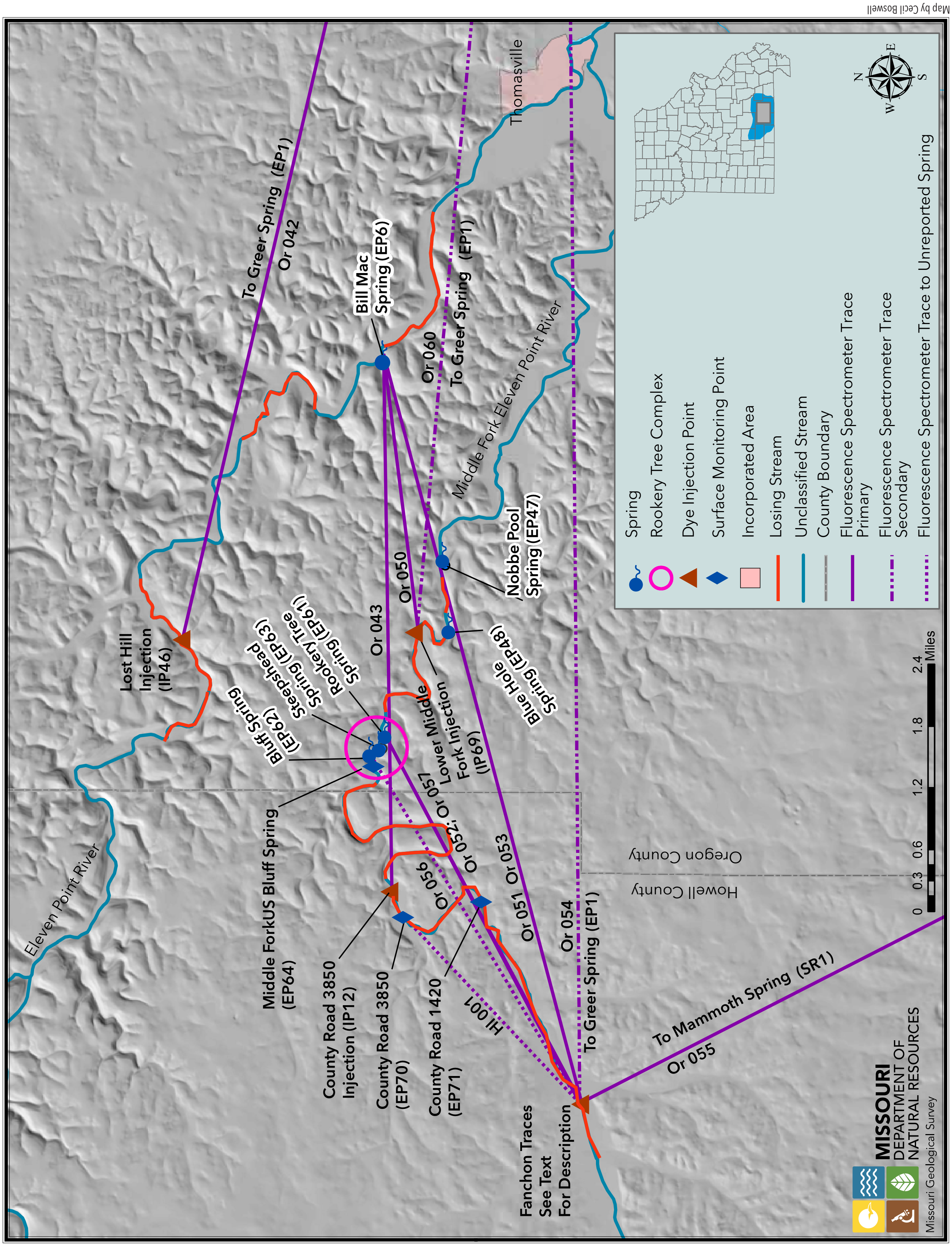


Figure 68: Current interpretation of traces in close proximity to Bill Mac Spring.

This is consistent with the timing of the earlier recovery of dye from the Lower Middle Fork trace, which also resurfaced at Bill Mac Spring and was apparently recovered at Greer Spring about two weeks later.

The resurgence of dye upstream of County Road 3850 at a later date than at the other springs in the Middle Fork downstream is best explained by additional precipitation late in the trace that raised the water table near the injection site to a level that supplied a higher intermittent spring in that area. Dye was not recovered in the Middle Fork at the County Road 1420 (EP71) crossing about one mile upstream at any time during the trace

The results of all dye traces conducted in the Spring Group D region are shown on Figure 68.

Spring Group E - Rainbow/North Fork/Hodgson Mill Complex

Rainbow Spring and North Fork Spring Descriptions

Rainbow Spring, also known as Double Spring, rises from a conduit on private property on the west side of the North Fork River at the base of a bluff composed of Roubidoux Formation sandstone (Figure 69). The discharge splits and flows through two channels to the North Fork, hence the alias Double Spring. Figure 70 shows the relationship of all springs in the complex. North Fork Spring, sometimes called Gravel Spring, rises from dissolution-enlarged joints or fractures in the channel of the North Fork several hundred yards upstream from Rainbow Spring (Figure 71). Interaction between the spring and the river has produced a sizable gravel bar from which much of the flow emerges.

Photo by Bill Duley.

Figure 69. Rainbow Spring.

Date	North Fork Spring Discharge	Rainbow Spring Discharge
Nov. 16, 1964	75.9 ft^3/s	47 ft^3/s
April 8, 1966	66 ft^3/s	180 ft^3/s
July 6, 1966	75.3 ft^3/s	150 ft^3/s
Oct. 6, 1966	68.4 ft^3/s	132 ft^3/s

Table 5. Discharge at Rainbow and North Fork Spring. (Vineyard and Feder, 1974)

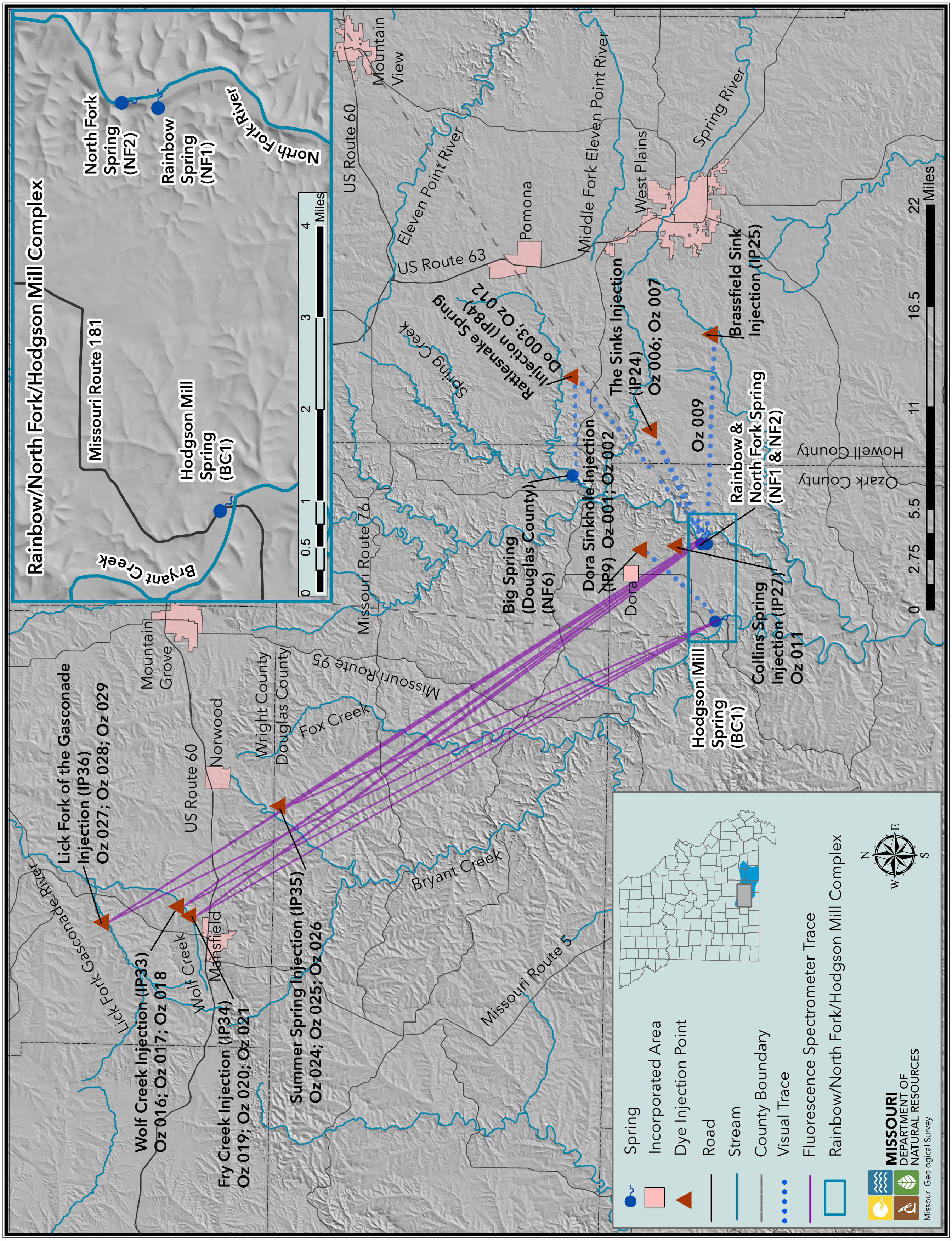


Figure 70. Spring Group E legacy traces.

Photo by Bill Duley.

Figure 71. North Fork Spring rises in a gravel bar in the North Fork River.

Rainbow Spring and North Fork Spring have long been suggested to represent two outlets of the same groundwater flow system due to their proximity and nearly identical water quality (Skelton and Harvey, 1968; Vineyard and Feder, 1974). The discharge relationship between the two, depicted in table 5, is described as "difficult to explain" by Vineyard and Feder (1974, p. 165). There seems to be little correlation between these springs that are likely two outlets of a single conduit. Vineyard and Feder (1974) suggest that the outlet of North Fork Spring may be restricted, leading to relatively consistent discharge values. Because this spring is in

Photo by Bill Duley.

Figure 72. Hodgson Mill Spring.

the middle of the North Fork River, it can only be calculated indirectly by measuring the river upstream and downstream of the spring and subtracting the difference between the two.

Measurements of the discharge from Rainbow Spring have been more numerous. Vineyard and Feder report twenty seven flow measurements with a maximum of 232 ft^3/s, a minimum of 47.0 ft^3/s, and an average of 127 ft^3/s.

Hodgson Mill Spring Description

Built in 1897, Hodgson Mill is one of a declining number of grist mills still standing in the Ozarks (Figure 72). Skelton and Harvey (1968) and Vandike (1979) clearly viewed Hodgson Mill Spring as receiving recharge from the Bryant Creek watershed. The spring has a relatively stable discharge with 15 measurements recorded by Vineyard and Feder (1974) showing a maximum of 43.8 ft^3/s, a minimum of 23.6 ft^3/s and an average of 36.4 ft^3/s. Since Hodgson Mill Spring is in the Bryant Creek watershed several miles distant from Rainbow and North Fork springs, early investigators never linked the three together. However, dye traces by Williams (1986 and 1987) and Brown (1989) showed a substantial connection between the three springs. If Hodgson Mill Spring is considered to be a part of the Rainbow/North Fork Complex, average discharge for all three springs is well over 200 ft^3/s. The combined average discharge would rank the system as third largest in Missouri and fourth largest in the Ozarks.

Legacy Traces to Spring Group E Using Visual Methods (Traces Oz 006, Oz 007, Oz 009, Oz 011, Oz 012, Oz 001 and Oz 002)

Vandike (1979) reported several traces to Rainbow Spring (NF1) and North Fork Spring (NF2), primarily from tracer injections on the east side of the North Fork River (see Appendix A). The trace (Oz 012) from Rattlesnake Spring Branch (IP84) to Rainbow Spring could not be replicated during this study. In addition a near-replication described later in this report casts some doubt on trace Oz 009 from the Brassfield Sink (IP25) to Rainbow Spring.

Techniques used in the 1970s employed carbon packets followed by elution in a basic solution and visual analyses. Vandike (retired MGS, personal communication, 2014) reports that USFS personnel sometimes assisted with analysis if the recovery was weak or questionable. That means that eluate was stored in contact with carbon for relatively long periods prior to a second visual observation, leading to possible misinterpretations.

The USFS also injected fluorescein and lycopodium spores on July 22, 1971 into a sinkhole dump near Dora (IP9). Both tracers were reportedly recovered at Hodgson Mill Spring (Oz 001 and Oz 002) with fluorescein first observed from Aug. 3 to Aug. 11, 1971 (Aley, 1972). Though Rainbow and North Fork springs were both monitored during this trace neither fluorescein nor lycopodium spores were recovered at those locations.

During this study an unsuccessful semi-replication attempt of Oz 006 and Oz 007 was conducted from The Sinks while monitoring Spring Group E (NF1, NF2 and BC1), Wilder Spring (NF4), Althea Spring (NF3) and Blue Spring (Ozark County – NF5). This does not prove the original traces were in error, but it raises questions about them.

Legacy Traces to Spring Group E Using Fluorescence Spectrometry Methods (Oz 016, Oz 017, Oz 018, Oz 019, Oz 020 and Oz 021)

Beginning in 1985, Williams (1986) attempted to determine resurgence points of water lost from Wolf Creek (Gasconade River watershed), which included the discharge from the Mansfield wastewater treatment facility. After several unsuccessful trace attempts while monitoring springs and surface water in the Gasconade basin and upper Bryant Creek, he determined that dye injected in Wolf Creek resurfaces at Rainbow Spring (NF1) and North Fork Spring (NF2) in the North Fork watershed and Hodgson Mill Spring (BC1) in the Bryant Creek drainage.

Two key factors were involved in completing the MGS Rainbow/North Fork/Hodgson Mill Complex traces described below. One was understanding that regional groundwater was migrating along the Mansfield Fault System, a major geologic structure that extends in a northwest-southeast trend from north of Mansfield to the Howell County line southwest of Rainbow and North Fork springs (Missouri Department of Natural Resources, 2010). Skelton and Harvey (1968) discussed this structure and its relationship to Rainbow and North Fork springs but believed that the fault was intercepting joints on the east side of the North Fork River which provide recharge to these large springs.

The second factor was that Williams (1986 and 1987) and Brown (1989) were using eluted carbon packets, followed by fluorescent spectrometric analysis. Without the objective data provided by this method it is almost certain that the first trace would never have been completed. Because Williams (1986) was confident that earlier attempts had not monitored the actual resurgence point, he persevered and ultimately delineated a large part of the recharge area for the Rainbow/North Fork/Hodgson Mill Complex.

The first series of successful traces (Oz 016, Oz 017 and Oz 018) were from a 10 pound injection of fluorescein in Wolf Creek in the Gasconade River watershed in the north half of Section 11, Township 28 North, Range 15 West (IP33) on April 18, 1986. Carbon packets were used to collect dye followed by elution in a basic alcohol solution and fluorescent spectrometric analysis using methods developed by the MGS. Dye was first recovered at Rainbow, North Fork and Hodgson Mill springs in the packets collected May 2, 1986. Time-of-travel was less than 14 days after the injection to Rainbow and North Fork springs (Williams, 1986). The peak recovery at Hodgson Mill Spring however, lagged behind, occurring between May 2 and May 14 (Figure 73).

A second series of traces (Oz 019, Oz 020 and Oz 021) was completed using two gallons of Rhodamine WT™ from Fry Creek, also in the Gasconade watershed (IP34), with injection on Aug. 19, 1987. The first reported recovery of dye from this injection was in Hodgson Mill Spring where packets were replaced daily. These packets show that dye first emerged at Hodgson Mill Spring between Sept. 11 and Sept. 12, 1987, 23 to 24 days after injection. Longer-term packets (Figure 74) indicated that the dye emerged at Rainbow and North Fork springs as well between Sept. 11 and Sept. 16, 1987. Peak dye concentrations occurred between Sept.11 and Sept. 16 at Rainbow and Hodgson Mill springs and between Sept. 16 and Sept. 22 at North Fork Spring. These data tend to confirm that all three springs are part of a single complex (Williams, 1987).

A third series of traces (Oz 024, Oz 025, Oz 026, Oz 027, Oz 028 and Oz 029,) was reported by Brown (1989). Though the spectral charts are no longer available, the work was summarized as follows. On Sept. 2, 1988, one gallon of Rhodamine WT™ was injected into Summer Spring Branch located in Dry Creek, a tributary to Bryant Creek, in Section 3, Township 27 North, Range 14 West in Douglas County (IP35). On the same date, 10 pounds of fluorescein were injected into a losing segment of Lick Fork of the Gasconade River Basin in the northern part of Section 22, Township 29 North, Range 15 West (IP36). Both dyes were reportedly recovered in Rainbow, North Fork, and Hodgson Mill springs between Sept. 10 and Sept. 17, 1988. The dye trace summaries on file at MGS indicate that both tracers passed rapidly through the system with near background levels achieved within two weeks of the first recovery.

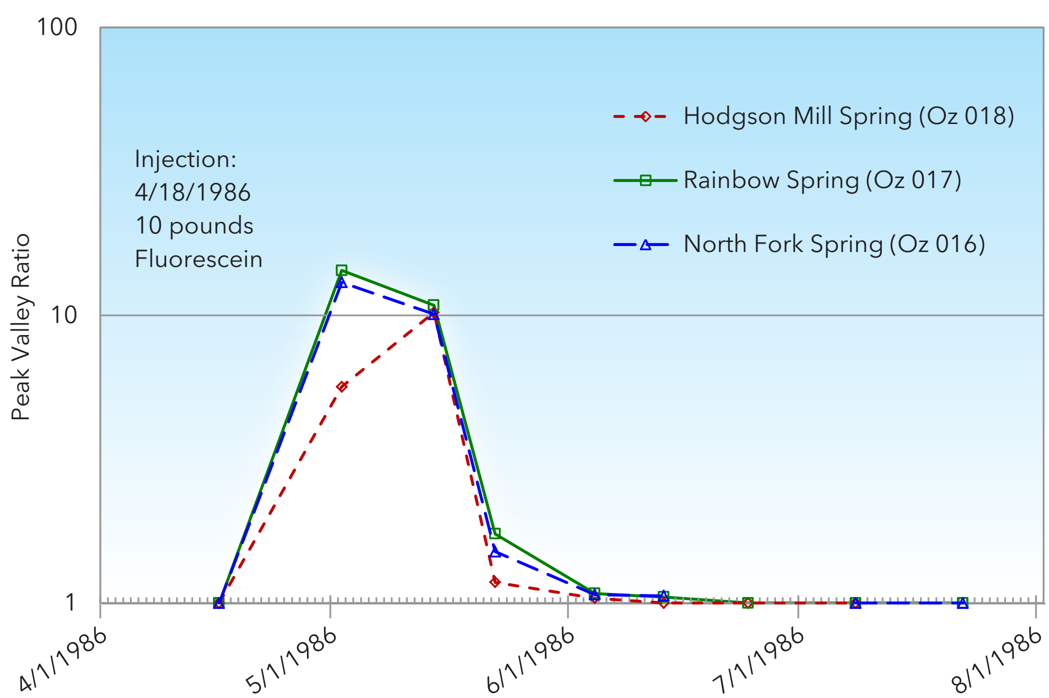


Figure 73. Dye recovery curves (carbon packet eluate) Wolf Creek traces (Oz 016, Oz 017 and Oz 018).

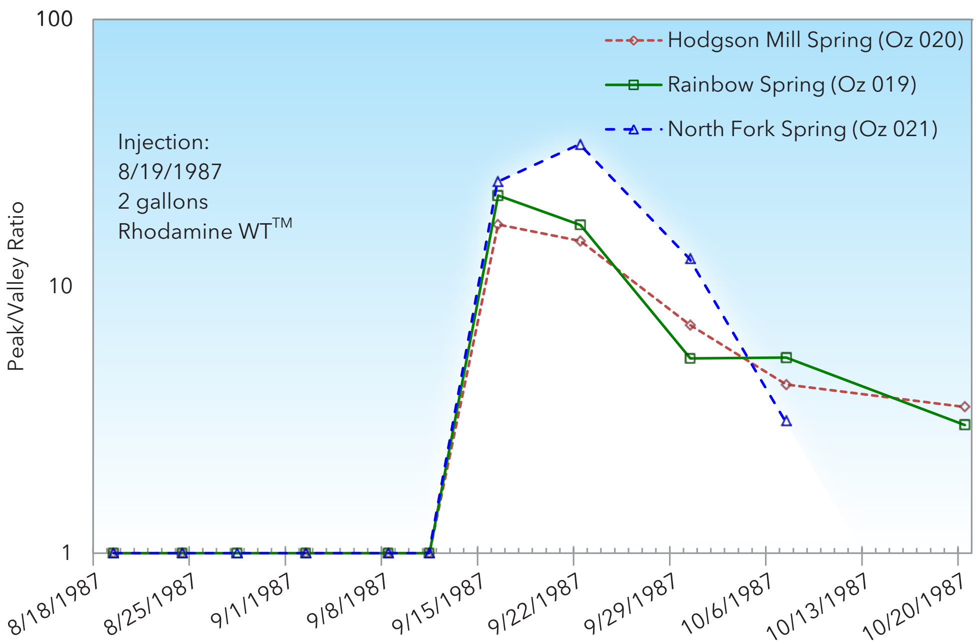


Figure 74. Dye recovery curves (carbon packet eluate) Fry Creek traces (Oz 019, Oz 020 and Oz 021).

Contemporary Traces Completed to Spring Group E

Fox Creek Injection (Traces Oz 035, Oz 036 and Oz 037)

While a number of small springs are present in the upper reaches of Fox Creek south of Mountain Grove, the Fox Creek watershed - a major tributary of Bryant Creek - is losing downstream. Fox Creek is typically dry from its upper to middle reaches to a point just upstream of its confluence with Bryant Creek. Available potentiometric mapping (Missouri Department of Natural Resources, 2006A) suggests this water resurges to the south. At 6:33 p.m. on Aug. 19, 2014, five pounds of eosine were injected into a losing reach of upper Fox Creek downstream of Mountain Grove (Figure 75). Surface flow at the injection site (IP45) was about 15 gpm, which entered a small pool; no flow occurred downstream.

Discussions with landowners indicate that the actual water loss zone in this branch of Fox Creek migrates upstream as weather conditions become drier. Limited observation by MGS staff confirmed landowner statements in this regard. Extensive background testing was conducted prior to dye injection with packets in place at numerous locations in the North Fork basin (NF5, NF6, NF9, NF10, NF15 and NF21) and the Rainbow/North Fork/Hodgson Mill Complex (NF1, NF2, NF26 and BC1). The only location where eosine was detected during the months of monitoring prior to the injection was in Blue Spring (Ozark County, NF5) on the North Fork. The dye recovered at Blue Spring was from the above-mentioned trace from Rattlesnake Spring in February 2014 and had dissipated prior to the injection.

First dye recovery from the Fox Creek injection was eight to 14 days later at all three springs of the Rainbow/North Fork/Hodgson Mill Complex in packets in place between Aug. 27 and Sept. 2, 2014. Large amounts of dye were recovered at Rainbow and Hodgson Mill springs with smaller recoveries at North Fork Spring. North Fork Spring was not monitored directly throughout most of the trace. The recovery curve (Figure 76) is from data collected downstream of the spring in the North Fork River. Packets upstream near Blue Spring did not contain dye while those downstream of North Fork Spring and upstream of Rainbow Spring did contain eosine. Peak dye recoveries occurred at all three springs in the complex between Sept. 2 and Sept. 9, 2014.

Photo by Cecil Boswell.

Figure 75. The senior author injecting eosine in upper Fox Creek.

Dora Semi-Replication Attempt (Trace Oz 038)

During this study, periodic specific conductance and temperature measurements of Hodgson Mill and Rainbow springs indicate that Hodgson Mill Spring water quality is impacted by local influxes of precipitation (Figure 77). Specific conductance at Hodgson Mill Spring was observed to nearly duplicate that of Rainbow Spring during drier periods. However, specific conductance decreased noticeably at Hodgson Mill Spring with respect to Rainbow Spring immediately after significant local precipitation events. This is consistent with the legacy Dora traces (Oz 001 and Oz 002) of Aley (1972) which indicate a local recharge area for Hodgson Mill Spring that is separate from the larger system that supplies the entire complex.

A semi-replication attempt was conducted to augment earlier work by Aley (1972). To that end, 2 pounds of sulphorhodamine B were injected into a small losing stream (IP64) downstream of the Dora School sewage discharge at 2:00 p.m. on April 14, 2015. Flow was estimated to be about five gpm at the time of injection with all flow lost to the subsurface within 10 feet downstream of the injection pool. This location is about one mile west of the Dora sinkhole injections. Among the points monitored during this trace were: Hodgson Mill Spring (BC1), Rainbow Spring (NF1),the North Fork River downstream of North Fork Spring (NF26), and Blue Spring (Ozark County, NF6).

Dye was first recovered at Hodgson Mill Spring in the packet in place from April 21 to April 27, 2015 with peak recovery occurring between April 27 and May 5, 2015 (Figure 78). Dye was not recovered during this trace at any of the other monitoring points which suggests that the supposition of a separate local recharge area for Hodgson Mill Spring is correct. Straight line travel distance was approximately 4.8 miles and time-of travel for first recovery was about seven to 13 days. All of the traces reported to the Rainbow/North Fork/Hodgson Mill Complex are shown on Figure 79.

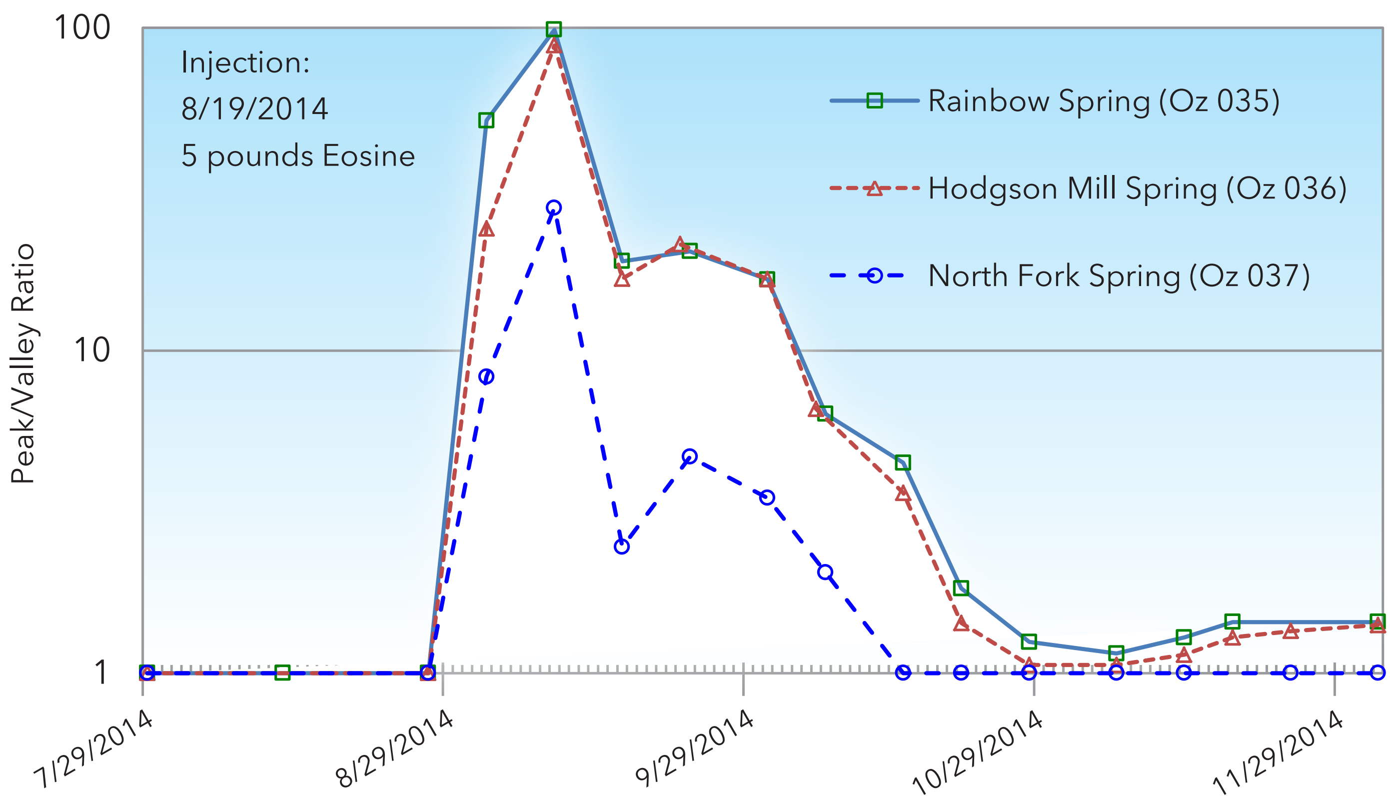


Figure 76: Dye recovery curves (carbon packet eluate) Fox Creek traces (Oz 035, Oz 036 and Oz 037).

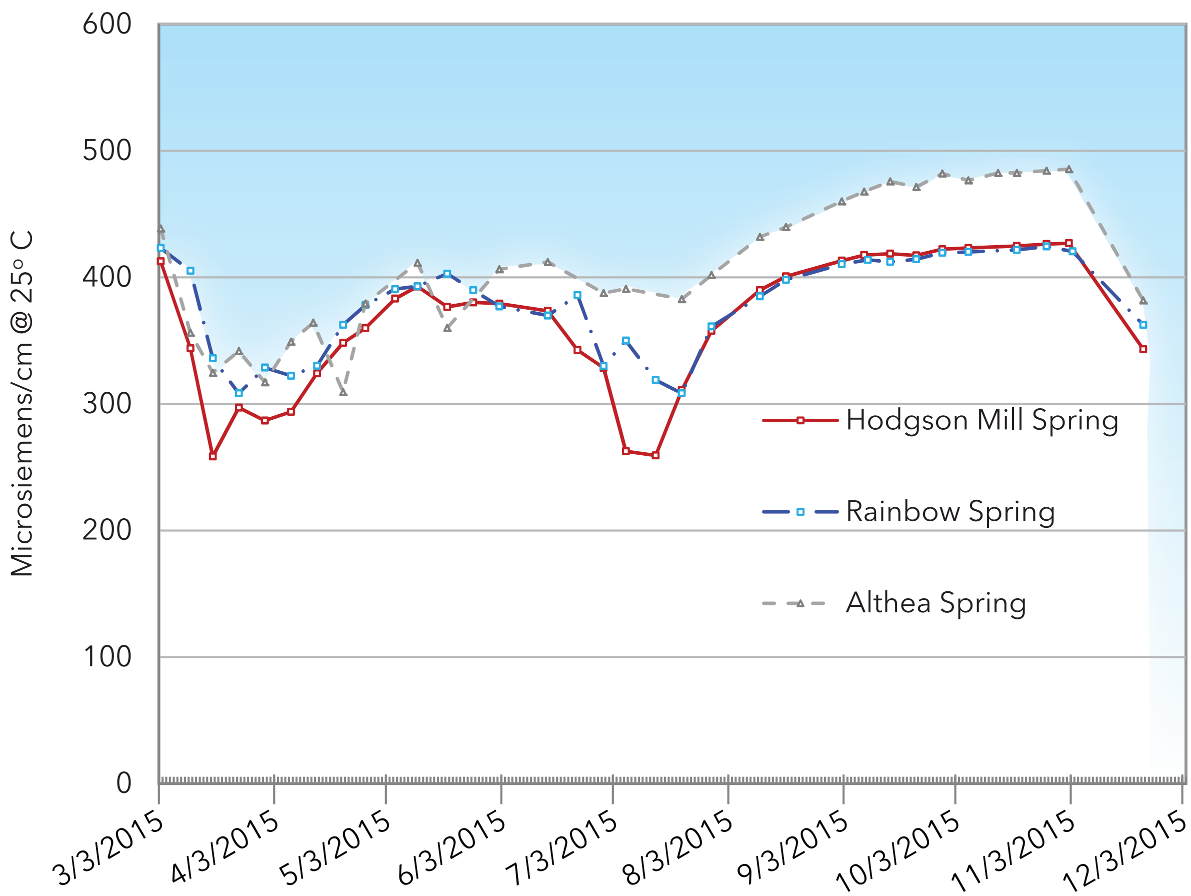


Figure 77: Temporal variation of specific conductance for selected springs in Ozark County.

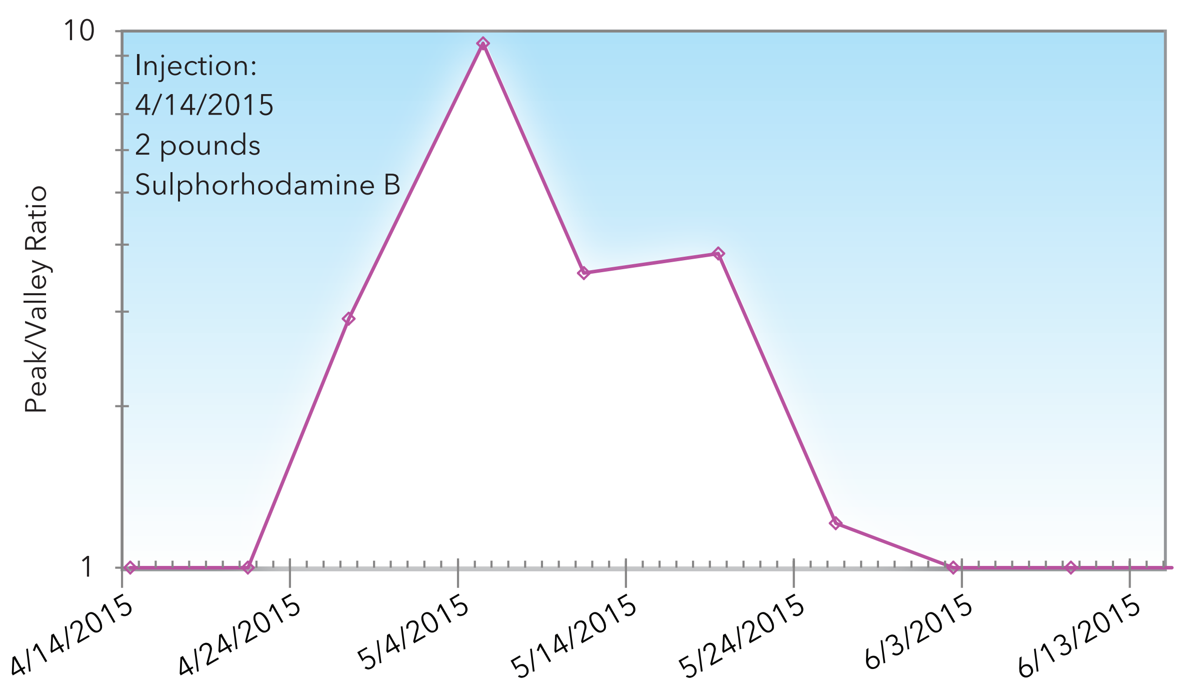


Figure 78. Dye recovery curve (carbon packet eluate) upper Bollinger Branch trace to Hodgson Mill Spring (Oz 038).

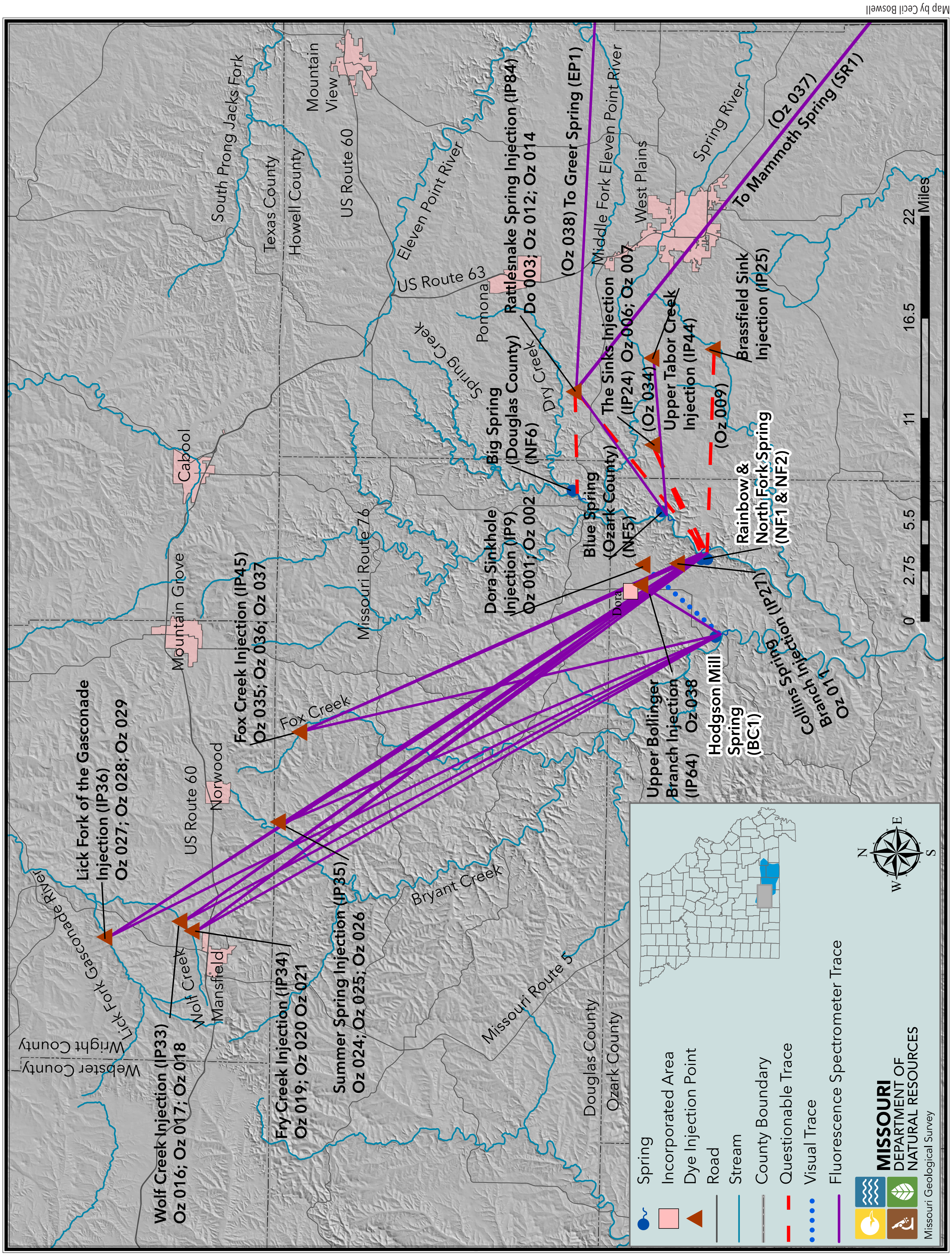


Figure 79: Current interpretation of traces in close proximity to the Rainbow/North Fork/Hodgson Mill Complex.


Photo by Bill Duley.

Figure 80. Panoramic view of Althea Spring.

Spring Group F - Althea and Wilder Springs

Althea Spring Description

Althea Spring, also known as Patrick Spring, is located just south of the North Fork River downstream of Missouri Route H in Ozark County on property owned by the Missouri Department of Conservation (Figure 80). It issues from the base of a small bluff of Gasconade Dolomite and flows through an alluvial valley for approximately 200 yards before flowing into the North Fork. Bolon (1935) reports that Althea Spring was the site of a historic mill while Vandike (1979, p.16) notes that a "dam and turbine were installed by a recent owner to generate electricity." The dam apparently installed for the electrical generation effort still remains. Vineyard and Feder (1974) report seven discharge measurements for Althea Spring with a maximum of 26.5 ft^3/s, a minimum of 13.3 ft^3/s and an average of 18.8 ft^3/s. Althea Spring has been measured by MGS on several occasions in recent years (Table 6). In addition, Crews (2008) installed a pressure transducer upstream of the dam to measure stage, from which flow was calculated on a periodic basis from Oct. 1, 2007 to Jan. 8, 2008, which indicated a general upward trend from about 11 ft^3/s to about 22 ft^3/s. The sign located on the trail to the spring which states that Althea Spring is the "23rd largest spring in the state," is based on data by Bolon (1935) and is overly optimistic. Nevertheless, the spring displays a relatively large and constant flow (Figure 81).

Source	Date	Measurement in ft^3/s
Crews, 2008	Dec. 18, 2007	19.0
Crews, 2008	Jan. 16, 2008	21.6
This Study	Nov. 3, 2015	21.05

Table 6: Althea Spring Discharge Measurements by MGS.

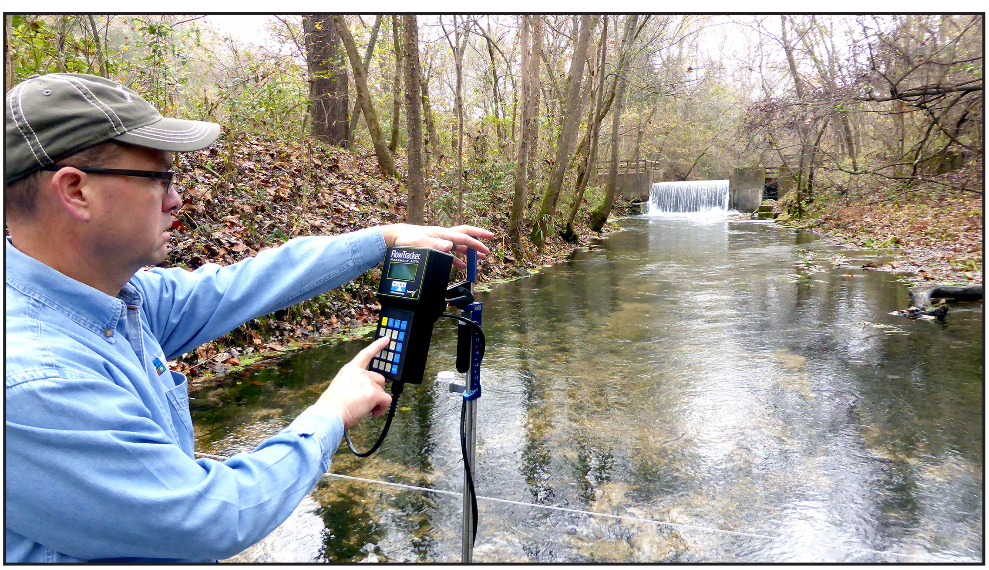


Photo by Bill Duley.

Figure 81. The coauthor measuring stream flow at Althea Spring.

Photo by Bill Duley..

Figure 82. Blue heron at Wilder Spring.

Wilder Spring Description

Wilder Spring, also known as Breakup Spring, is located on private property and issues from a low Roubidoux Formation bedrock bluff in the Spring Creek watershed that drains the area west of West Plains (Figure 82). During drier months, Wilder Spring is the largest spring in the Spring Creek watershed as there is continuous flow from this point downstream. Several stream flow measurements have been reported for Wilder Spring (Vineyard and Feder, 1974; Crews, 2008). In addition, Spring Creek has been measured at Duncan Ford, downstream from Wilder Spring on three occasions (Crews, 2008; Table 7). During relatively dry periods, flow from Wilder Spring constitutes the large majority of flow at Duncan Ford.

Legacy Traces to Group F Springs (Oz 003, Oz 030, Oz 031, Oz 032, and Oz 033)

Fletcher (1972A) described an injection on July 24, 1972 into Cureall Spring branch (IP16) that was traced to Althea Spring (NF3); a fluorometer was used to verify dye detection. This trace was based on a single carbon packet since there were no reported analyses after the first dye recovery in the packet representing the period between July 7 and Aug. 8, 1972.

Crews (2008) conducted traces (Oz 030, Oz 031, Oz 032 and Oz 033) from a losing stream in an upland area southwest of West Plains in support of an animal waste site evaluation. On Oct. 23, 2007, he injected three gallons of Rhodamine WT™ in conjunction with three gallons of liquid fluorescein into a losing stream

Location	Source	Date	Measurement in ft³/s
Wilder Spring	Vineyard and Feder, 1974	Sept. 5, 1925	6.20
Wilder Spring	Vineyard and Feder, 1974	Aug. 28, 1926	19.60
Wilder Spring	Vineyard and Feder, 1974	Aug. 18, 1934	9.03
Wilder Spring	Vineyard and Feder, 1974	Aug. 17, 1936	5.76
Wilder Spring	Vineyard and Feder, 1974	Nov. 6, 1954	8.51
Wilder Spring	Crews, 2008	Dec. 3, 2007	10.60
Wilder Spring	Crews, 2008	Dec. 18, 2007	58.20
Wilder Spring	Crews, 2008	Jan, 19, 2008	25.20
Duncan Ford	Crews, 2008	Dec. 18, 2007	44.30
Duncan Ford	Crews, 2008	Jan. 19, 2008	26.90
Duncan Ford	This Study	Nov. 3, 2015	21.47

Table 7: Wilder Spring and Duncan Ford Discharge Measurements

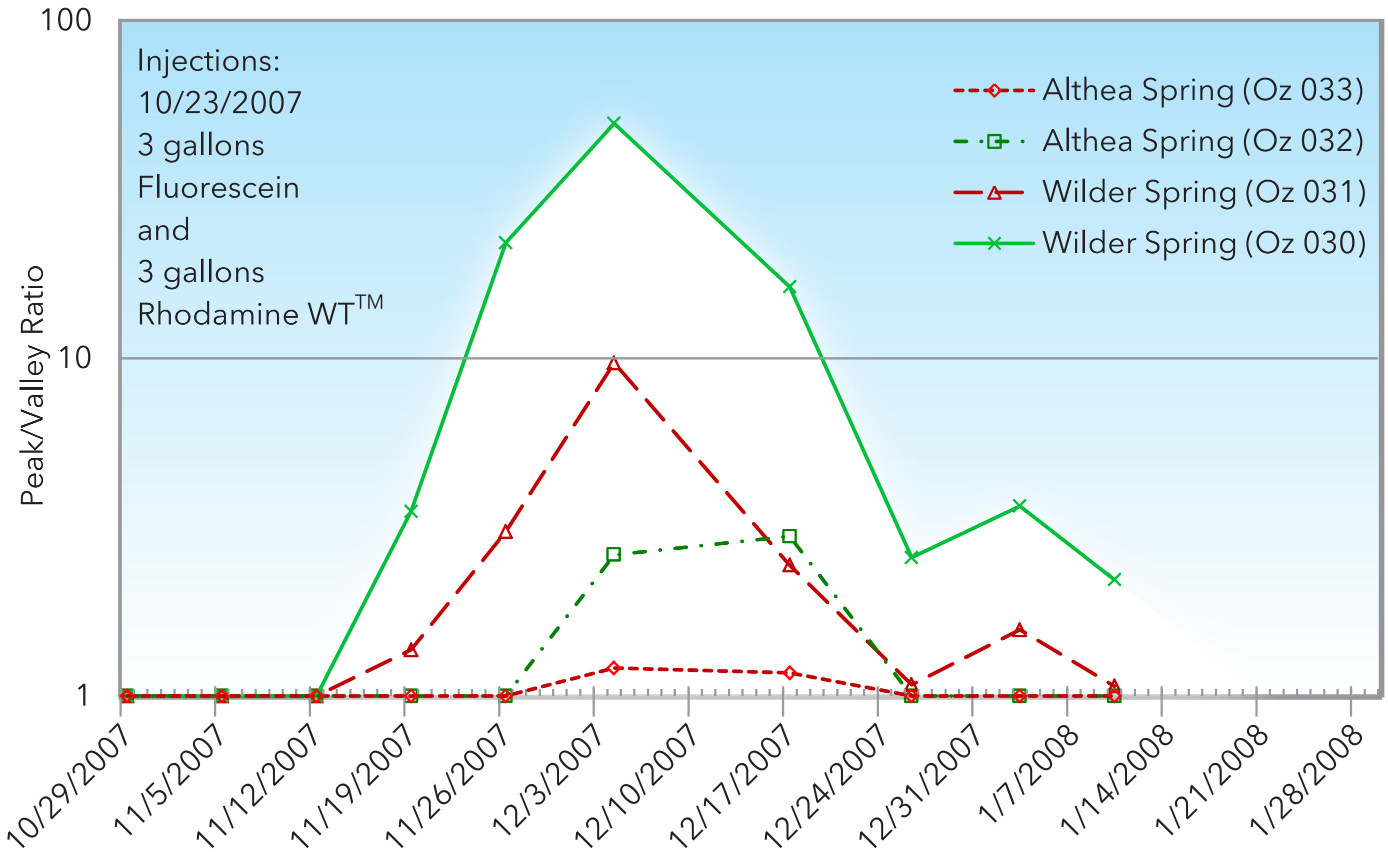


Figure 83. Dye recovery curves (carbon packet eluate) Collins Dairy traces (Oz 030, Oz 031, Oz 031 and Oz 033). Red lines represent Rhodamine WT™. Green lines represent fluorescein.

downstream of a dairy (IP37). Points monitored included the North Fork of the White River downstream of North Fork and Rainbow springs. Protocol 1 was used to collect and extract dye with analysis using a Hitachi model F-4500 fluorescence spectrometer in the MGS laboratory.

Both dyes were recovered at Wilder Spring (NF4) beginning with carbon packets representing the monitoring period of Nov. 12 to Nov. 19, 2007 (Oz 030 and Oz 031). Recovery of both dyes continued at Wilder Spring until the end of the field study in early January 2008. Althea Spring (NF3) in the North Fork basin also received both tracers, though at significantly reduced PVRs, with first recovery between Nov. 26 and Dec. 4, 2007 (Oz 032 and Oz 033). Both dyes were detected in packets collected through Dec. 17, 2007, but not after that date (Figure 83).

Contemporary Pottersville Injection (Trace Oz 039)

During this study, questions arose about some legacy traces from the east side of the North Fork that were reportedly recovered at Rainbow and North Fork springs. Traces conducted by Crews (2008) to Wilder and Althea springs (Oz 030, Oz 031, Oz 032 and Oz 033) from an area previously presumed to recharge Rainbow and/or North Fork springs indicated no recoveries in those locations. Consequently, MGS initiated a semi-replication attempt for trace Oz 009 (Vandike, 1979) by injecting five pounds of eosine into a losing stream, Spring Creek upstream of Pottersville (IP68), at 10:55 a.m. on Sept. 1, 2015 (Figure 84). Monitoring points included Althea Spring (NF3), Wilder Spring (NF4 and NF13), Rainbow Spring (NF1), Hodgson Mill Spring (BC1) and North Fork Spring (monitored in the river at NF26) as well as other points in the North Fork watershed (NF5, NF15).

The only recoveries for this injection occurred at Wilder Spring and downstream of Wilder Spring in Spring Creek. The dye recovery curve in Figure 85 is from Duncan Ford on Spring Creek since Wilder Spring was not monitored on a constant basis due to difficulty of access. Water samples and two carbon packets collected at Wilder Spring contained large amounts of eosine with the packet eluate achieving a maximum PVR of 162. First recovery occurred 14 to 21 days after injection while peak recovery occurred 21 to 28 days after injection. No evidence of surface flow was observed between the injection and Wilder Spring throughout the trace. To date, recharge to the Rainbow/North Fork/Hodgson Mill Complex from the east side of the North Fork of the White River has not been confirmed using fluorescent spectrometry methods (Figure 86).

Figure 84. Spring Creek Pottersville injection.

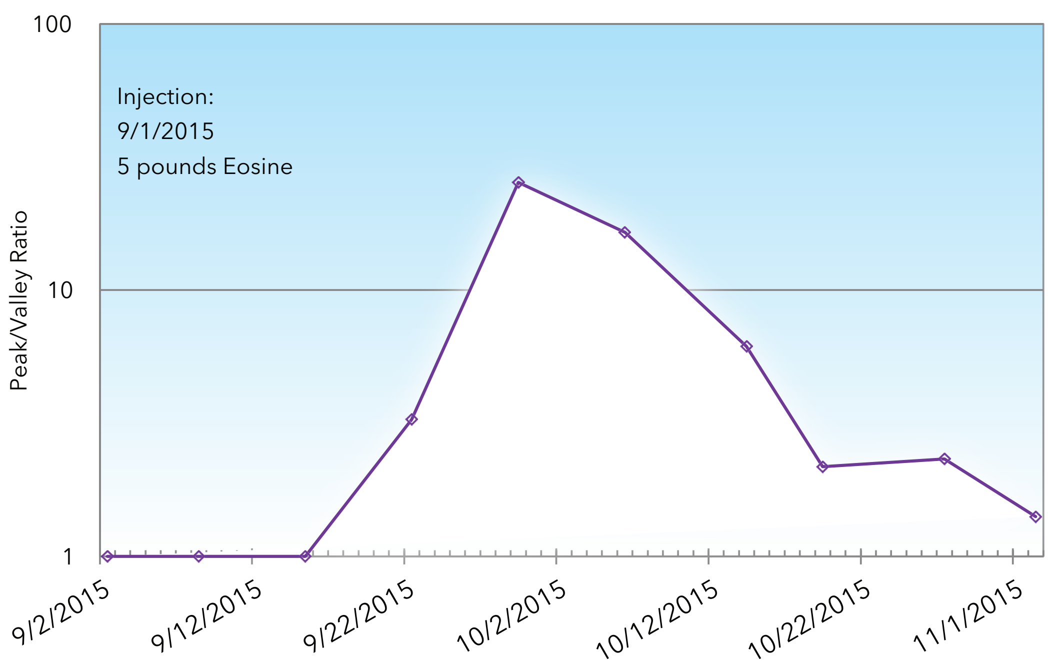


Figure 85: Dye recovery curve (carbon packet eluate) Spring Creek Pottersville to Wilder Spring trace (Oz 039).

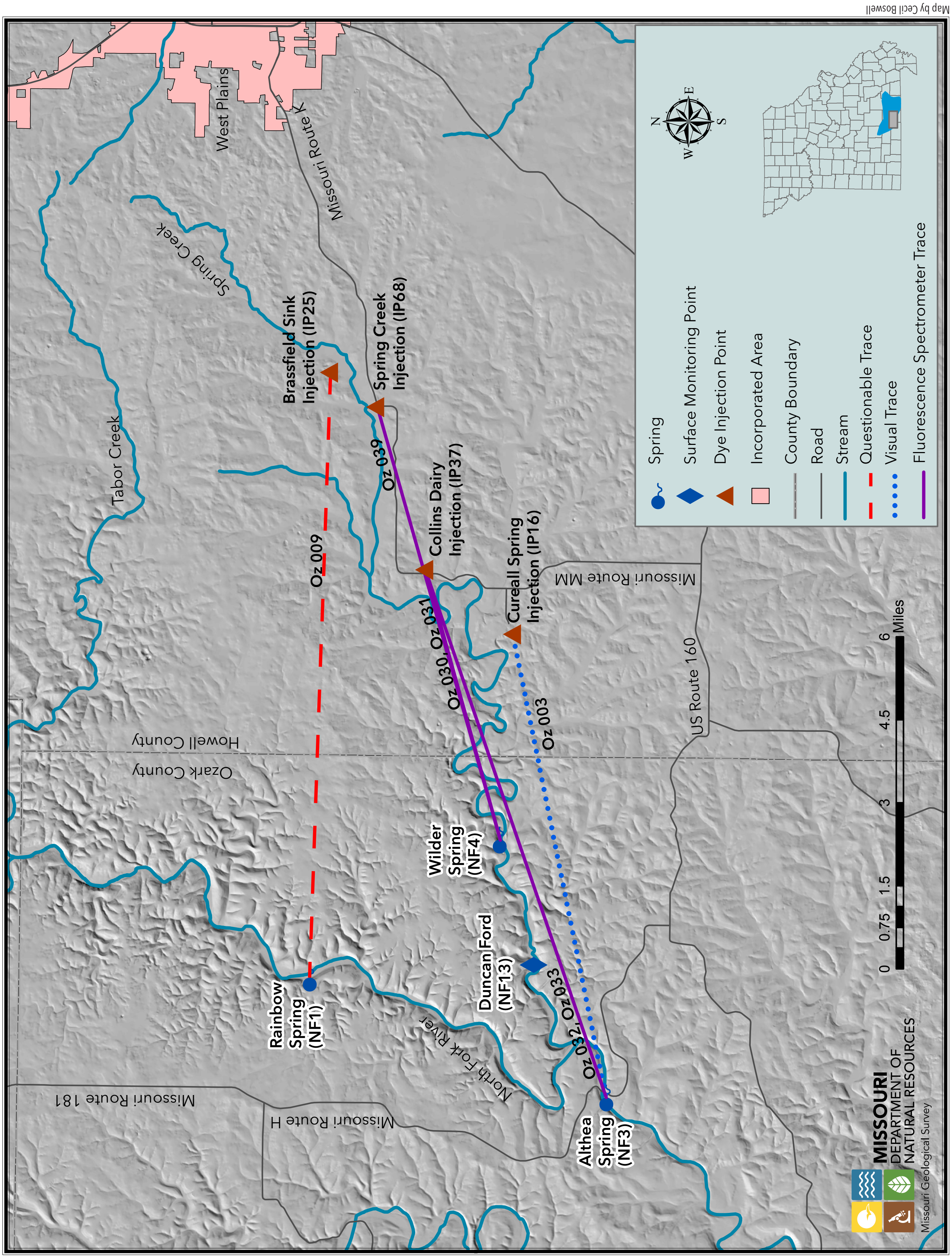


Figure 86. Current interpretation of traces in close proximity to Althea and Wilder springs recharge areas.


Photo by Bill Duley.

Figure 87. Big Spring (Carter County) in Winter.

Spring Group G – Big Spring (Carter County)

Big Spring (Carter County) Description

Big Spring is the largest spring in the Ozarks with discharge gaged continuously since 1922 (U.S. Geological Survey, 2016) at a mean rate of 448 ft^3/s (Figure 87). From water year 1982 to 2015 the average discharge has been about 478.3 ft^3/s. The main outlet issues from a large ascending conduit at the base of a bluff composed of Eminence Dolomite and Gasconade Dolomite adjacent to the Current River. A secondary outlet issues from the bluff downstream of the main boil.

Beginning in the late 1960s, the USFS and Ozark Underground Laboratories, under contract to the National Park Service, completed extensive studies to define the recharge area of Big Spring. Aley (1975) summarizes the early work. MGS staff used the original reports (Aley, 1968, 1973; Chaney, 1974; Fletcher, 1971, 1972C, 1975; Tryon 1975A) where available to summarize these traces. Additional traces, including replications, were completed in intervening years (Aley, 1992; Aley and Aley, 1987; Duley, 1982C; Imes, 1996; Imes and Fredrick, 2002; Imes et al., 2007) and are summarized in Appendices A-C as well. Descriptions of selected replication attempts follow.

Legacy Replications of Big Spring (Carter County) Traces (Cr 016, Cr 022, Cr 023 and Cr 024)

Attempts to replicate traces to Big Spring on the Current River have been limited. On July 9, 1982, Duley (1982C) injected two and one half gallons of Rhodamine WT™ into the discharge from the Mountain View wastewater treatment facility (IP13). Other points monitored included the Eleven Point River at Thomasville (EP12), and at Greer Crossing (EP26), Greer Spring (EP1A and EP1B), two points on the Jacks Fork (JF4 and JF5) and 10 nearby private wells. Activated carbon packets were used to collect dye. Packets were eluted in a 5 percent solution of potassium hydroxide in ethyl alcohol with the eluate analyzed using a filter fluorometer (Figure 88). Dye was first recovered in the Haley well located just north of U.S. Route 60 and 1000 feet northwest of Jam Up Creek from seven to 20 days after the injection.

Dye was also recovered at Big Spring (CR1), with the first recovery between 35 and 41 days after the injection and was present in packets in place until about 84 days after injection (Duley, 1982C).

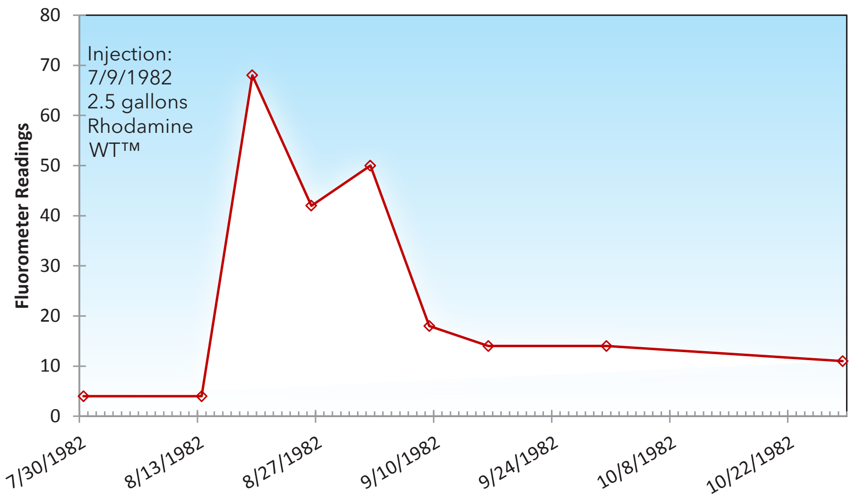


Figure 88. Fluorometer readings of carbon packet eluate at Big Spring (Carter County) during Cr 016 (Duley, 1982C).

This trace was replicated again in 2001 by the USGS using a water sampler with fluorescence spectrometric analysis (Imes and Fredrick, 2002). Four and one half pounds of Rhodamine WT™ dye were injected at 10:30 a.m. on July 10, 2001. Monitored points with no dye recovered included Jam Up Creek at Jam Up Cave (JF1), Jacks Fork near the mouth of Jam Up Creek (JF2), and Jacks Fork at Rymers Landing (JF3). First recovery of dye at Big Spring (CR1) was about 33 days after injection with peak concentrations recorded 42 days after injection. As the USGS dye trace was conducted, MGS monitored the Haley well with carbon packets using MGS Protocol 1. First recovery of dye at the well was 20 to 29 days after the injection and the peak recovery was 50 to 56 days after the injection (Peter Price, MGS, 2016 and unpublished file data). The peak PVR was 3.5.

The USGS completed two traces (CR 023 and Cr 024) from Barrett Spring Branch (IP70) in the Hurricane Creek watershed during 2002 (Imes et al, 2007). Four pounds of Rhodamine WT™ were injected on Jan. 31 after a storm. First recovery at Big Spring (CR1) was about six days later with the peak observed in fluorescence spectrometric analysis of a water sample collected 11 days after the injection. This trace (Cr 023) was replicated with a second post-storm injection of two pounds of Rhodamine WT™ on March 8. First recovery (Cr 024) was about six days after injection with the peak occurring on day eight.

A trace from the Middle Fork of the Eleven Point River has reportedly been replicated using lycopodium spores (Aley, 1975). However, both the original trace (Cr 009) and the replication (Cr 010) followed other traces (Cr 007 and Cr 008) that used the same tracers, injected at other locations, which were also reportedly recovered at Big Spring (CR1). It is possible that both of the Middle Fork traces (Cr 009 and Cr 010) represent a second pulse of tracer from the earlier injections. Recent depictions of the recharge area boundaries of Big Spring (Imes et al., 2007; Mugel, et al., 2009) do not include this injection location.

Legacy Attempt to Replicate Pig Spring Trace (Or 020)

Aley (1975) reported a trace from McCormack Hollow (IP53) to Dennig Spring (EP11). An attempt to replicate that trace (Imes, 1996) revealed a possible connection to Big Spring (Carter County-CR1) and positive connections (Or 062 and Or 061) to Wolfpen Hollow #1 and #2 springs (EP99, EP100). PVR analysis by MGS (Trace Cr 027) revealed that the Big Spring recovery (with a PVR of 2.5) was actually larger than the recovery at Wolfpen Hollow Spring #2 (PVR of 1.87). Wolfpen Hollow Spring #1 had a maximum PVR of more than 80 and was likely the primary recovery site (Or 062).

Attempts to Replicate the Middle Fork Eleven Point Traces (Cr 009 and Cr 010)

The Middle Fork of the Eleven Point River gains flow through a short reach on the east side of Howell County. This flow is normally lost to the subsurface at a point just upstream of the Oregon County line. At this location (IP12), Aley (1975) reported an injection of 10 pounds of fluorescein on Jan. 18, 1972. He reportedly recovered that dye at Big Spring (Figure 89) between Jan. 31 and Feb. 4, 1972. He also injected six pounds of Lycopodium spores at the same location on Feb. 9 of the same year and reported his first recovery of spores at Big Spring between Feb. 14 and Feb. 23, 1972.

MGS attempted three replication attempts from this location (see section describing traces to Bill Mac and other Middle Fork springs). The MGS interpretation of all data collected from these three injections is that this injection point is hydrologically connected to Bill Mac Spring (EP6) on the Eleven Point River and other points downstream in the Middle Fork. A number of springs are located downstream of the injection site and upstream of losing reaches that supply water to Bill Mac Spring. When a heavy precipitation and runoff event occurs, water apparently flows through a shallow karst system and surfaces at a series of springs downstream in the Middle Fork. Discharge from these springs flows through a series of large pools, but some - or all - of it is lost to the subsurface upstream of Blue Hole Spring depending on flow conditions. Water lost from the surface ultimately resurfaces at Bill Mac Spring.

MGS could find no new evidence to support the two legacy traces reported from the Middle Fork to Big Spring (Carter County). Reexamination of legacy data suggests that both of these traces closely followed other traces to Big Spring (Cr 007 and Cr 008) that used the same tracers (Lycopodium spores and fluorescein) as Cr 009 and Cr 010.

During the Cr 009 fluorescein trace, dye was injected just 39 days after the Cr 008 injection into Dowler Sink (IP11) and 29 days after the peak recovery for dye at Big Spring for that trace. Dye from the Dowler Sink injection was still present at Big Spring until 31 days before the first recovery reported for the Middle Fork injection (Aley, 1975). Given the inherent subjectivity of visual dye detection, it is likely that the first injection gave rise to misinterpretation of the supposed recovery from the Middle Fork injection.

Figure 89. Big Spring in Carter County.

The Lycopodium injections, Cr 007 at Blowing Spring (IP2) in Hurricane Creek and Cr 010 into the Middle Fork (IP12) were separated by about 110 days and the final recovery of Lycopodium from Cr 007 was recorded about 60 days prior to the first recovery for Cr 010. As Lycopodium spores are particulate, spores temporarily trapped en route by receding water levels, reduced flow velocities or transitory blockages or reversals in the recharge/transport process, could lead to a second or even a third pulse of spores as hydrologic conditions change.

MGS has documented slow pulses of fluorescent tracers at another large spring (Greer) with secondary, tertiary and even quaternary peaks taking up to six months to occur. It is reasonable to conclude that similar pulses could occur with dye or spores in the Big Spring system.

Both reported recoveries of the Middle Fork traces at Big Spring were weaker than the possible overlap traces that preceded them. Possible injection overlap in earlier traces combined with three failed replication attempts using improved detection methods suggest that the legacy injections (Cr 009 and Cr 010) were not actually recovered at Big Spring.

Contemporary Birch Creek Injection (Traces Cr 025 and Or 049)

Since recent tracing events show that the lower parts of Spring Creek (Eleven Point watershed) recharge Greer Spring and not Big Spring, a new trace was conducted using sewage from the city of Birch Tree as the impetus to carry dye into the aquifer. The Birch Tree wastewater treatment and disposal system discharges into Birch Creek, a tributary to Spring Creek. A straight line drawn from previous dye injections into the sewage discharge at Mountain View in Jam Up Creek that later resurfaced at Big Spring, would pass near the Birch Tree discharge. Thus it has long been assumed that flow from both discharges recharge Big Spring.

MGS staff injected 10 pounds of eosine at 1:30 p.m. on Aug. 4, 2015, into Birch Creek at the Shannon County Road 651 crossing (IP67). On the date of the injection all flow, about 10 gpm, was lost from Birch Creek within 0.5 mile downstream. A storm event in the area that evening led to three inches of precipitation in Winona. A flood surge may have washed some of the injected tracer farther down the valley than originally intended. Monitoring was conducted at Big Spring (CR1), Greer Spring (EP1A and EP1B), Eleven Point River at Thomasville (EP12) and the Eleven Point River at Greer Crossing (EP26).

Eosine was first detected in Big Spring in packets in place from Aug. 18 to Aug. 25, 2015. The peak recovery (6.35 PVR) at Big Spring occurred in packets in place from Aug. 25 to Sept. 2. Eosine was also first detected in Greer Spring upper and lower outlet packets from Aug. 18 to Aug. 25. This was the peak recovery as well, with PVRs of 1.7 and 1.87 at the upper and lower packets respectively.

The Big Spring dye recovery curve (Figure 90) indicates that it was the principal recovery site. The dye recovery curves for upper and lower Greer Spring are consistent in that they illustrate a more dilute and more complex passage of dye. Because of the precipitation event on the injection date, it is not possible to determine with certainty whether some of the dye recovered at Greer Spring was the result of a direct subsurface connection to upper Birch Creek or of water loss at some point downstream. The most likely scenario is that the first and largest peak at Greer Spring is the result of direct runoff into a lower losing segment of Spring Creek while the later, smaller recoveries represent a slower minor subsurface connection from upper Birch Creek. This and other traces to Big Spring are shown on Figure 91.

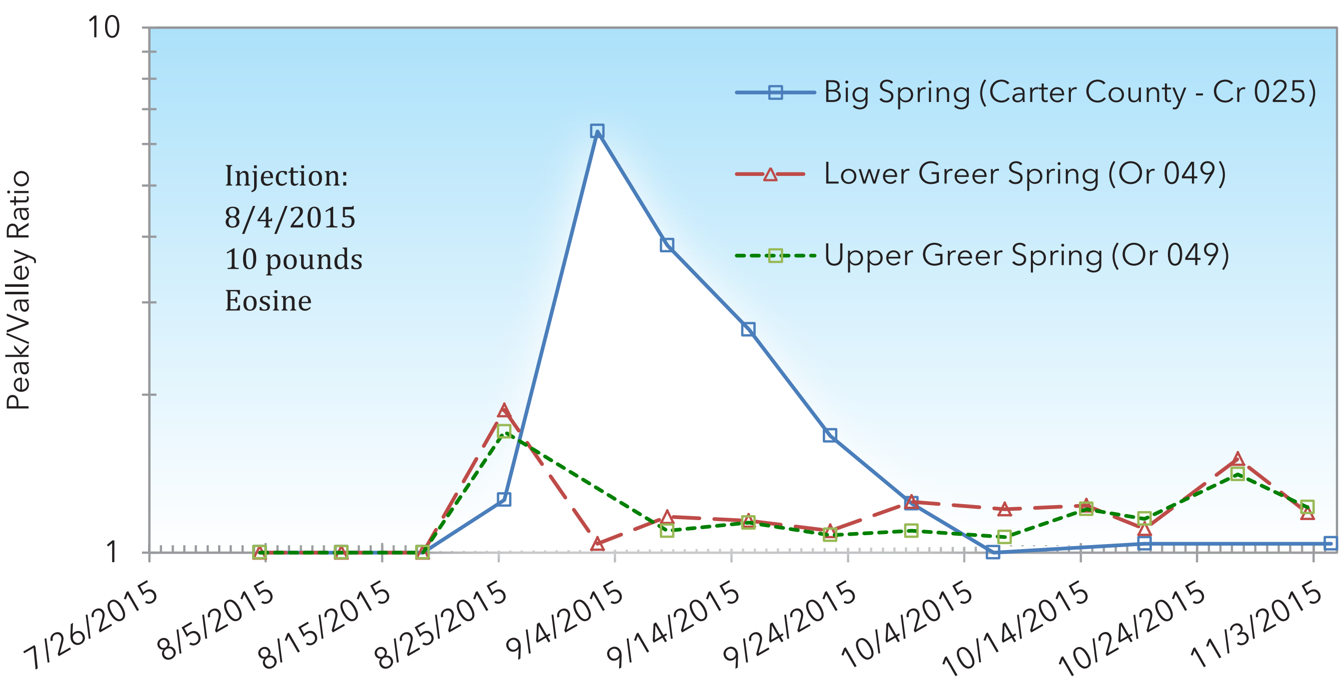


Figure 90. Dye recovery curves (carbon packet eluate) Birch Creek traces (Cr 025 and Or 049).

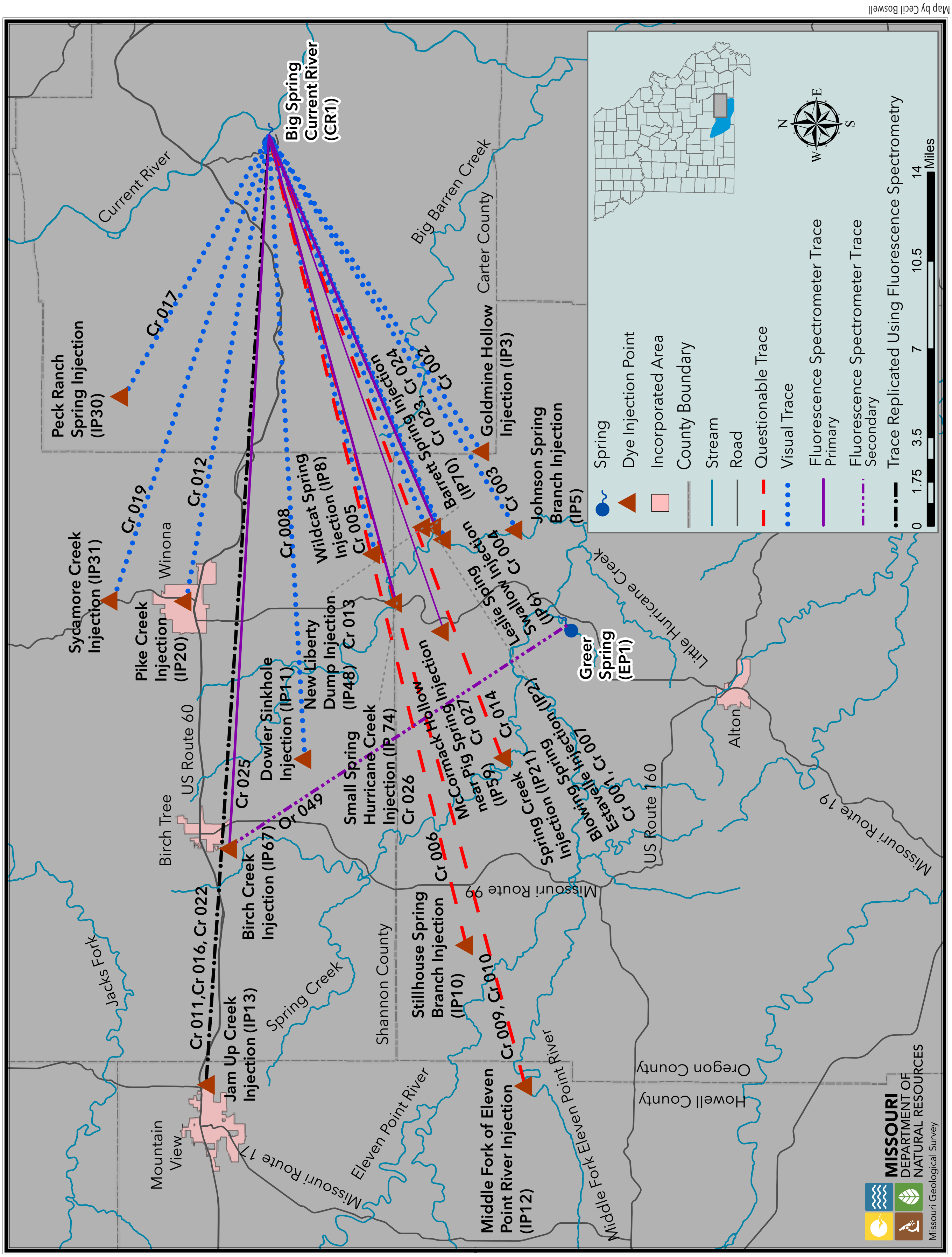


Figure 91. Current interpretation of dye traces attributed to Big Spring (Carter County) recharge area.


Photo by Bill Duley.

Figure 92. Panoramic view of Big Spring (Douglas County) on Spring Creek, North Fork watershed.

Spring Group H – Big Spring (Douglas County)

Big Spring (Douglas County) Description

Big Spring on Spring Creek (Douglas County) is a relatively large spring located on USFS property (Figure 92). It issues from the base of a steep hillslope composed of huge boulders of Roubidoux sandstone. Vineyard and Feder (1974) list four measurements that range from 3.2 to 26.8 ft^3/s. Visual estimates of flow from this spring on numerous occasions suggest that the 3.2 ft^3/s measurement was during prolonged drought, with a more normal discharge in the 10 to15 ft^3/s range. MGS staff measured Big Spring on one occasion during the study with the resulting discharge of about 21 ft^3/s under relatively high flow conditions.

Legacy Traces to Big Spring, (Douglas County) (Do 001, Do 002, and Do 003)

The only documented traces reported to Big Spring in the past were from Still Spring Branch (IP26) and IP 84 (Do 003) in Rattlesnake Spring Branch (Vandike, 1979). The Still Spring Branch connection was essentially replicated by Vandike (1979) by using optical brightener and fluorescein in the same injection (Do 001 and Do 002). The Rattlesnake Spring Branch trace must be considered speculative since an attempt to replicate Do 003 indicated that it is unlikely that any significant amount of water from Rattlesnake Spring resurfaces here during low or even moderately high flow conditions. It is possible, however, that some water from the upper reaches of Dry Creek, which include Rattlesnake Spring, may resurge here after large precipitation events saturate the deeper karst system that feeds Greer Spring, Mammoth Spring, and Blue Spring (Ozark County). As reported in this study, one small recovery of dye occurred here during the upper Dry Creek replication attempt. The authors concluded that this recovery was due to unusually wet conditions in the latter part of that trace.

Contemporary Dribble Cave Spring Injection (Trace Do 009)

As a result of the replication attempt from Rattlesnake Spring, an additional trace was conducted from a lower reach of Dry Creek. The purpose for this trace was to better determine interrelationships between the recharge areas of Greer, Mammoth and Big Spring (Douglas County). The new injection point (IP61) was located about 1.8 miles northwest of Rattlesnake Spring and is in the valley bottom of Dry Creek at an elevation of about 880 feet msl. A very small spring – less than one gpm discharge – issues from the mouth of a small cave in the right valley wall (looking downstream).


Photo by Bill Duley.

Fig 93. The coauthor during Dribble Cave Spring dye injection.

Observation of Dry Creek indicated that this reach rarely sees flow from upstream, as the main channel was dry on numerous occasions even after heavy precipitation events. MGS named the spring "Dribble Cave Spring" which, on the date of the injection, flowed only several feet on the surface before going underground in a small puddle near the valley bottom (Figure 93).

At 4:45 p.m. on March 11, 2015 MGS staff injected two gallons of Rhodamine WT™ 20 percent solution into the Dribble Cave Spring discharge in the Dry Creek valley. A repeat observation of the injection site on March 17 indicated that no surface flow had occurred in the valley since the injection. Leaves from the previous fall remained strewn across the valley floor as they had during previous visits. The only obvious sign of the earlier injection was a few stained leaves in the small puddle where flow goes underground. Points monitored included: Blue Spring (Ozark County-NF5), Rainbow Spring (NF1), Spring Creek (NF 24), Dry Creek (NF25) and two points on the North Fork (NF15 and NF26).

First dye recovery (PVR of 78.89) was less than six days after injection at Big Spring in packets in place between March 11 and March 17 (Figure 94). Much smaller amounts of dye were also recovered in the North Fork in packets collected as far downstream as North Fork Spring (NF26) on March 17.There was no indication that any of the dye recovered downstream of the Big Spring recovery travelled through the subsurface. It is only mentioned here to note that the dye clearly had been issuing from Big Spring for a considerable amount of time before the first recovery packet was collected. Peak dye recovery was six to 13 days after injection.

Since dye from this injection was not recovered in any of the same locations as the nearby Rattlesnake Spring injection, it appears that there is a significant groundwater divide between this injection site and Rattlesnake Spring. The upper reaches of Dry Creek (North Fork basin) flow to Mammoth and Greer springs with a minor component flowing to Blue Spring (Ozark County) while the lower reaches flow to Big Spring (Ozark County). See Figure 95 for a map of traces to Big Spring Douglas County.

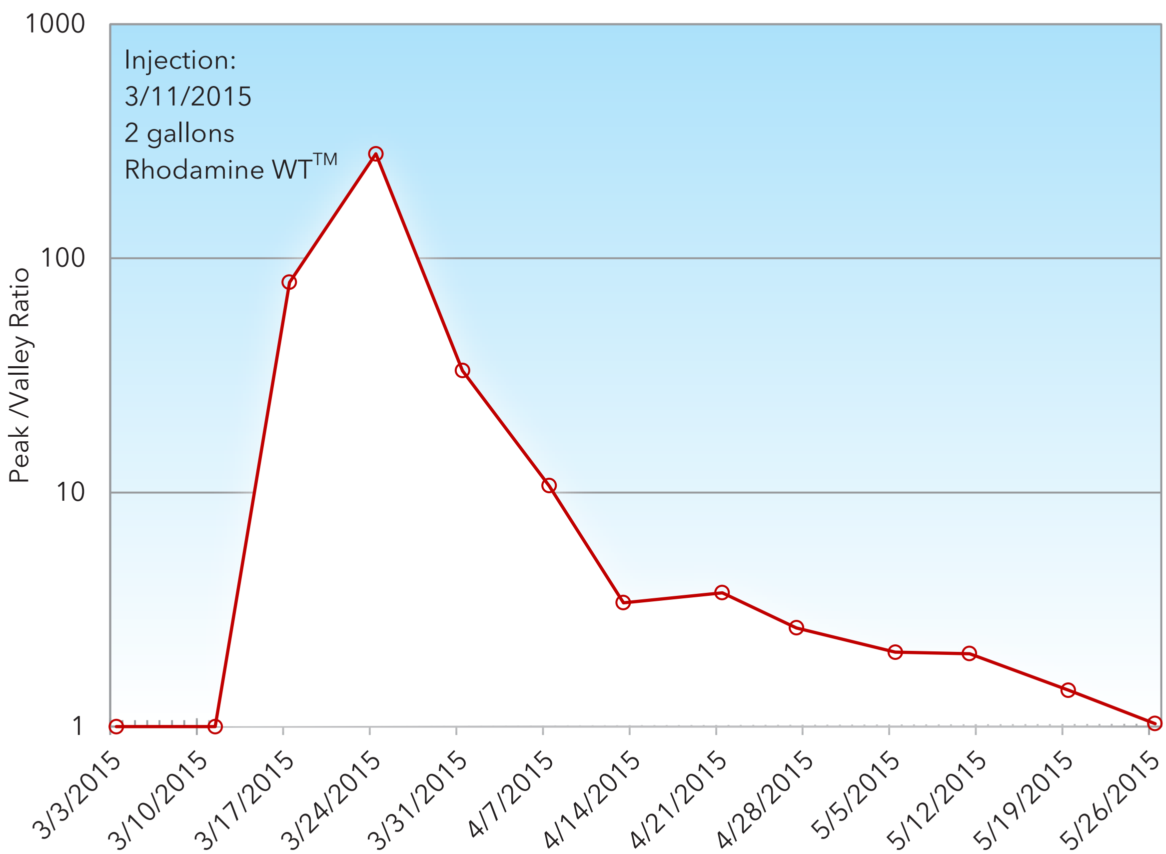


Figure 94: Dye recovery curve (carbon packet eluate) Dribble Cave Spring to Big Spring Douglas County (Do 009).

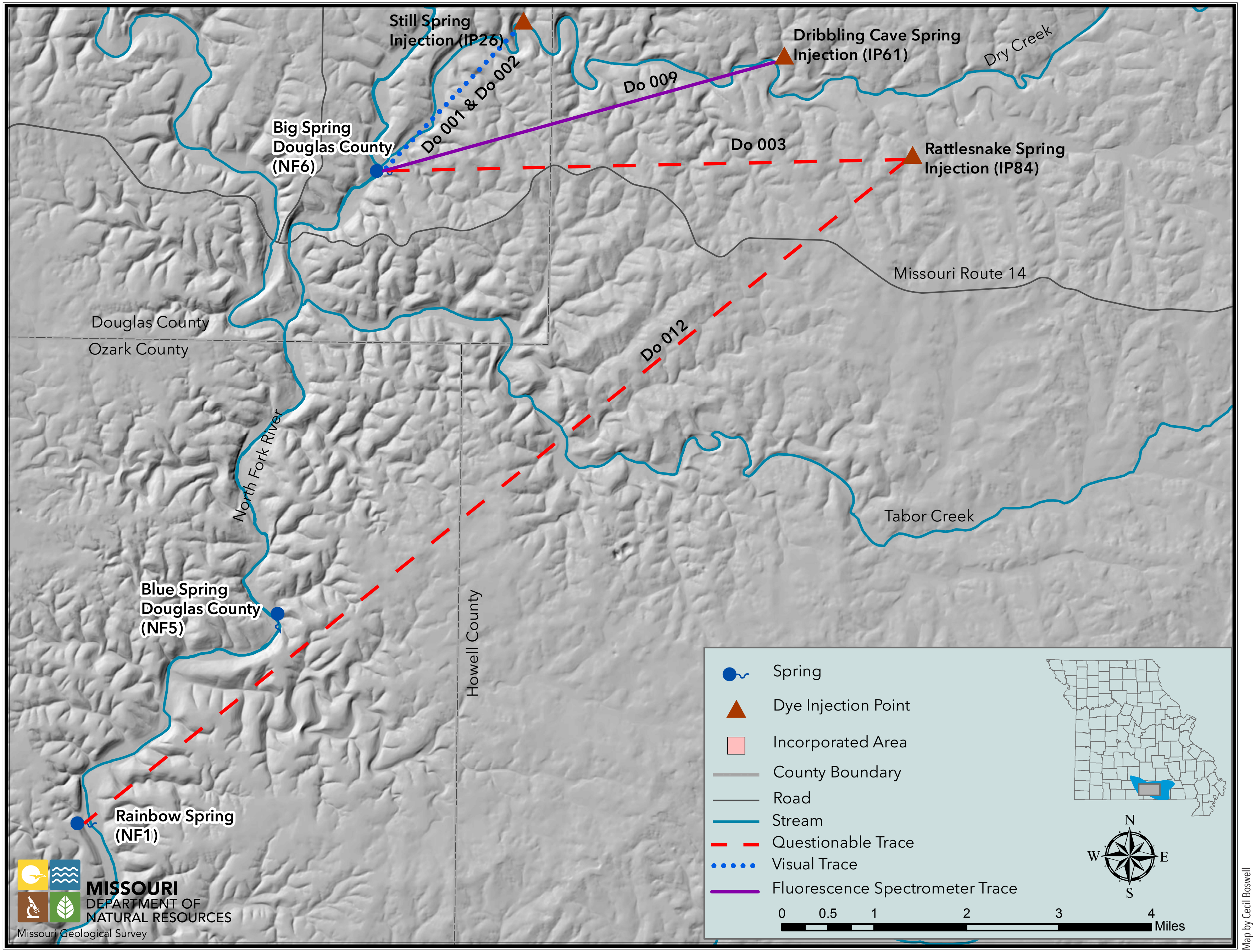


Figure 95. Current interpretation of traces in close proximity to Big Spring Douglas County.

Spring Group I - Warm Fork Spring

Warm Fork Spring Description

Warm Fork Spring is located on private property on the Warm Fork of the Spring River just upstream from the MDC's Warm Fork Conservation Area. MGS was unable to gain access to the actual spring but did gain information about its source and flow (Figure 96). Since Warm Fork Spring is not described in Vineyard and Feder (1974) the Warm Fork was measured by MGS staff on two occasions to obtain a baseline flow for future investigators. On both occasions no surface flow was observed at Oregon County Road 348 just upstream of Warm Fork Spring suggesting that these measurements are indicative of the actual flow of Warm Fork Spring on these dates. Two discharge measurements, taken slightly more than 3 months apart during this study, show a variable flow rate (65.29 to 5.85 ft^3/s).

The Warm Fork is an interesting stream in that the largest part of its surface drainage comes from the northwest, with its headwaters north of West Plains where the stream is called Howell Valley. Much of the watershed upstream of Warm Fork Spring would be classified as a losing stream. Legacy water tracing efforts indicate that at least some of the water lost from Howell Valley resurfaces at Mammoth Spring in Arkansas. Limited observations within about five miles upstream of Warm Fork Spring show that surface flow at Missouri Route M occurs only during extremely wet periods. Significant flow can often be observed downstream of Missouri Route M at Oregon County Road 333 at Culp Ford.

Since no significant surface drainages enter the Warm Fork between these crossings, a spring or series of springs appear to produce significant amounts of discharge for some time after large precipitation and runoff events. Discharge at County Road 333 was measured at 6.37 ft^3/s on July 29, 2015. The most likely sources are upstream in the channel of Howell Valley and its tributaries and in the large sinkhole plain (Harbeston Sinkhole Karst Zone) located just west of Koshkonong (Figure 96). The origin of this water can only be determined by additional investigations.

Photo by Bill Duley.

Figure 97. The coauthor injecting dye at Oregon County Road 333.

Map by Cecil Boswell

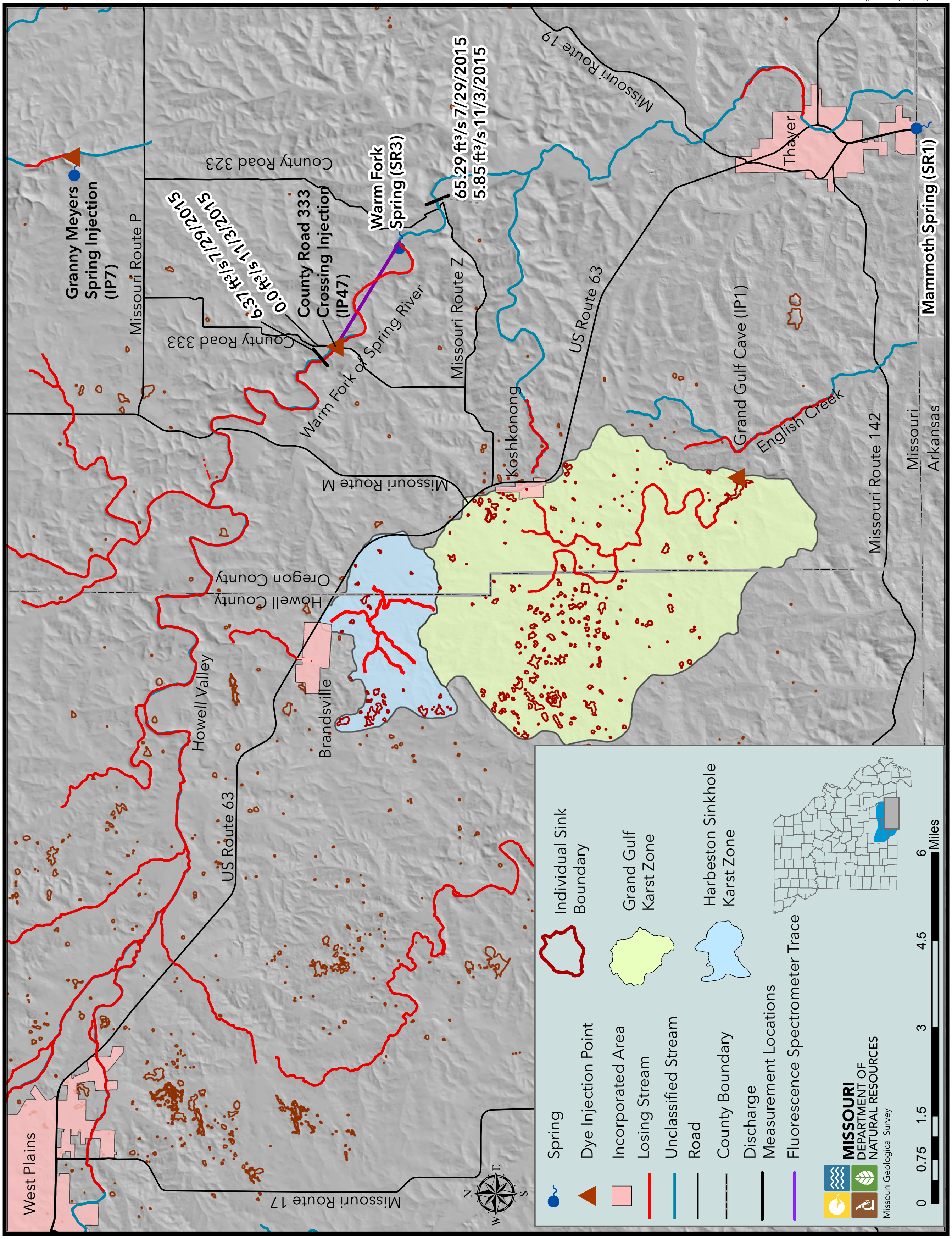


Figure 96. Warm Fork Spring region and Trace Or 044.

Warm Fork Spring Trace (Or 044)

Water that is observed flowing through Culp Ford under some conditions is lost to the subsurface before it reaches Warm Fork Spring. At 7:50 a.m. on Jan. 21, 2015, one pound of fluorescein was injected into approximately one ft³/sec flow at Culp Ford (Figure 97 - IP47). No flow was observed downstream at County Road 348 throughout most of the trace. Since the authors were unable to access Warm Fork Spring, MGS monitored the Warm Fork downstream at County Road 323 (SR9). Mammoth Spring (SR1) was also monitored throughout the trace with no dye recovered there.

First recovery and peak dye recovery at SR9 occurred in the same packet retrieved six days after injection on Jan. 27, 2015 (Figure 98). Notably, by Jan. 27, the pool used for dye injection on Jan. 21 was dry. The small secondary recovery of dye that began in early March likely represented flushing of dye through the injection pool as rains brought flow to Culp Ford. The recharge area of Warm Fork Spring remains largely undefined at this point. While the MGS trace demonstrates that some water from the Warm Fork does resurge here, a bigger portion, and certainly base flow, comes from another source or sources.

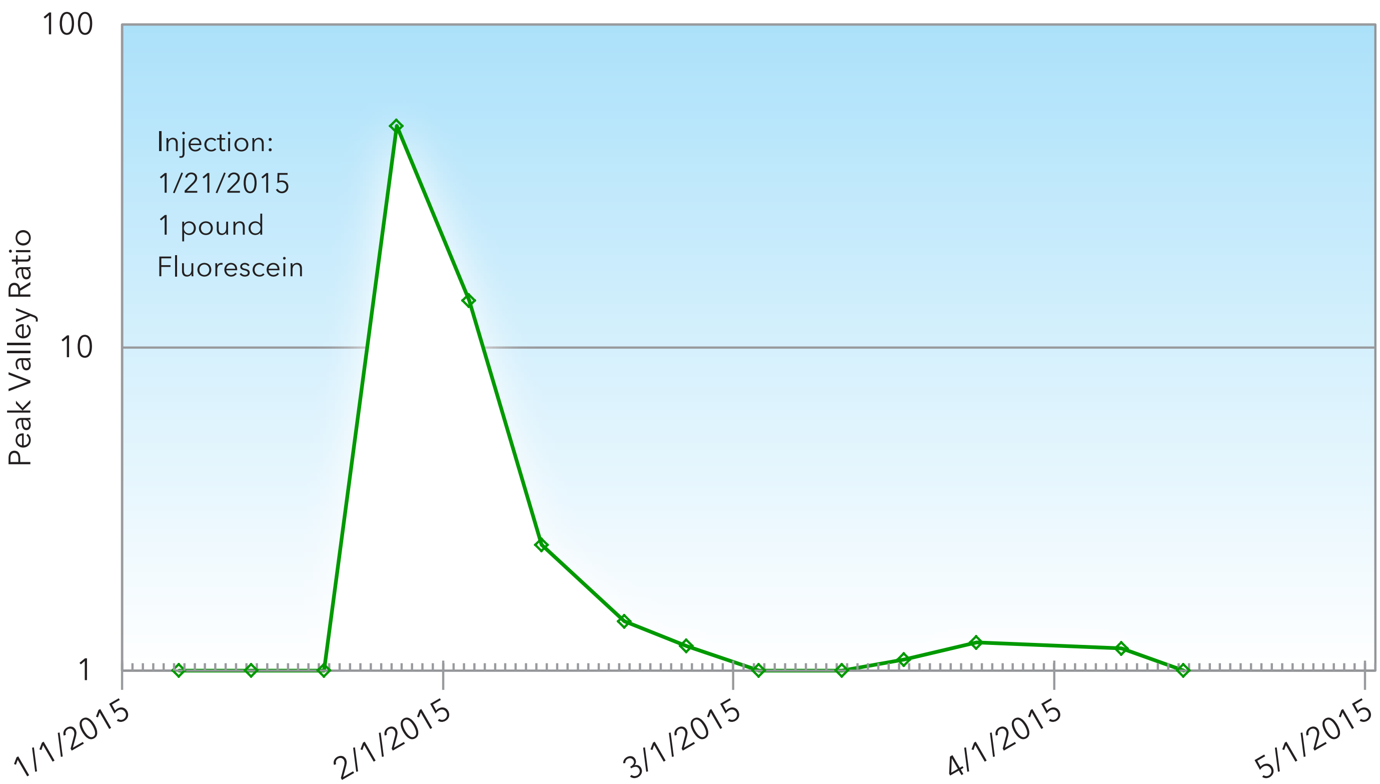


Figure 98. Dye recovery curve (carbon packet eluate) Warm Fork to Warm Fork Spring trace (Or 044).

Spring Group J - Dennig Complex, Graveyard Complex and unrecorded Little Hurricane Creek Spring

Spring Group J Descriptions

Past investigations of the Dennig and Graveyard complexes (Fletcher, 1972F; Vineyard and Feder, 1974; Kleeschulte, 2000) reference springs located in the southern half of Section 32, Township 25 North, Range 3 West located just north of the Eleven Point River. Unfortunately, at least three different names - Huff, Dennig and Graveyard - have been used and the locations given are imprecise. USFS internal memos (Fletcher, 1972F, p. 1; Tryon 1975D, p. 1) dealing with traces in the region normally link all of these names together as "Huff Spring." Fletcher (1972F, p. 1) refers to a complex of "upper" and "lower" outlets. Vineyard and Feder (1974, p. 68) use the terms "Dennig upper" and "Dennig lower" with the "upper" spring having a smaller recorded discharge than the "lower" spring. Kleeschulte (2000, p. 5) recorded two Dennig springs followed by the notation: "Series." He measured the flow of upper Dennig at 56 ft^3/s while estimating flow of lower Dennig at 5 ft^3/sec.

The authors of this study located two significant springs in the general area that are similar in size to the Dennig or Huff Spring of the literature. One (Figure 99) is about 100 yards downstream of the Ross Cemetery shown on the Greer USGS 7.5' quadrangle map.

A larger spring is located approximately 0.4 miles downstream from the spring near the cemetery (Figure 100). To further complicate the matter, each of these springs has more than one outlet with smaller rises seen as sand boils on the alluvial floodplain. In addition, the upstream complex has a wet-weather orifice located near the north edge of the alluvial valley that normally has no discharge (Figure 101).

While the springs near the graveyard could be called "upper Dennig" and the large series of springs downstream could be called "lower Dennig," there is good reason not to do so. The upstream complex near the cemetery has a distinct specific conductance signature as compared with that of the larger downstream complex. Thus, for this report, the upstream complex is termed "Graveyard" while the larger complex downstream is called "Dennig" (Figure 102).


Photo by Bill Duley.

Figure 99: Perennial portion of Graveyard Complex (Graveyard - Main).


Photo by Bill Duley.

Figure 100. Dennig Complex Main spring branch.

The following descriptions are given to aid future investigators. A series of small sand boils in the alluvium mark the upstream end of Dennig Complex. Flow from the boils proceeds about 50 feet to the southeast where a large orifice discharges a large amount of flow into an alluvium-walled valley. For the purposes of this study, this large spring is termed "Dennig Complex – Main." This spring branch parallels the Eleven Point River for


Photo by Bill Duley.

Figure 101. Wet weather orifice Graveyard Complex during low flow.


Photo by Bill Duley.

Figure 102. Changing packets at Dennig Complex – Minor.

about 1/3 mile to the southeast before discharging into it. Another part of the complex, termed Dennig Complex – Minor, issues from the alluvium between the Main Dennig Complex spring branch and the Eleven Point River (Figure 102). The flow from this spring splits; most of the water follows a small channel about 100 feet to the southwest into the Eleven Point River, about 0.2 miles upstream of the discharge from the rest of the complex. The remaining flow from Dennig Complex - Minor moves to the northeast where it enters the Dennig Complex – Main spring branch upstream of the river (Figure 103).

There is at least one unreported spring of note in Little Hurricane Creek south of the Eleven Point River discussed below. Resources did not allow locating and sampling springs in the Little Hurricane as part of this study. They are mentioned because a trace conducted during the study partially resurged at some point in this valley. Further investigation would be required to determine the location of this spring - or springs.

Legacy Traces to Dennig Complex (Or 004, Or 006, Or 011 and Or 020)

Four legacy traces - Or 004, and Or 006 (Aley 1975), Or 020 (Tryon 1975D) and Or 011 (Fletcher, 1972F) - have been reported to this complex, all from locations north and west. None of these traces have been directly replicated though the Pig Spring (IP54) trace (Or 020) could be considered to be a semi-replication of the Horse Trail Spring (IP52) trace (Or 011). A replication attempt of the Pig Spring trace (Or 020) by Imes (1996), reinterpreted during this study, revealed that dye was recovered in three other springs (Or 062 to Wolfpen #1 at EP99, Or 061 to Wolfpen #2 at EP100 and Cr 027 to Big Spring in Carter County – CR1), but not at the Dennig Complex (EP11) or the Graveyard Complex (EP 68).

In fact, review of all the legacy traces to the Dennig or Graveyard complexes reveal inconsistencies (Table 8). Regional studies by the USGS have either disregarded these traces (Imes et al., 2007) or did not use them to alter recharge area interpretations (Mugel et al., 2009).

	Pond Hollow Or 004 (Aley, 1975)	Davis Pond Or 006 (Aley, 1975)	Horse Trail Spring Or 011 (Fletcher, 1972F)	Pig Spring Or 020 (Tryon, 1975D)	Simpson Pond Or 010 (Fletcher, 1972D)
Discounted by other studies	✓	✓	✓	✓	✓
Potentiometric Map Conflict	✓				
Subjective Detection Methods	✓	✓	✓	✓	✓
Questionable Timing	✓		✓	✓	✓
Single Recovery of Tracer		✓		✓	
Near Recharge Area Boundary	✓		✓	✓	✓
Lacks Monitoring Point Data					✓

Table 8: Checklist of potential reasons for replication of traces near the Dennig Complex.

Map by Cecil Boswell

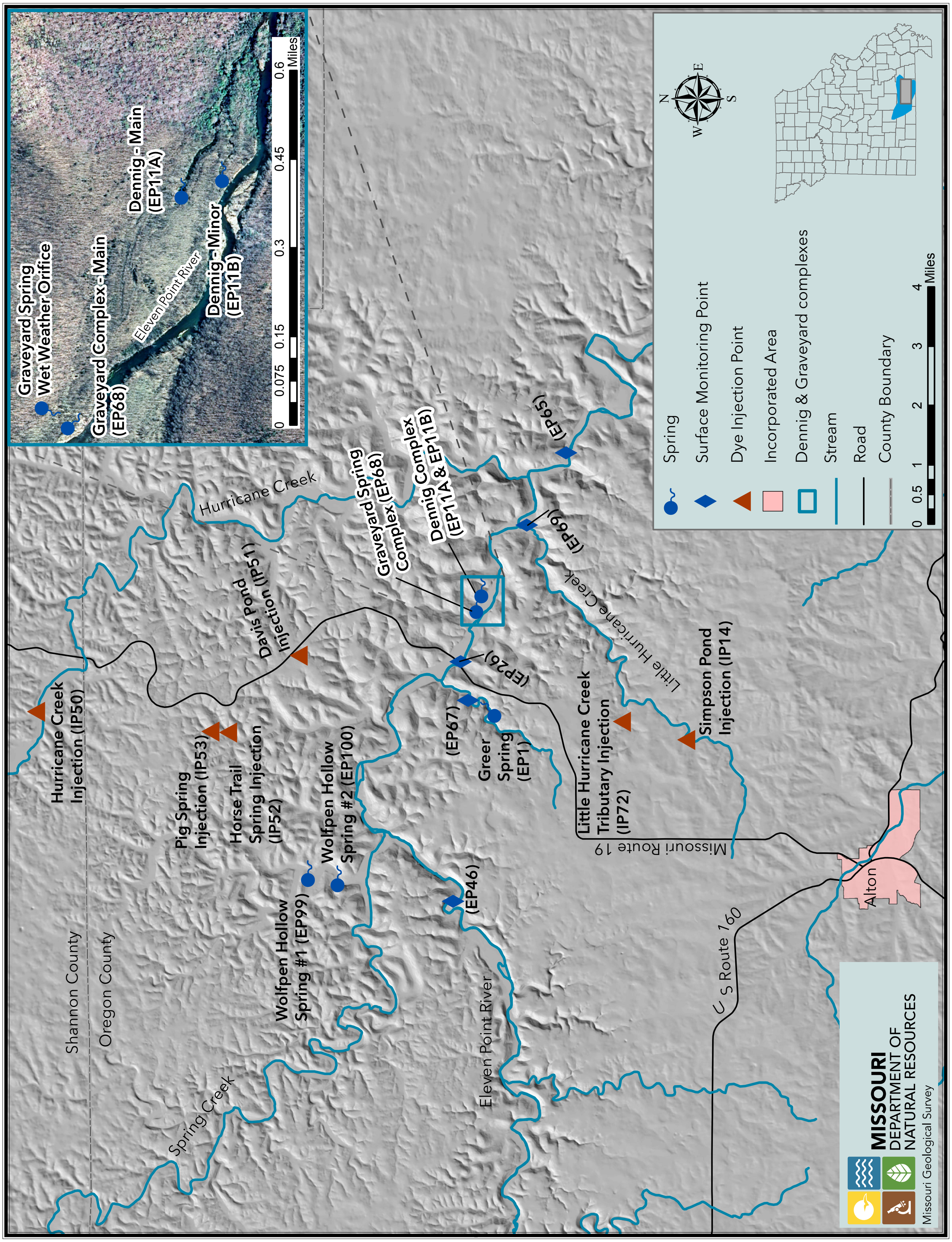


Figure 103. Dennig and Graveyard complexes vicinity.

An attempt to conduct a semi-replication trace from the area near Simpson Pond shows a clear connection (Or 059) between that area and the Dennig Complex (see discussion below). While this connection does not eliminate the possibility of recharge coming from the north, it clearly shows that a sizeable area may recharge the Dennig Complex from the southwest side of the Eleven Point River. The legacy dye recovery at Dennig Spring which was attributed to the Horse Trail Spring injection, may represent dye from the Simpson Pond Injection (Figure 104). The earliest investigators may not have considered flow beneath the river to be likely. Analysis of the information attributed to the legacy traces reveals the following:

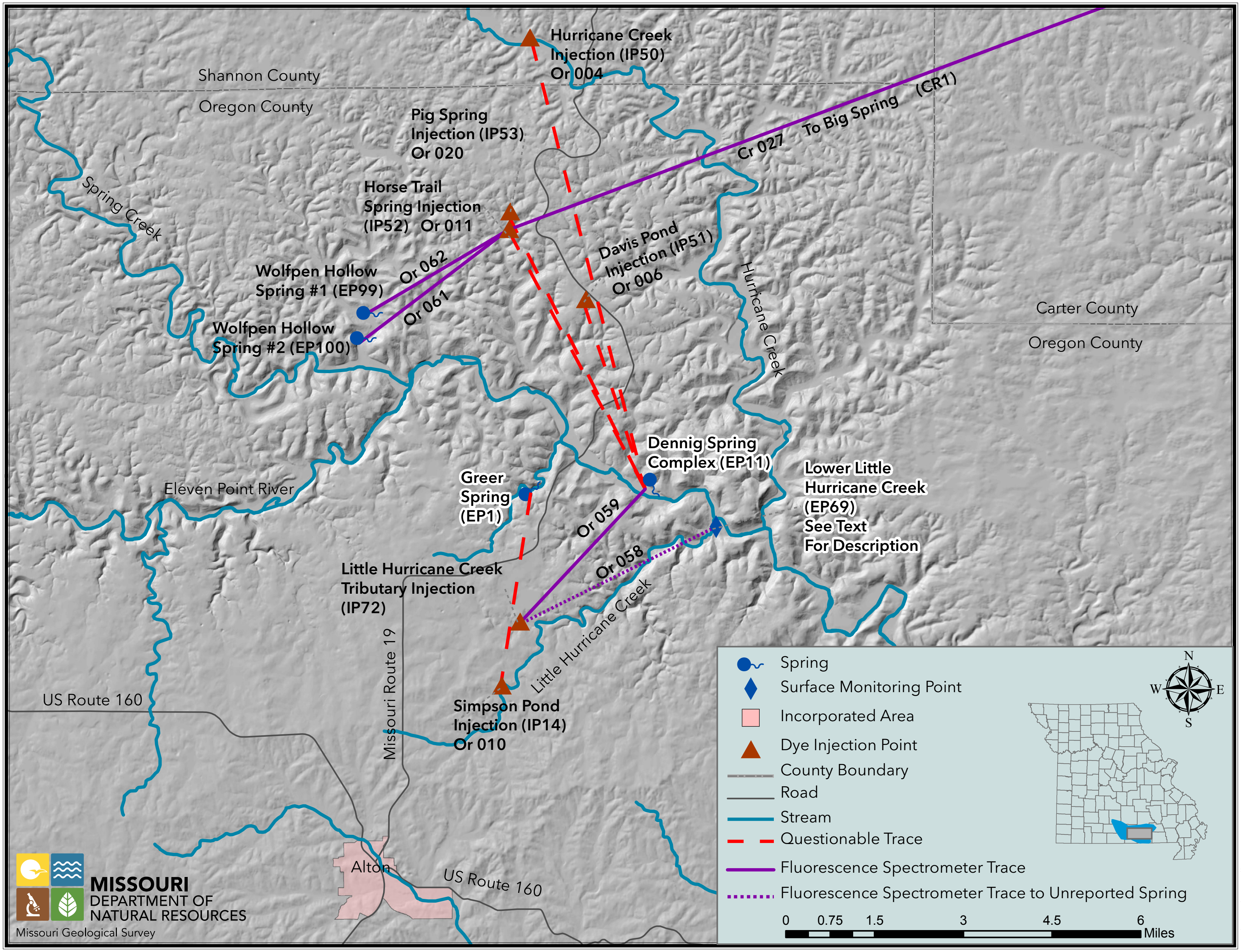
1. The Pond Hollow trace (Or 004), which began in the Hurricane Creek watershed, indicates that although dye was injected into flow "at the end of a storm flow" event (Aley, 1975, p. A-16), it required nearly two months for dye to resurface at Dennig Complex. No other injection in Hurricane Creek has been recorded to resurge in the Dennig Complex;
2. Only one packet was reported to have been analyzed from Dennig Spring after the Davis Pond injection. No background packet results are given (Aley, 1975, p. A-22);
3. The reported dye recovery for the Horse Trail Spring trace (Or 011) may represent recovery of the injection at Simpson Pond (see Little Hurricane trace below) that occurred two to three weeks prior to the reported recovery at Dennig Complex (Fletcher, 1972F);
4. The first Pig Spring trace (Or 020) reportedly took at least two months from injection to first recovery, and used packets in place for about one month (Tryon, 1975D);
5. A replication attempt of the Pig Spring trace (Imes, 1996) indicates water movement to other springs – not to the Dennig Complex;
6. The Simpson Pond trace was listed as the "first successful subsurface water trace to Greer Spring in a series of attempts" (Fletcher, 1972D, p. 2). An unsuccessful "series" of injections in the area of Dennig Complex and Greer Spring could have been misinterpreted by early investigators.
7. A nearby series of traces (Or 058 and Or 059) during this study also calls this trace into question;
8. All of the legacy traces to Dennig Complex were completed using visual analysis.

Contemporary Little Hurricane Creek Semi-Replication Attempt (Or 010)

One trace was initiated during this study that was recovered at the Dennig Complex. The opportunity arose to complete a semi-replication attempt of trace Or 010. Two gallons of Rhodamine WT™ were injected into a small losing tributary to Little Hurricane Creek (Figure 105 - IP72) at 1:40 p.m. on Jan. 12, 2016. On that date, about 15 gpm were flowing into a pool that contained about 1000 gallons of water. No flow was observed downstream in limited investigations, and the landowner reported that there is normally no flow on his property when flow ceases in this part of the creek.

Limited data are available for the semi-replication attempt since a small number of locations were monitored in the early part of the trace and packets were retrieved less frequently than most traces completed in the study. Besides Greer Spring branch (EP67), additional points were monitored in the Eleven Point River at Turner Mill (EP65) and Boze Mill (EP66) and at Boze Mill Spring (EP5). None of the background packets removed on Jan. 12 contained detectable amounts of Rhodamine WT™. The next round of sampling, on Jan. 26, revealed the presence of dye only in packets placed in the Eleven Point River near Turner and Boze mills. On Feb. 1, packets were placed at the lower end of Little Hurricane Creek (EP69), Greer Crossing on the Eleven Point River (EP26), Graveyard Complex (EP68), and Dennig Spring – Major (EP11B). The packets from both Little Hurricane Creek (PVR of 3.59) and Dennig Complex– Major Spring (PVR of 4.8) contained moderate amounts of Rhodamine WT™ when replaced on Feb. 9. Analysis of packets in place at Dennig – Main Spring from Feb. 9 to Feb. 17 displayed a PVR of 2.02 with the Rhodamine WT™ showing signs of deaminoalkylation. The packet in Little Hurricane Creek during the same time frame displayed similar results with a PVR of 2.23. On Feb. 17, a packet was placed in Dennig Complex – Minor Spring (EP11A). Dye was recovered at this outlet as well. No dye was found at Greer Spring (EP67) or any other points monitored except for those mentioned above.

Because background data are not available for either point at which dye was recovered, these traces lack



Map by Cecil Boswell

Figure 104. Current interpretation of traces in close proximity to Dennig Complex and unreported spring in Little Hurricane Creek.

Figure 105. Dye injection in tributary to Little Hurricane Creek.

complete dye recovery curves. The actual time of first recovery cannot be pinpointed other than to say dye likely resurged from one or both of these locations prior to Jan. 26. Dye was resurging from both of these points before Feb. 9. Because the actual resurgence point for the dye in the Little Hurricane Creek watershed is not known precisely, the path for that trace is drawn to the point monitored (Figure 104); the actual resurgence point is somewhere upstream in Little Hurricane Creek. Nevertheless sufficient evidence exists to demonstrate a subsurface connection.

SUMMARY

Conclusions

MGS conducted a number of water traces in the Ozarks of southern Missouri and near the northern border of Arkansas between 2013 and 2016 (Figure 106). Results allowed refinement of the recharge areas of Mammoth Spring (Fulton County, Arkansas); Greer, Blue, Morgan, Boze Mill springs (Oregon County, Missouri), Big Spring (Carter County, Missouri) Big Spring (Douglas County, Missouri) Blue, Rainbow, North Fork, Hodgson Mill, Wilder springs (Ozark County, Missouri) and the Dennig Complex (Oregon County, Missouri).

Previously unpublished reports and data produced by MGS and USGS staff that refine the recharge areas of Boze Mill, Morgan, Blue, and Greer springs (Oregon County, Missouri) and Blue, Rainbow, North Fork, Hodgson Mill, Wilder and Althea springs (Ozark County, Missouri) are also described.

In many instances, fluorescent tracers were injected at locations where tracers had not been injected before. Some legacy tracer injection sites were reused – to verify legacy traces and to gather new information. The resulting data clearly show there is value in applying fluorescence spectrometry dye detection techniques when attempting to replicate selected older traces. A combination of new injection points and repeat injections at locations used for legacy traces helped to create a clearer picture of the recharge areas of a number of springs in the region (Tables 8 and 9, Figure 106). A number of repetition attempts showed that some past traces may have erroneously reported positive dye recoveries. In some cases actual recovery points were not monitored or tracers were not detected due to limitations of older detection methods. In addition, injection overlap was revealed as a serious problem for some traces.

Some of the questionable or faulty legacy traces have been used in recent interpretations (see Weary et al., 2014). Specifically, the presence of a deep conduit connecting the region of the Middle Fork of the Eleven Point and the main stem Eleven Point River to Big Spring (Carter County) on the Current River as suggested by Cr 009 and Cr 010, should be considered speculative at best. A relatively large body of new tracing evidence (Or 041, Or 042, Or 043, Or 045, Or 046, Or 047, Or 049, Or 050, Or 060, Or 051, Or 052, Or 053, Or 054, Or 055, Or 056 and Or 057) shows that this region recharges Bill Mac and Greer springs, both on the Eleven Point River.

A matrix-based analysis method was developed to prioritize older traces for replication attempts. The matrix helped determine which areas would likely benefit from more objective, sensitive and precise tracing techniques.

A new interpretive method termed "peak valley ratio" or PVR was developed. PVR uses fluorescent spectroscopy analyses to produce smoother dye recovery curves when using activated carbon packets to collect tracers in the field. This method was also applied to legacy traces conducted using a fluorescence spectrometer.

This study produced the first meaningful recharge area determinations of the Blue/Morgan Complex and Boze Mill Spring. The estimated recharge area of the Blue/Morgan Complex extends to the west and south of the city of Alton, likely encompassing most of the drainage of Frederick Creek excluding the upper reaches of Piney Creek, a tributary of Frederick Creek. Piney Creek, which flows through the city of Alton, is largely in the recharge area of Boze Mill Spring. During wetter periods, surface flow likely extends into the lower reaches of Piney Creek or Frederick Creek basins where it is subsequently lost to the subsurface and resurfaces at the Blue/Morgan Complex. This connection is minor because it is transitory in nature; water movement between the upper reaches of Piney Creek and the Blue/Morgan Complex occurs only during runoff events.

Additional work is needed to define the boundary between Boze Mill Spring and the Blue/Morgan Complex. Specific areas where new traces would be helpful include the middle through lower parts of Frederick Creek and the lower reaches of Piney Creek.

New traces in the recharge area of Mammoth Spring show that some early traces were accurate or partially accurate. However, new traces from replicated injection points (IP84 and IP17) indicate that a significant portion of the northern end of the Mammoth Spring recharge area is shared with Greer Spring and, at least locally, Blue Spring (Ozark County) on the North Fork River.

Significant questions still remain about what appears to be a shared boundary between the recharge area of Greer Spring to the north and Mammoth Spring to the south in the central part of Howell County and immediately to the east in Oregon County.

MGS ID#	From	To	Dye* (Amount)	Length Miles	Injection Date	First Recovery in Days	First Velocity (ft/hr)	Peak Recovery in Days	Peak Velocity (ft/hr)	Peak PVR
Or 033, Or 034	Frederick Creek	Blue/Morgan Complex	Fl (10 lb)	16.2	8/27/2013	22-30	118-161	30-35	101-119	33.9
Or 036	Frederick Creek	Boze Mill Spring	Fl (10 lb)	13.9	8/27/2013	30-35	87-102	35-42	73-87	2.1
Or 029	Grand Gulf	Mammoth Spring	RWT (3 gal)	6.8	10/9/2013	4	355	8	193	15.9
Or 030	Piney Creek in Alton	Boze Mill Spring	RWT (3 gal)	11.3	12/3/2013	9-15	178-315	9-15	131-178	133.2
Or 031, Or 032	Piney Creek in Alton	Blue/Morgan Complex	RWT (3 gal)	15.0	12/3/2013	27-36	91-122	36-42	78-91	1.3
Or 035	Mustion Creek	Mammoth Spring	Fl (10 lb)	25.3	2/14/2014	11-20	278-504	20-25	223-278	217.3
Or 037	Rattlesnake Spring	Mammoth Spring	Eos (9 lb)	35.2	2/26/2014	20-29	266-384	29-34	227-266	9.2
Or 038	Rattlesnake Spring	Greer Spring	Eos (9 lb)	37.6	2/26/2014	28-29	284-294	29-34	243-285	13.9
Oz 014	Rattlesnake Spring	Blue Spring (Ozark County)	Eos (9 lb)	8.4	2/26/2014	41-48	38-45	76-82	22-24	4.2
Or 028	Dry Creek near Pomona	Mammoth Spring	RWT (3 gal)	32.7	3/26/2014	20-27	266-360	20-27	266-360	8.4
Or 027	Dry Creek near Pomona	Greer Spring	RWT (3 gal)	33.9	3/26/2014	20-27	277-374	20-27	277-374	10.2
Oz 034	Upper Tabor Creek	Blue Spring (Ozark County)	Fl (5 lb)	8.7	6/17/2014	7-21	91-277	21-28	68-91	246.9
Or 039	Granny Meyers Spring	Mammoth Spring	Eos (5 lb)	14.5	7/23/2014	13-20	119-160	20-27	94-119	29.9
Oz 035, Oz 037	Upper Fox Creek	Rainbow/NorthFork Complex	Eos (5 lb)	24.1	8/19/2014	8-14	375-674	14-21	251-380	98.7
Oz 036	Upper Fox Creek	Hodgson Mill Spring	Eos (5 lb)	23.3	8/19/2014	8-14	368-651	14-21	246-368	88.3
Or 042	Lost Hill	Greer Spring	Eos (5 lb)	16.3	10/28/2014	6-16	227-611	6-16	227-611	18.2
Or 043	Middle Fork	Bill Mac Spring	RWT (3 gal)	5.3	12/11/2014	19-26	44-61	33-40	29-35	5.0
Or 044	Warm Fork	Warm Fork Spring	Fl (1 lb)	2.1	1/21/2015	<6	>72	<6	>72	48.5
Or 045	Cave Spring, Spring Creek	Greer Spring	Fl (5 lb)	11.0	1/21/2015	20-28	86-121	28-34	71-86	7.6
Do 009	Dribble Cave Spring	Big Spring on Dry Creek	RWT (2 gal)	4.4	3/11/2015	<6	>161	6-13	74-161	279.1
Oz 038	Bollinger Branch	Hodgson Mill Spring	SRB (2 lb)	4.8	4/14/2015	7-13	80-148	13-21	50-80	9.5
Or 047	Upper Kenaga Hollow	Greer Spring	RWT (2 gal)	24.3	5/18/2015	8-15	358-673	15-22	244-358	10.6
Or 048	Dean Davis CA	Greer Spring	Fl (10 lb)	32.5	6/18/2015	12-19	378-601	19-26	276-378	8.5
Cr 025	Birch Creek near Birch Tree	Big Spring (Carter County)	Eos (10 lb)	28.2	8/4/2015	14-21	298-450	21-29	216-298	6.4
Or 049	Birch Creek near Birch Tree	Greer Spring	Eos (10 lb)	16.0	8/4/2015	14-21	169-254	14-21	169-254	1.9
Or 050	Lower Middle Fork	Bill Mac Spring	Fl (2 lb)	2.7	9/9/2015	<6	>98	<6	>98	784.0
Or 060	Lower Middle Fork	Greer Spring	Fl (2 lb)	15.7	9/9/2015	13-20	173-268	13-20	173-268	2.7
Oz 039	Spring Creek, Pottersville	Wilder Spring	Eos (5 lb)	8.1	9/1/2015	14-21	84-126	21-28	63-84	162.5
Or 051	Middle Fork Fanchon #1	Bill Mac Spring	RWT (2 gal)	7.4	9/9/2015	28-35	48-59	91-98	17-18	2.2
Or 052	Middle Fork Fanchon #1	Rookery Tree Complex	RWT (2 gal)	4.1	9/9/2015	<91	>9	<91	>9	3.4
Or 059	Little Hurricane Creek	Dennig Complex	RWT (2 gal)	3.2	1/12/2016	<28	>35	<28	>35	4.8
Or 058	Little Hurricane Creek	Little Hurricane Creek Spring	RWT (2 gal)	3.8	1/12/2016	<28	>42	<28	>42	3.6
Or 053	Middle Fork Fanchon #2	Bill Mac Spring	Eos (10 lb)	7.4	2/9/2016	8-20	83-213	8-20	83-213	53.2
Or 057	Middle Fork Fanchon #2	Rookery Tree Complex	Eos (10 lb)	4.1	2/9/2016	<8	>118	8-20	46-118	361.0
Or 055	Middle Fork Fanchon #2	Mammoth Spring	Eos (10 lb)	22.4	2/9/2016	20-34	146-249	20-34	146-249	3.3
Or 054	Middle Fork Fanchon #2	Greer Spring	Eos (10 lb)	20.3	2/9/2016	20-34	132-225	20-34	132-225	1.2
Or 056	Middle Fork Fanchon #2	Spring above Bluff Spring	Eos (10 lb)	3.9	2/9/2016	<8	>112	8-20	44-112	32.0
Hl 001	Middle Fork Fanchon #2	Spring above CR 3850	Eos (10 lb)	2.6	2/9/2016	20-34	17-28	34-49	12-17	4.9
***Fl = Fluorescein, RWT = Rhodamine WT™ 20 percent, Eos = Eosine**										

Table 9: Traces completed during this study.

MGS ID #	From	To	Dye* (Amount)	Length in Miles	Injection Date	First Recovery In Days	First Velocity (ft/hr)	Peak Recovery in Days	Peak Velocity (ft/hr	Peak PVR	Source
Or 025	Alton Wastewater Plant	Boze Mill Spring	RWT (1 gal)	10.4	10/30/1984	<16	>143	<29	79-143	1.2	Kraft, 1985
Or 026	Alton Wastewater Plant	Boze Mill Spring	RWT (2 gal)	10.4	7/23/1985	<17	>134	<17	>134	1.3	Kraft, 1985
Oz 017	Wolf Creek Gasconade River	Rainbow Spring	Fl (10 lb)	34.8	4/18/1986	<14	>545	<14	>545	14.3	Williams, 1986
Oz 016	Wolf Creek Gasconade River	North Fork Spring	Fl (10 lb)	34.6	4/18/1986	<14	>541	<14	>541	13.0	Williams, 1986
Oz 018	Wolf Creek Gasconade River	Hodgson Mill Spring	Fl (10 lb)	33.1	4/18/1986	<14	>519	14-26	280-519	10.2	Williams, 1986
Oz 019	Fry Creek Gasconade River	Rainbow Spring	RWT (2 gal)	34.5	8/19/1987	23-28	272-331	23-28	272-331	32.4	Williams, 1987
Oz 021	Fry Creek Gasconade River	North Fork Spring	RWT (2 gal)	34.3	8/19/1987	23-28	270-329	28-34	222-270	34.0	Williams, 1987
Oz 020	Fry Creek Gasconade River	Hodgson Mill Spring	RWT (2 gal)	32.7	8/19/1987	23-24	301-314	23-28	258-314	22.1	Williams, 1987
Oz 024	Summer Spring Bryant Creek	Rainbow Spring	RWT (1 gal)	27.6	11/2/1988	8-15	407-766	8-15	407-766	----	Brown, 1989
Oz 025	Summer Spring Bryant Creek	North Fork Spring	RWT (1 gal)	27.4	11/2/1988	8-15	403-758	8-15	403-758	----	Brown, 1989
Oz 026	Summer Spring Bryant Creek	Hodgson Mill Spring	RWT (1 gal)	26.2	11/2/1988	8-15	386-726	8-15	386-726	----	Brown, 1989
Oz 027	Lick Fork Gasconade River	Rainbow Spring	Fl (10 lb)	38.7	11/2/1988	8-15	567-1063	8-15	567-1063	----	Brown, 1989
Oz 029	Lick Fork Gasconade River	North Fork Spring	Fl (10 lb)	38.5	11/2/1988	8-15	563-1055	8-15	563-1055	----	Brown, 1989
Oz 028	Lick Fork Gasconade River	Hodgson Mill Spring	Fl (10 lb)	37.2	11/2/1988	8-15	545-1020	8-15	545-1020	----	Brown, 1989
Or 067	Katie Sisco Hollow	Turner Mill Spring	RWT (2 lb)	1.7	1/3/1992	<7	>52	<7	>52	101.0	Aley, 1992
Or 066	Inject. Hollow on Eleven Point River	Deadman Spring	RWT (2 lb)	1.4	1/3/1992	<14	>22	<14	>22	170.0	Aley, 1992
Or 064	Lower Injection Hollow	Eleven Point River Spring	Fl (1 lb)	0.3	1/3/1992	<14	>4	<14	>4	89.0	Aley, 1992
Or 065	Long Hollow	Eleven Point River above Greer	Fl (1 lb)	2.0	2/25/1992	7-36	12-62	----	----	27.6	Aley, 1992
Or 063	Hurricane Creek Spring	Falling Spring	RWT (2 lb)	2.3	3/16/1992	16-43	12-31	16-43	12-31	1.2	Aley, 1992
Cr 026	Hurricane Creek Spring	Big Spring on Current River	RWT (2 lb)	19.1	3/16/1992	17-45	94-249	17-45	94-249	1.0	Aley, 1992
Or 040	Sims Creek at US Route 60	Greer Spring	RWT (2 lb)	30.8	5/22/2002	8	857	8	818	----	USGS files
Or 062	McCormack Hollow	Wolfpen Hollow Spring #1	Fl (1.5 lb)	2.8	6/28/1995	8-14	45-79	14-26	24-45	>80	Imes, 1996
Or 061	McCormack Hollow	Wolfpen Hollow Spring #2	Fl (1.5 lb)	3.5	6/28/1995	14-26	29-55	14-26	29-55	1.9	Imes, 1996
Cr 027	McCormack Hollow	Big Spring, (Carter County)	Fl (1.5 lb)	21.0	6/28/1995	27-42	110-172	27-42	110-172	2.5	Imes, 1996
Or 041	Paty Spring	Greer Spring	RWT	8.1	3/12/2003	1-16	>110	1-16	>110	1.7	USGS files
Or 046	Spring Creek Tributary	Greer Spring	Fl (4 lb)	8.3	11/2/2004	15	122	18	102	6.5	USGS files
Oz 031	Losing Stream at Dairy	Wilder Spring	RWT (3 gal)	5.1	10/23/2007	20-27	41-56	34-42	27-33	9.7	Crews, 2008
Oz 033	Losing Stream at Dairy	Althea Spring	RWT (3 gal)	10.1	10/23/2007	34-42	53-65	34-42	53-65	1.2	Crews, 2008
Oz 030	Losing Stream at Dairy	Wilder Spring	Fl (3 gal)	5.1	10/23/2007	20-27	41-56	34-42	27-33	49.6	Crews, 2008
Oz 032	Losing Stream at Dairy	Althea Spring	Fl (3 gal)	10.1	10/23/2007	34-42	53-65	42-55	40-53	3.0	Crews, 2008
***Fl=Fluorescein, RWT=Rhodamine WT™ 20 percent**											

Table 10: Legacy traces with limited publication exposure but completed with fluorescence spectrometer.

Nine new traces (Or 038, Or 027, Or 042, Or 045, Or 047, Or 048, Or 049, Or 060 and Or 054) to Greer Spring were completed during this study. Three of them (Or 038, Or 027, Or 054) indicate that Greer Spring shares recharge with Mammoth Spring extending the known recharge area boundary of Greer to the west and south of Pomona and west of Thomasville. Two traces (Or 054 and Or 060) also indicate that Bill Mac Spring provides some of the recharge for Greer Spring. A losing reach downstream of Bill Mac Spring apparently resurfaces at Greer Spring. This connection should be considered speculative since this losing reach was not used as a primary dye injection site.

In addition, traces Cr 025 and Or 049 from the Birch Tree area demonstrate that Big Spring (Carter County) shares recharge with Greer Spring during some hydrologic conditions. Big Spring is the principal recipient of this water as the dye recovery at Greer Spring was relatively small.

New data also show that, while upper and lower Greer Spring are clearly part of the same system, on one occasion dye recovery at upper Greer Spring lagged behind lower Greer Spring, presumably due to the head differential and circuitous route for discharging water flowing to the surface at the higher cave outlet.

File searches by USGS staff recovered three traces (Or 040, Or 041 and Or 046) to Greer Spring that had not been widely reported. These traces, in conjunction with new MGS traces, demonstrate that flow to Greer Spring largely occurs through openings that pass beneath a gaining segment of the Eleven Point River from northwest to southeast. Some early investigators (Aley, 1975; Tryon, 1975C) believed that the bulk of recharge to Greer Spring traveled south on the west side of Thomasville and then east on the south side of the Eleven Point River where it is a gaining stream. While that was a reasonable assumption based on the data available at the time those studies were conducted, new data clearly suggest otherwise.

A semi-replication attempt from Little Hurricane Creek south of the Eleven Point River did not agree with a nearby visual trace done in the early 1970s. The Simpson Pond legacy trace indicated a connection to Greer Spring whereas new traces from a nearby point in the same watershed (IP72) show a connection (Or 059) to the Dennig Complex just north of the Eleven Point River and (Or 058) an unreported resurgence point downstream of the injection in Little Hurricane Creek. Analysis of legacy trace records shows that there may have been tracer overlap for the Simpson Pond and Horse Trail Spring legacy traces. It is likely that at least part of the dye reported at the Dennig Complex for the Horse Trail Spring trace came from the Simpson Pond injection.

Given the tracer overlap in the Dennig Complex trace in 1972, and the results of an additional injection in the upper end of McCormack Hollow in 1995 (Imes, 1996), legacy data for other traces reported to the Dennig Complex were evaluated, revealing concerns about each. Preliminary MGS data suggests that the Dennig Complex is recharged by losing streams and sinkholes south of Greer Spring and west of the Eleven Point River – not by the area previously supposed to the northwest of the Complex. The authors suggest that there may be no significant recharge to Greer Spring from the south though additional work is needed to verify this hypothesis.

One new trace (Oz 034) was completed from an upper reach of Tabor Creek to Blue Spring (Ozark County, on the North Fork) which helps to define the boundary between the recharge areas of Blue, Greer and Mammoth springs.

The first known trace to Warm Fork Spring in Oregon County (Or 044) was conducted. While more work is needed to define the recharge area, it is clear that Warm Fork Spring is partially supplied by a wet-weather section of the Warm Fork upstream. The sinkhole plains to the west (Harbeston and Grand Gulf karst zones) would be a good starting point for those looking for the source of the intermittent spring or springs located upstream of Warm Fork Spring and of Warm Fork Spring as well.

Results of some unpublished legacy traces completed in the 1980s by MGS staff were described to document the recharge area of Rainbow, North Fork, and Hodgson Mill springs. Williams (1986) first showed that these three springs are part of a single complex fed from as far away as the Gasconade watershed 40 miles to the north. Contemporary traces completed to the Rainbow/North Fork/Hodgson Mill Complex during this study expand the known recharge area for the complex east to the upper Fox Creek watershed. Kraft (1985) traced water from the Alton liquid waste treatment facility to Boze Mill on the opposite side of the Eleven Point River.

At least one legacy connection to Rainbow Spring completed using visual methods (Oz 012), was discounted by an attempt to replicate the old trace, while another semi-replication attempt added credence to legacy traces (Oz 001 and Oz 002) from the Dora Sinkhole Dump to Hodgson Mill Spring. This confirmed that Hodgson Mill Spring has its own local recharge area that it does not share with Rainbow Spring or North Fork Spring even though Hodgson Mill clearly receives water from the major conduit system that feeds the rest of the complex.

Results by Crews (2008) are included with PVR dye recovery curves that helped define the recharge areas of Wilder and Althea springs. A new trace from Spring Creek east of Pottersville (Oz 039, near legacy trace Oz 009 that reportedly resurfaced at Rainbow Spring) resurfaced at Wilder Spring. Though this trace does not entirely invalidate the legacy trace, new data collected during the study on the east side of the North Fork River do not show any connection with the Rainbow/North Fork/Hodgson Mill Complex.

Recommendations

A number of legacy traces were questioned for a variety of reasons. Thus additional replication or semi-replication attempts are recommended to clarify the following traces:

- Oz 006 and Oz 007 from the Sinks to North Fork and Rainbow springs;
- Oz 011 from Collins Spring branch to Rainbow Spring;
- Or 012 from Renfrow Spring Sink to Mammoth Spring;
- Or 024 from West Plains wastewater treatment facility to Mammoth Spring;
- Or 010 from Simpson Pond to Greer Spring;
- Or 004 from Hurricane Creek to the Dennig Spring Complex
- Or 006 from Davis Pond to the Dennig Spring Complex;
- Or 011 from Horse Trail Spring to the Dennig Spring Complex;
- Cr 027 from McCormack Hollow near Pig Spring to Big Spring (Carter County, on the Current River);
- Cr 006 from Stillhouse Spring Branch to Big Spring (Carter County, on the Current River);
- Cr 014 from Spring Creek (Oregon County) to Big Spring (Carter County, on the Current River).

During this study a number of other locations were investigated that would benefit from additional work. Specific recommendations for new injections or replications of new traces include the following:

- Eleven Point River immediately downstream of Bill Mac Spring;
- Piney Creek lower losing reach (Frederick Creek watershed);
- The Grand Gulf Karst Zone;
- The Harbeston Karst Zone;
- Lower reach of Dry Creek near Big Spring (Douglas County) on Spring Creek (North Fork watershed);
- Upper reach of Noblett Creek (North Fork watershed);
- Upper reach of Spring Creek (North Fork watershed in northeast Howell County);
- Middle to lower reaches of Frederick Creek;
- Warm Fork Creek downstream of Warm Fork Spring;
- Althea and Wilder springs recharge areas;
- Cr 025 and Or 049 from Birch Creek to Big Spring (Carter County, on the Current River) and Greer Spring during dry weather.

It is recommended that additional tracing be conducted to determine what amount, if any, of the recharge area of the Rainbow/North Fork/Hodgson Mill Complex is located east of the North Fork River. The authors also recommend that additional work be done to better characterize the relationship between Hodgson Mill Spring and the larger resurgences of the complex at Rainbow and North Fork springs. Additional injections are needed to better define the recharge area of this complex east and south of the Mansfield area as well.

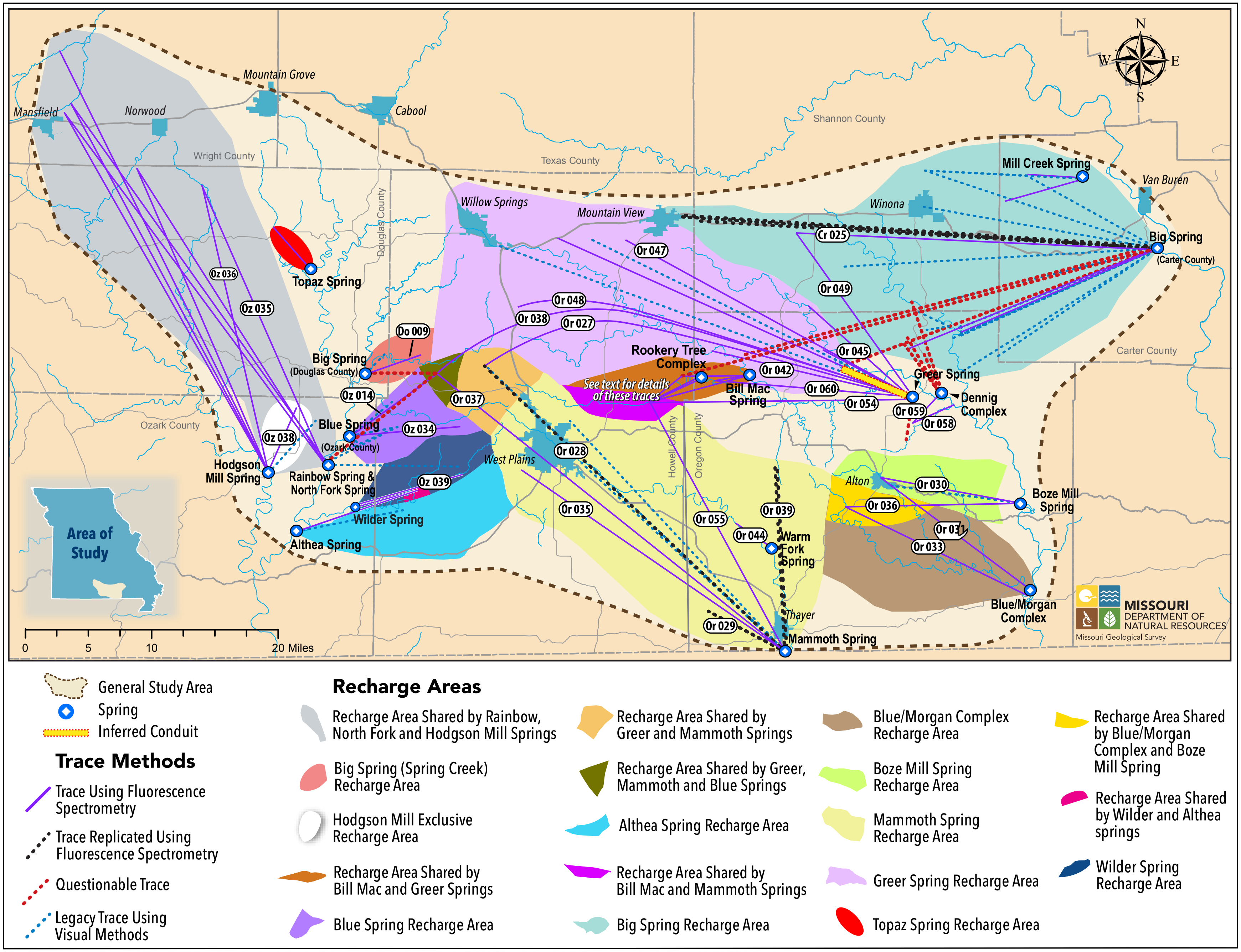
This study raised a number of questions about recharge areas of springs that are either in error or have never been investigated in detail. The following are examples of issues still remaining.

Warm Fork Spring is located on private property and is currently shown (Figure 106) to be a part of the Mammoth Spring recharge area. A subsurface connection between Warm Fork Spring and Mammoth Spring has not been established. A seepage run during relatively low-flow conditions would help to determine if the Warm Fork loses any flow downstream of Warm Fork Spring. While some water that discharges from Warm Fork Spring is coming from the Warm Fork valley upstream, evidence to date, accounts for only a fraction of the flow. Additional traces are needed to define the recharge area of Warm Fork Spring as well as the unknown spring upstream that contributes flow to it during relatively high flow conditions.

The watershed for the Dennig Complex is still in question. Traces that employed fluorescence spectrometric methods have been completed from only two injection sites that shed light on the issue. They suggest errors in legacy data. A USGS injection in the upper end of McCormack Hollow indicated that groundwater in that region is resurfacing in Wolfpen Hollow (EP99 and EP100) and possibly in Big Spring (Carter County, on the Current River - CR1), but not in the Dennig Complex (EP11). The only trace completed during this study to the complex was initiated in the Little Hurricane Creek Watershed, southwest of the Eleven Point River. The authors anticipate that the bulk of the recharge for the Dennig Complex will be found southwest of the Eleven Point River, but additional work is needed to confirm this hypothesis.

Remaining issues include location of the (intermittent?) springs in the Middle Fork of the Eleven Point River downstream of Fanchon and upstream of Thomasville. The interrelationship of these springs and the Rookery Tree Complex is not well-defined. Initial indications are that bedrock and surficial deposits locally act as a short-term groundwater storage receptacle that is flushed by large precipitation events. When large precipitation events occur, some of the stored water resurfaces only to be lost downstream to the Bill Mac Spring system or to flow out of the watershed on the surface. The storage delay has made tracing in the area difficult to complete and has led to confusing interpretations.

As a final recommendation, the entire region would benefit from detailed geologic mapping. The limited detailed mapping available gives clues helpful in predicting groundwater flow direction and resurgence points, but additional work is required to provide a more complete picture of bedrock influences on the karst system. Geologic mapping at 1:24,000 scale is needed to show the location of structures involved in directing groundwater movement. This mapping would benefit those parties dealing with water supply, waste disposal, watershed protection and resource development issues alike.



Map by Cecil Boswell and Mark Gordon

Figure 106. Compilation of traces and current interpretations of recharge area boundaries of the Big Four region.

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Appendix A

Explanation

Appendix A is a summary of water traces completed in the study area, listed alphabetically by recovery point. It is not an exhaustive list since some traces may have been lost or are unknown to the authors.

The MGS ID# is used to identify all traces in the online GIS database of Missouri dye traces (Missouri Department of Natural Resources, 2016A-C) wherein traces are listed numerically by county of recovery. Counties within the study area are abbreviated as follows: Carter-Cr, Douglas-Do, Howell-Hl, Oregon-Or and Ozark-Oz. The county designation is followed by a three digit number. Some summaries included do not have a trace number because they are not currently in the database; nor are they likely to be included in the database in the future, unless corroborative information is obtained. These questionable traces are included for reference with the notation –"No ID#." Other currently-questioned traces have an MGS ID# listed since they are already in the database.

The authors' concerns about specific traces are highlighted in yellow in the remarks field at the bottom of each trace summary. PVR data, if available, are highlighted in bright blue in the remarks field as well.

Recovery point ID# is the Monitoring Point ID# of Appendix B. Monitoring points are referenced by watershed abbreviation and a two or three digit number. Only documented monitoring points are listed; references often omit points monitored where dye was not recovered.

Injection point ID# is listed in Appendix C beginning with the prefix "IP" followed by a sequential number.

Trace length is the straight line distance between the injection point and recovery point. Actual trace paths are unknown but are longer than listed.

Injection time is listed in 24 hour format.

Recovery dates (velocity range) refers to the measurable time-of-travel of each trace. Some investigators recorded only the first recovery of tracer – normally expressed as "First" followed by a range of dates. Peak recovery data, where available, are normally expressed as "Peak" followed by a range of dates. Velocity ranges were calculated by dividing the straight line distance by the time to recovery and expressed in feet/hour (ft/hr). When packet collection or dye injection times were not available velocity was calculated assuming packet collection or injection at 12:00 noon.

Appendix A
Summary of Water Traces to Selected Springs

MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Althea Spring (Ozark County, Missouri) Traces						
Oz 003	Althea Spring {NF3} (8.54 mi.)	Cureall Spring Branch (IP16)	Fluorescein (10 pounds)	7/24/1972 (13:15)	Carbon Packet Visual	First: 7/31/1972 to 8/8/1972 (126-270 ft/hr)
"Very strongly positive" recovery confirmed by fluorometer. Source: Fletcher,1972A, p.1. Monitoring points: NF3, NF1, NF2, NF4.						
Oz 032	Althea Spring {NF3} (10.08 miles)	Collins Dairy (IP37)	Fluorescein (3 gallons)	10/23/2007 (12:12)	Carbon Packet Fluorescence Spectrometer	First : 11/26/2007 to 12/4/2007 Peak: 12/4/2007 to 12/17/2007 (First: 53-65 ft/hr) (Peak: 40-53 ft/hr)
Maximum PVR = 2.97 Dye also recovered at Wilder Spring (NF4). Source: Crews, 2008. Monitoring points: NF3, NF4, NF11, NF13, NF14, NF17, NF16, NF18, BB1, BB2.						
Oz 033	Althea Spring {NF3} (10.08 miles)	Collins Dairy (IP37)	Rhodamine WT™ (3 gallons)	10/23/2007 (12:12)	Carbon Packet Fluorescence Spectrometer	First: 11/26/2007 to 12/4/2007 Peak:11/26/2007 to 12/4//2007 (53-65 ft/hr)
Maximum PVR = 1.21 Dye also recovered at Wilder Spring (NF4). Source: Crews, 2008. Monitoring points: NF3, NF4, NF11, NF13, NF14, NF17, NF16, NF18, BB1, BB2.						
Barrett Spring (Oregon County, Missouri) Trace						
Or 017	Barrett Spring {EP33} (0.39 miles)	New Liberty Dump (IP48)	Fluorescein (2.5 pounds)	2/17/1974 (21:20)	Carbon Packet Visual	First: 2/19/1974 to 2/20/1974 Peak: 2/20/1974 to 2/26/1974 (First: 32-53 ft/hr) (Peak: 10-32 ft/hr)
"Weakly positive" but no background packet was collected prior to injection. Source: Chaney, 1974, p. 4. Dye also reported at CR1, EP51 and EP52. Monitoring points: CR1, EP33, EP51, EP52, EP53, EP54, EP55, EP56.						
Big Spring (Carter County, Missouri) Traces						
Cr 001	Big Spring, Carter County {CR1} (17.05 miles)	Hurricane Creek below Blowing Spring (IP2)	Fluorescein (10 pounds)	6/11/1968 (Early PM)	Carbon Packet Visual	First: 6/18/1968 to 6/25/1968 (269-539 ft/hr)
"Strongly positive" but only one recovery interval noted. Trace later replicated with Lycopodium spores. Source: Aley, 1968, p. 1; Aley and Aley, 1987. Monitoring points: CR1, EP17, EP10, EP28, EP29, EP32.						

Appendix A
Summary of Water Traces to Selected Springs

MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Cr 002	Big Spring, Carter County {CR1} (15.23 miles)	Goldmine Hollow Channel (IP3)	Fluorescein (10 pounds)	2/11/1969 (13:30)	Carbon Packet Visual	First: 2/18/1969 to 2/25/1969 (240-483 ft/hr)
"Very strongly positive" but only one recovery interval noted. Source: Aley, 1975, p. A-20; Aley and Aley, 1987. Monitoring points: CR1, EP10, EP28.						
Cr 003	Big Spring, Carter County {CR1} (18.19 miles)	Johnson Spring Branch (IP5)	Fluorescein (5 pounds)	8/29/1969 (15:00)	Carbon Packet Visual	First: 9/8/1969 to 9/15/1969 (237-405 ft/hr)
"Very strongly positive" but only one recovery interval noted. Source: Aley, 1975, p. A-19. Monitoring points: CR1, EP10, EP28, EP11.						
Cr 004	Big Spring, Carter County {CR1} (17.64 miles)	Leslie Spring Swallow Hole (IP6)	Fluorescein (10 pounds)	11/18/1970 (13:00)	Carbon Packet Visual Fluorometer	First: 11/24/1970 to 12/1/1970 Peak: 11/24/1970 to 12/1/1970 (299-651 ft/hr)
Only one recovery interval noted. Source: Fletcher, 1970. Monitoring points: CR1, EP1, EP9, EP10, EP11, EP27, EP28.						
Cr 005	Big Spring, Carter County {CR1} (17.17 miles)	Wildcat Spring Branch (IP8)	Fluorescein (10 pounds)	2/11/1971 (11:30)	Carbon Packet Visual	First: 2/19/1971 to 2/25/1971 Peak: 2/25/1971 to 3/17/1971 (First: 269-471 ft/hr) (Peak: 111-269 ft/hr)
"Strongly positive." Source: Aley, 1975, p. A-19; Aley and Aley, 1987. Monitoring points: CR1, EP8, EP9, EP10, EP11, EP27, EP28, EP32, EP33, EP34, EP35.						
Cr 006	Big Spring, Carter County {CR1} (33.63 miles)	Stillhouse Spring Branch (IP10)	Fluorescein (7 pounds)	8/26/1971 (10:25)	Carbon Packet Visual	First: 10/22/1971 to 11/9/1971 Peak: 10/22/1971 to 11/9/1971 (99-130 ft/hr)
"Weakly positive." Source: Aley, 1975, p. A-20; Aley and Aley, 1987. Later traces in the region indicate that this trace should be considered questionable. Monitoring points: CR1, EP1, SR1, EP6.						
Cr 007	Big Spring, Carter County {CR1} (17.05 miles)	Hurricane Creek below Blowing Spring (IP2)	Lycopodium Spores (5 pounds)	10/22/1971 (11:30)	Nylon Net Visual	First: 11/2/1971 to 11/4/1971 Peak: 11/2/1971 to 11/4/1971 (288-340 ft/hr)
Replicated trace CR 001. Source: Fletcher, 1971. Monitoring point: CR1.						

Appendix A
Summary of Water Traces to Selected Springs

MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Cr 008	Big Spring, Carter County {CR1} (24.82 miles)	Dowler Sinkhole (IP11)	Fluorescein (10 pounds)	12/10/1971 (12:10)	Carbon Packet Visual	First: 12/13/1971 to 12/20/1971 (546-1824 ft/hr)
"Strongly positive." Source: Aley, 1975, p. A-19. Monitoring points: CR1, EP1, EP11.						
Cr 009	Big Spring, Carter County {CR1} (39.01 miles)	Middle Fork 11 Point River (IP12)	Fluorescein (10 pounds)	1/18/1972 (14:00)	Carbon Packet Visual	First: 1/31/1972 to 2/4/1972 Peak: 2/4/1972 to 2/14/1972 (First: 507-664 ft/hr) (Peak: 319-507 ft/hr)
"Moderately positive." Source: Aley, 1975, p. A-20; Aley and Aley, 1987. Unable to replicate in this study with multiple attempts and should be considered invalid. Monitoring points: CR1, EP1, CR1, EP6, EP12.						
Cr 010	Big Spring, Carter County {CR1} (39.01 miles)	Middle Fork 11 Point River (IP12)	Lycopodium (6 pounds)	2/9/1972 (15:00)	Nylon Net Visual	First: 2/14/1972 to 2/23/1972 Peak: 2/14/1972 to 2/23/1972 (618-1660 ft/hr)
Source: Aley, 1975; Aley and Aley, 1987. Unable to replicate in this study with multiple attempts and should be considered invalid. Monitoring points: CR1, EP1.						
Cr 011	Big Spring, Carter County {CR1} (37.65 miles)	Jam Up Creek (IP13)	Fluorescein (15 pounds)	4/17/1972 (10:30)	Carbon Packet Visual	First: 4/27/1972 to 5/2/1972 Peak: 5/2/1972 to 5/9/1972 (First: 550-823 ft/hr) (Peak: 375-550 ft/hr)
"Weakly positive." Source: Fletcher, 1972C, p. 1; Aley and Aley, 1987. Monitoring points: CR1, EP1. Trace has been replicated twice (Duley, 1982C; Imes and Frederick, 2002).						
Cr 012	Big Spring, Carter County {CR1} (18.79 miles)	South Branch of Pike Creek in Winona (IP20)	Fluorescein (10 pounds)	5/10/1973 (17:05)	Carbon Packet Visual	First: 5/16/1973 to 5/22/1973 (351-714 ft/hr)
"Very strongly positive" but only one recovery interval noted. Source: Aley, 1975, p. A-23; Aley, 1973, p, 1. Monitoring points: CR1 and "a number of springs in the region."						
Cr 013	Big Spring, Carter County {CR1} (16.74 miles)	New Liberty Dump (IP48)	Fluorescein (2.5 pounds)	2/17/1974 (21:20)	Carbon Packet Visual	First: 2/20/1974 to 2/28/1974 (349-1422 ft/hr)
"Very weakly positive" with dye also recovered at EP33, EP51 and EP52. Source: Chaney, 1974, p. 4. Monitoring points: CR1, EP33, EP51, EP52, EP53, EP54, EP55, EP56.						

Appendix A
Summary of Water Traces to Selected Springs

<table>
<tr><th>MGS ID #</th><th>Recovery Point {ID#} (length)</th><th>Injection Point (ID #)</th><th>Tracer (Amount)</th><th>Injection Date (time)</th><th>Recovery Method Analysis Method</th><th>Recovery Dates (Velocity Range)</th></tr>
<tr><td>Cr 014</td><td>Big Spring, Carter County {CR1} (26.36 miles)</td><td>Spring Creek at Mouth of Jenny Hollow (IP21)</td><td>Fluorescein (8 pounds)</td><td>12/17/1974 (11:45)</td><td>Carbon Packet Visual</td><td>First: 1/24/1975 to 2/20/1975 (89-153 ft/hr)</td></tr>
<tr><td colspan="7">“Positive but numerous recent traces nearby do not agree. ”Source: Tryon, 1975A. p.1. Monitoring points: CR1, EP1A, EP1B, EP11, EP30, EP31.</td></tr>
<tr><td>Cr 016</td><td>Big Spring, Carter County {CR1} (37.65 miles)</td><td>Jam Up Creek (IP13)</td><td>Rhodamine WT™ (2.5 gallons)</td><td>7/9/1982 (11:00)</td><td>Carbon Packet Fluorometer</td><td>First: 8/13/1982 to 8/19/1982
Peak: 8/13/1982 to 8/19/1982
(194-227 ft/hr)</td></tr>
<tr><td colspan="7">Dye also recovered in a private well (JF5). Replicated trace Cr 011 and has been replicated by trace Cr 022. Source: Duley, 1982C. Monitoring points: CR1, EP1A, EP1B, EP12, EP26, JF4, JF5.</td></tr>
<tr><td>Cr 017</td><td>Big Spring, Carter County {CR1} (11.93 miles)</td><td>Peck Ranch Losing Stream (IP30)</td><td>Fluorescein (6 pounds)</td><td>8/1/1984 (14:00)</td><td>Carbon Packet Visual</td><td>First: 8/13/1984 to 8/22/1984 (124-220 ft/hr)</td></tr>
<tr><td colspan="7">“Strongly positive” with additional recovery at Mill Creek Spring (CR2). Note: No confirmation by fluorescence spectrometer due to “sample deterioration.” Source: Aley and Aley, 1987, p. A2, 3-40. Monitoring points: CR1, CR2, CR3, CR4, CR5, CR6</td></tr>
<tr><td>Cr 019</td><td>Big Spring, Carter County {CR1} (19.39 miles)</td><td>Losing Reach of Sycamore Creek (IP31)</td><td>Fluorescein (6 pounds)</td><td>3/19/1985 (14:45)</td><td>Carbon Packet Visual</td><td>First: 3/25/1985 to 4/11/1985 (186-721 ft/hr)</td></tr>
<tr><td colspan="7">"Moderately positive" but only one recovery interval noted. Dye also reported at Mill Creek Spring (CR2) and Plum Spring (CR7). Source: Aley and Aley, 1987, p. A2. Monitoring points: CR1, CR2, CR3, CR7.</td></tr>
<tr><td>Cr 026</td><td>Big Spring, Carter County {CR1} (19.13 miles)</td><td>Small Spring Hurricane Creek (IP74)</td><td>Rhodamine WT™ (2 pounds)</td><td>3/16/1992 (14:30)</td><td>Carbon Packet Fluorescence Spectrometer</td><td>First 4/2/1992 to 4/30/1992
Peak 4/2/1992 to 4/30/1992
(94-249 ft/hr)</td></tr>
<tr><td colspan="7">PVR never exceeded 1.0. Only one reported recovery interval. Dye also reported at Falling Spring (EP32). Source: Aley, 1992, Appendix B. Monitoring points: CR1, EP32, EP11A, EP11B.</td></tr>
<tr><td>Cr 027</td><td>Big Spring, Carter County {CR1} (21.0 miles)</td><td>McCormack Hollow near Pig Spring (IP53)</td><td>Fluorescein, (1.5 pounds)</td><td>6/28/1995 (15:30)</td><td>Carbon Packet Fluorescence Spectrometer</td><td>First: 7/25/1995 to 8/9/1995
Peak: 7/25/1995 to 8/9/1995
(110-172 ft/hr)</td></tr>
<tr><td colspan="7">Maximum PVR = 2.5 Replication attempt of Or 020 (Aley, 1975) with conflicting results. Dye reportedly recovered, with slightly lower PVR, at Wolfpen Hollow Spring #2 (EP100) though Big Spring trace is listed as a “possible recovery.” Source: Imes, p. 1, 1996. Much larger amounts were recovered at Wolfpen Hollow Spring #1 (EP99). Monitoring points: CR1, EP1, EP8, EP10, EP11, EP29, EP33, EP99, EP100, EP101, EP102.</td></tr>
</table>

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Summary of Water Traces to Selected Springs

MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Cr 022	Big Spring, Carter County {CR1} (37.65 miles)	Jam Up Creek (IP13)	Rhodamine WT™ (4.5 pounds)	7/10/2001 (10:30)	Water Sample Fluorescence Spectrometer	First: 8/12/2001 Peak: 8/21/2001 (First: 197 ft/hr) (Peak: 251 ft/hr)
Dye also recovered in a private well (JF5, as reported via personal communication from Peter Price, MGS, 2016). Source for Cr 022: Imes and Fredrick, 2002 Monitoring points: CR1, JF1, JF2, JF3, JF5.						
Cr 023	Big Spring, Carter County {CR1} (16.92 miles)	Barrett Spring Branch (IP70)	Rhodamine WT™ (4 pounds)	1/31/2002 (14:40)	Carbon Packet Fluorescence Spectrometer	First: 2/10/2002 Peak: 2/10/2002 (376 ft/hr)
One of two time-of- travel studies (see Cr 024 below) conducted with a water sampler and fluorescence spectrometer. Source: Imes et. al, 2007. Monitoring points: CR1.						
Cr 024	Big Spring, Carter County {CR1} (16.92 miles)	Barrett Spring Branch (IP70)	Rhodamine WT™ (2 pounds)	3/8/2002 (13:00)	Carbon Packet Fluorescence Spectrometer	First: 3/14/2002 Peak: 3/16/2002 (First: 625 ft/hr) (Peak: 468 ft/hr)
One of two time-of- travel studies (see Cr 023 above) conducted with a water sampler and fluorescence spectrometer. Source: Imes et. al, 2007. Monitoring points: CR1.						
Cr 025	Big Spring, Carter County {CR1} (28.18 miles)	Birch Creek downstream of Birch Tree sewage discharge (IP67)	Eosine (10 pounds)	8/4/2015 (13:30)	Carbon Packet Fluorescence Spectrometer	First: 8/18/2015 to 8/25/2015 Peak: 8/25/2015 to 9/2/2015 (First: 298-450 ft/hr) (Peak: 216-298 ft/hr)
Maximum PVR = 6.35 Large recovery. Dye was also recovered at Greer Spring (EP1A and EP1B) but may be the result of surface flow into lower losing reach of Spring Creek. Source: this study. Monitoring points: CR1, EP1A, EP1B, EP6, EP12, EP26.						
Big Spring (Douglas County, Missouri) Traces						
Do 001	Big Spring, Douglas County {NF6} (2.17 miles)	Still Spring Branch (IP26)	Fluorescein (4 pounds)	3/19/1978 (11:00)	Carbon Packet Visual	First: 3/19/1978 to 4/2/1978 (>34 ft/hr)
Source: Vandike, 1979. Monitoring points: NF6.						
Do 002	Big Spring, Douglas County {NF6} (2.17 miles)	Still Spring Branch (IP26)	Optical Brightener #28 (1 gallon)	3/19/1978 (11:00)	Cotton Ball Visual	First: 3/19/1978 to 4/2/1978 (>34 ft/hr)
Source: Vandike, 1979. Monitoring points: NF6.						

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MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Do 003	Big Spring, Douglas County {NF6} (5.67 miles)	Rattlesnake Spring Branch (IP84)	Fluorescein (8 pounds)	5/7/1978 (16:30)	Carbon Packet Visual	First: 5/14/1978 to 5/23/1978 (79-183 ft/hr)
Unable to replicate in this study. Injection apparently overlapped one by Dean (1978). Reported recovery at Rainbow Spring (NF1) as well. Source: Vandike, 1979. Monitoring points: NF6, NF1, NF2.						
Do 009	Big Spring, Douglas County {NF6} (4.39 miles)	Dribble Cave Spring (IP61)	Rhodamine WT™ (2 gallons)	3/11/2015 (16:45)	Carbon Packet Fluorescence Spectrometer	First: 3/11/2015 to 3/17/2015 Peak: 3/17/2015 to 3/24/2015 (First >161 ft/hr) (Peak: 74 to 161 ft/hr)
Maximum PVR = 279.09 Dye resurged at Big Spring West (NF6) and traveled downstream via surface flow in the North Fork to NF15 and NF26. Source: this study. Monitoring points: NP6, NF15, NF26, NF1, NF3, NF5, NF24, NF25, EP1A, EP1B, SR1.						
Bill Mac Spring (Oregon County, Missouri) Trace						
Or 043	Bill Mac Spring Oregon Co. {EP6} (5.25 miles)	Middle Fork of Eleven Point River below County Road 3850 (IP12)	Rhodamine WT™ (3 gallons)	12/11/2014 (11:45)	Carbon Packet Fluorescence Spectrometer	First: 12/30/2014 to 1/6/2015 Peak: 1/13/2015 to 1/20/2015 (First: 44-61 ft/hr) (Peak: 29-35 ft/hr)
Maximum PVR = 5.04 Dye recovered only at Bill Mac Spring (EP6) and downstream in the Eleven Point and Middle Fork of the Eleven Point River. Failed to replicate earlier legacy traces. Source: this study. Monitoring points: CR1, EP1A, EP1B, EP2, EP3, EP5, EP6, EP12, EP14, EP15, EP26, EP46, EP47, EP48, EP60, SR1, SR4.						
Or 050	Bill Mac Spring Oregon Co. {EP6} (2.66 miles)	Middle Fork Eleven Point River upstream of Blue Hole Spring (IP69)	Fluorescein (2 pounds)	9/9/2015 (11:45)	Carbon Packet Fluorescence Spectrometer	First: 9/9/2015 to 9/15/2015 Peak: 9/9/2015 to 9/15/2015 (>98 ft/hr)
Maximum PVR = 784.04 Definite dye recovery at Bill Mac Spring (EP6) and downstream in the Eleven Point and Middle Fork of the Eleven Point River. Possible recovery at Greer Spring. Source: this study. Monitoring points: CR1, EP1A, EP1B, EP6, EP12, EP14, EP26, EP42, EP44, EP47, EP48, EP60, SR1, SR9.						
Or 051	Bill Mac Spring Oregon Co. {EP6} (7.43 miles)	Middle Fork Eleven Point River near Fanchon (IP71)	Rhodamine WT™ (2 gallons)	9/9/2015 (10:20)	Carbon Packet Fluorescence Spectrometer	First: 10/7/2015 to 10/14/2015 Peak: 12/9/2015 to 12/16/2015 (First: 48-59 ft/hr) (Peak: 17-18 ft/hr)
Maximum PVR = 2.2 Dye also recovered at Rookery Tree Complex (EP61-63) and an unreported spring upstream of Bluff Spring (EP64). Relatively small recovery may be due to dye being in shallow storage (see detailed description). Source: this study. Monitoring points: CR1, EP1A, EP1B, EP6, EP12, EP14, EP26, EP42, EP44, EP47, EP48, EP60, EP61, EP62, EP63, EP64, EP70, SR1.						

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MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Or 053	Bill Mac Spring Oregon Co. {EP69} (7.41 miles)	Middle Fork Eleven Point River near Fanchon (IP73)	Eosine (10 pounds)	2/9/2016 (16:00)	Carbon Packet Fluorescence Spectrometer	First: 2/17/2016 to 2/29/2016 Peak: 2/17/2016 to 2/29/2016 (83-213 ft/hr)
Maximum PVR = 53.21 Dye also recovered at Rookery Tree Complex (EP61-63) Greer Spring (EP67) Mammoth Spring (SR1) and two unreported springs - EP70 and EP64. Larger recovery may be due to higher flow conditions than earlier trace (see detailed description). Source: this study. Monitoring points: EP1A, EP1B, EP6, EP12, EP14, EP26, EP42, EP44, EP47, EP48, EP60, EP61, EP62, EP63, EP64, EP70, EP71, SR1.						
Blue Spring (Ozark County, Missouri) Traces						
Oz 004	Blue Spring Ozark County {NF5} (0.54 miles)	McGarr Spring Branch (IP18)	Fluorescein (4 pounds)	10/21/1972 (13:30)	Carbon Packet Visual	First: 10/28/1972 to 11/11/1972 (6-17 ft/hr)
"Very strongly positive" but only one recovery interval noted. Source: Fletcher, 1972E, p. 2. Monitoring points: NF5, NF6, NF1, NF2.						
Oz 005	Blue Spring Ozark County {NF5} (1.18 miles)	Amber Spring Branch (IP23)	Fluorescein (1 pound)	8/1/1977 (09:30)	Carbon Packet Visual	First: 8/1/1977 to 8/5/1977 (>63 ft/hr)
Source: Vandike, 1979. Monitoring points: NF5.						
Oz 008	Blue Spring Ozark County {NF5} (3.73 miles)	The Sinks (IP24)	Fluorescein (6 pounds)	8/17/1977 (15:30)	Carbon Packet Visual	First: 8/31/1977 to 9/7/1977 (39-59 ft/hr)
This trace should be questioned because of potential overlap with injection (Oz 005). Also reported recovery at Rainbow (NF1) and North Fork (NF2) springs. Source: Vandike, 1979. Monitoring points: NF5, NF6, NF1, NF2.						
Oz 013	Blue Spring Ozark County {NF5} (4.22 miles)	Siloam Spring Branch (IP86)	Fluorescein (8 pounds)	11/2/1979 (11:30)	Carbon Packet Visual	First: 11/14/1979 to 12/6/1979 (27-77 ft/hr)
"Very strong visually obvious positive" but only one recovery interval. Source:Tryon, p. 1, 1979. Monitoring points: NF5, NF6, NF19, NF20.						
Oz 014	Blue Spring Ozark County {NF5} (8.39 miles)	Rattlesnake Spring Branch (IP84)	Eosine (9 pounds)	2/26/2014 (09:00)	Carbon Packet Fluorescence Spectrometer	First: 4/8/2014 to 4/15/2014 Peak: 5/13/2014 to 5/19/2014 (First: 38-45 ft/hr) (Peak: 22-24 ft/hr)
Maximum PVR = 4.16 Larger recoveries at Mammoth (SR1) and Greer springs (EP1A, EP1B). Source: this study. Monitoring points: NF1, NF2, NF3, NF5, NF6, NF12, NF13, NF15, CR1, SR1, EP1A, EP1B, EP12, EP13, EP15, EP46, BC1.						

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<tr><th>MGS ID #</th><th>Recovery Point {ID#} (length)</th><th>Injection Point (ID #)</th><th>Tracer (Amount)</th><th>Injection Date (time)</th><th>Recovery Method Analysis Method</th><th>Recovery Dates (Velocity Range)</th></tr>
<tr><td>Oz 034</td><td>Blue Spring
Ozark County
{NF5}
(8.66 miles)</td><td>Upper Tabor Creek
(IP 44)</td><td>Fluorescein
(5 pounds)</td><td>6/17/2014
(17:00)</td><td>Carbon Packet
Fluorescence Spectrometer</td><td>First: 6/24/2014 to 7/8/2014
Peak: 7/8/2014 to 7/15/2014
(First: 91-277 ft/hr)
(Peak: 68-91 ft/hr)</td></tr>
<tr><td colspan="7">Maximum PVR = 246.89 Very large dye recovery. Source: Current Study. Monitoring points: NF5, CR1, EP1A, EP1B, SR1, EP2, EP3, EP12, EP13, EP15, NF6, NF1, NF2, NF3, NF12, NF13, NF15.</td></tr>
<tr><td colspan="7">Blue/Morgan Complex (Oregon County, Missouri) Traces
(Includes all traces to Blue Spring and Morgan Spring.</td></tr>
<tr><td>No ID#</td><td>Morgan Spring
{EP3}
(15.46 miles)</td><td>Alton Sinkhole Dump
(IP4)</td><td>Fluorescein
(10 pounds)</td><td>5/28/1969
(13:00)</td><td>Carbon Packet
Visual</td><td>First: 8/11/1969 to 8/25/1969
(38-45 ft/hr)</td></tr>
<tr><td colspan="7">"Very strongly positive" but only reported in one interval and not reported at Blue Spring (EP2). Semi-replication attempt (Or 030, Or 031, Or 032 in this study) shows nearby stream resurfaces primarily at Boze Mill Spring (EP5) with a secondary recovery at Blue/Morgan Complex (EP2,EP3, EP4). Source: Aley, 1969, p. 1; Aley, 1972. Monitoring points: EP3,EP1A, EP1B, EP2, EP37, EP50.</td></tr>
<tr><td>Or 033</td><td>Blue Spring
Oregon County
{EP2}
(16.06 miles)</td><td>Upper Frederick Creek
(IP41)</td><td>Fluorescein
(10 pounds)</td><td>8/27/2013
(11:50)</td><td>Carbon Packet
Fluorescence Spectrometer</td><td>First: 9/18/2013 to 9/26/2013
Peak: 9/26/2013 to 10/1/2013
(First: 118-161 ft/hr)
(Peak: 101-118 ft/hr)</td></tr>
<tr><td colspan="7">Maximum PVR = 33.93 Large recovery. Dye was also recovered at Morgan (EP3) Sullivan (EP4) and Boze Mill (EP5) springs. Source: this study. Monitoring points: CR1, EP1A, EP1B, EP2, EP3, EP4, EP5, EP12, EP13, EP15, EP25, EP26.</td></tr>
<tr><td>Or 034</td><td>Morgan Spring
{EP3}
(16.19 miles)</td><td>Upper Frederick Creek
(IP41)</td><td>Fluorescein
(10 pounds)</td><td>8/27/2013
(11:50)</td><td>Carbon Packet
Fluorescence Spectrometer</td><td>First: 9/18/2013 to 9/26/2013
Peak: 9/26/2013 to 10/1/2013
(First: 119-161 ft/hr)
(Peak: 101-119 ft/hr)</td></tr>
<tr><td colspan="7">Maximum PVR = 29.18 Large recovery. Dye was also recovered at Blue (Oregon County-EP2), Sullivan (EP4) and Boze Mill (EP5) springs. Source: Current Study. Monitoring points: CR1, EP1A, EP1B, EP2, EP3, EP4, EP5, EP12, EP13, EP15, EP25, EP26.</td></tr>
<tr><td>Or 031</td><td>Blue Spring
{EP2}
(14.94 miles)</td><td>Piney Creek between Hwy 19 and Hwy 160
(IP42)</td><td>Rhodamine WT™
(3 gallons)</td><td>12/3/2013
(14:05)</td><td>Carbon Packet
Fluorescence Spectrometer</td><td>First: 12/30/2013 to 1/8/2014
Peak: 1/8/2014 to 1/14/2014
(First: 91-122 ft/hr)
(Peak: 78-91 ft/hr)</td></tr>
<tr><td colspan="7">Maximum PVR = 1.34 Small recovery likely resulted from surface flow into a downstream losing reach. Very large recovery earlier at Boze Mill Spring (EP5) with small recoveries at Morgan (EP3) and Sullivan (EP4) springs. Source: this study. Monitoring points: CR1, EP1A, EP1B, EP2, EP3, EP4, EP5, EP12, EP13, EP15, EP25, EP26.</td></tr>
</table>

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Or 032	Morgan Spring {EP3} (14.98 miles)	Piney Creek between Missouri Route 19 and U.S. Route 160 (IP42)	Rhodamine WT™ (3 gallons)	12/3/2013 (14:05)	Carbon Packet Fluorescence Spectrometer	First: 12/30/2013 to 1/8/2014 Peak: 1/8/2014 to 1/14/2014 (First: 91-122 ft/hr) (Peak: 78-91 ft/hr)
Maximum PVR = 1.1 Small recovery likely resulted from surface flow into a downstream losing reach. Very large recovery earlier at Boze Mill Spring (EP5) with another small recovery at Blue Spring (EP2). Source: this study. Monitoring points: CR1, EP1A, EP1B, EP2, EP3, EP4, EP5, EP12, EP13, EP15, EP25, EP26.						
Boze Mill Spring (Oregon County, Missouri) Traces						
No ID#	Boze Mill Spring {EP5} (10.37 miles)	Alton Sewage Lagoon (IP29)	Fluorescein (14 pounds)	4/22/1982	Carbon Packet Visual	First: 6/29/1982 to 8/8/1982 (21-34 ft/hr)
Dye recovery reported by USFS as "strongly positive" but recovered in only one interval with no known background information. Source: Duley, 1982B, p. 1.Connection has been replicated twice (Or 025, Or 026). Monitoring points: EP2, EP3, EP4, EP5						
Or 025	Boze Mill Spring {EP5} (10.37 miles)	Piney Creek Alton Sewage Discharge (IP29)	Rhodamine WT™ (1 gallon)	10/30/1984	Carbon Packet Fluorescence Spectrometer	First: 10/30/1984 to 11/15/1984 Peak: 11/15/1984 to 11/28/1984 (First: >143 ft/hr) (Peak: 79-143 ft/hr)
Maximum PVR = 1.17 Dye recovery was small but has been replicated (Or 026). Source: Kraft, 1985. Monitoring points: EP5, EP1, EP2, EP16, EP17, EP18, EP19, EP20, EP21, EP22, EP23, EP24, EP39, EP40, EP41, EP45, SR1.						
Or 026	Boze Mill Spring {EP5} (10.37 miles)	Piney Creek Alton Sewage Discharge (IP29)	Rhodamine WT™ (2 gallon)	7/23/1985	Carbon Packet Fluorescence Spectrometer	First: 7/23/1985 to 8/9/1985 Peak: 7/23/1985 to 8/9/1985 (>134 ft/hr)
Maximum PVR = 1.34 Dye recovery was small but has been replicated (Or 025). Source: Kraft, 1985. Monitoring points: EP5, EP2, EP3, EP7, EP16, EP17, EP36, EP37, EP38.						
Or 036	Boze Mill Spring {EP5} (13.91 miles)	Upper Frederick Creek (IP41)	Fluorescein (10 pounds)	8/27/2013 (11:50)	Carbon Packet Fluorescence Spectrometer	First: 9/26/2013 to 10/1/2013 Peak: 10/1/2013 to 10/8/2013 (First: 87-102 ft/hr) (Peak: 73-87 ft/hr)
Maximum PVR = 2.13 Moderate dye recovery with larger recovery at Blue/Morgan Complex (EP2, EP3, and EP4). Source: this study. Monitoring points: CR1, EP1A, EP1B, EP2, EP3, EP5, EP12, EP13, EP15, EP25, EP26.						

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MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Or 030	Boze Mill Spring {EP5} (11.32 miles)	Piney Creek between Missouri Route 19 and U.S. Route 160 (IP42)	Rhodamine WT™ (3 gallon)	12/3/2013 (14:05)	Carbon Packet Fluorescence Spectrometer	First: 12/12/2013 to 12/18/2013 Peak: 12/12/2013 to 12/18/2013 (166-279 ft/hr)
Maximum PVR = 133.16 Source: this study. Monitoring points: CR1, EP1A, EP1B, EP2, EP3, EP4, EP5, EP12, EP13, EP15, EP25, EP26						
Cave Spring (Oregon County, Missouri) Trace						
Or 018	Cave Spring {EP52} (0.18 miles)	New Liberty Dump (IP48)	Fluorescein (2.5 pounds)	2/17/1974 (21:20)	Carbon Packet Visual	First: 2/19/1974 to 2/20/1974 Peak: 2/20/1974 to 2/27/1974 (First: 15-24 ft/hr) (Peak: 5-15 ft/hr)
"Weakly positive" but no background packet was collected prior to injection. Dye also recovered at EP33, EP51 and CR1. Source: Chaney, 1974, p.4. Monitoring points: EP52, CR1, EP33, EP51, EP53, EP54, EP55, EP56, EP57.						
Deadman Spring (Oregon County, Missouri) Traces						
Or 066	Deadman Spring {EP77} (1.36 miles)	Injection Hollow (IP76)	Rhodamine WT™ (2 pounds)	1/3/1992 (15:15)	Carbon Packet Fluorescence Spectrometer	First: 1/3/1992 to 1/17/1992 Peak: 1/3/1992 to 1/17/1992 (>22 ft/hr)
Maximum PVR = 170.00 No background packet reported. Source: Aley, 1992. Monitoring points: EP67, EP29, EP74, EP75, EP77, EP78, EP103, EP79, EP80, EP81, EP82.						
Dennig Complex (Oregon County, Missouri) Traces *(Includes all traces to"Graveyard," "Huff," and "Dennig" springs (see remarks).*						
Or 004	Dennig Complex {EP11} (8.07 miles)	Hurricane Creek near Pond Hollow (IP50)	Fluorescein (10 pounds)	4/30/1969 (15:15)	Carbon Packet Visual	First: 6/24/1969 to 7/1/1969 Peak: 6/24/1969 to 7/15/1969 (First: 29-32 ft/hr) (Peak: 23-32 ft/hr)
Aley (1975, p. A-21) reported "very strongly positive" recovery. Spring is called "Graveyard Spring" in Aley (1975, p A-7). Aley and Aley (1987, p. 4-4) implies that Big Spring (CR1) was monitored with no connection established. Monitoring points: CR1, EP11.						
Or 006	Dennig Complex {EP11} (3.57 miles)	Davis Pond (IP51)	Fluorescein (5 pounds)	4/1/1970 (12:45)	Carbon Packet Visual	First : 4/1/1970 to 4/9/1970 (>99 ft/hr)
Aley (1975, p. A-22) reports "very str. positive" recovery but only one recovery interval is noted. Spring is called "Graveyard Springs" in Aley (1975, p A-8). Aley and Aley (1987, p. 4-4) implied that Big Spring (CR1) was monitored with no connection established. Monitoring points: CR1, EP11.						

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MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Or 011	Dennig Complex {EP11} (5.24 miles)	Horse Trail Spring (IP52)	Fluorescein (2 pounds)	6/14/1972 (11:30)	Carbon Packet Visual	First: 6/12/1972 to 6/23/1972 Peak: 6/12/1972 to 6/29/1972 (First: >128 ft/hr) (Peak: >77 ft/hr)
"Moderately positive" recovery. Potential overlap with Simpson Pond Injection (Or 010 - which was reportedly recovered at Greer Spring – EP1) This study (trace Or 059) shows there is a potential connection between Simpson Pond and the Dennig Complex. Source: Fletcher, 1975F, p. 1. Monitoring points: EP11, CR1, EP59.						
Or 020	Dennig Complex {EP11} (5.49 miles)	Pig Spring (IP53)	Fluorescein (5 pounds)	8/21/1974 (12:00)	Carbon Packet Visual	First: "About" 12/4/1974 to 12/18/1974 (10-12 ft/hr)
Aley (1975, p. A-23) reports "moderately positive" recovery but only one recovery interval is noted with approximate dates of recovery. Replication attempt yielded different results. See CR 027, Or 061 and Or 062. Aley (1975, A-10) termed the spring "Graveyard Spr. Complex." Monitoring points reported by Tryon (1975A): EP11, EP59, CR1.						
Or 059	Dennig Complex {EP11A and B} (3.15 miles)	Little Hurricane Creek Trib (IP72)	Rhodamine WT™ (2 gallons)	1/12/2016 (13:40)	Carbon Packet Fluorescence Spectrometer	First: 1/12/2016 to 2/9/2016 (>35 ft/hr)
Maximum PVR = 4.80 Injection was into small losing stream. Dye also recovered in Little Hurricane Creek (Or 058, at EP69). Incomplete dye recovery curve. Background packets and first recoveries were in the Eleven Point River downstream. Source: this study. Monitoring points: EP11, EP67, EP26, EP65, EP66, EP68, EP69, EP5.						
Ditch Spring (Oregon County, Missouri) Trace						
Or 019	Ditch Spring {EP51} (0.18 miles)	New Liberty Dump (IP48)	Fluorescein (2.5 pounds)	2/17/1974 (21:20)	Carbon Packet Visual	First: 2/19/1974 to 2/20/1974 Peak: 2/19/1974 to 2/20/1974 (15-25 ft/hr)
"Strongly positive" but no background packet was collected prior to injection. Dye also recovered at EP33, EP52 and CR1. Source: Chaney, 1974, p.4. Monitoring points: EP52, CR1, EP33, EP51, EP53, EP54, EP55, EP56, EP57.						
Falling Spring (Oregon County, Missouri) Traces						
Or 016	Falling Spring {EP32} (1.73 miles)	Road Ditch (IP54)	Fluorescein (2 pounds)	9/5/1973 (07:00)	Carbon Packet Visual	First: 9/7/1973 to 9/11/1973 (60-168 ft/hr)
Source: Tryon, 1975C. Only one recovery interval reported. Monitoring points: EP32.						
Or 021	Falling Spring {EP32} (2.61 miles)	Intermittent Stream (IP55)	Fluorescein (5 pounds)	2/28/1975 (11:45)	Carbon Packet Visual	First: 3/3/1975 to 3/13/1975 Peak: 3/13/1975 to 3/19/1975 (First: 44-191 ft/hr) (Peak: 30-44 ft/hr)
"Moderately positive" recovery. Source: Aley (1975, p. A-23). Monitoring points: EP32.						

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MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Or 063	Falling Spring {EP32} (2.26 miles)	Small Spring Hurricane Creek (IP74)	Rhodamine WT™ (2 pounds)	3/16/1992 (14:30)	Carbon Packet Fluorescence Spectrometer	First: 4/1/1992 to 4/28/1992 Peak: 4/1/1992 to 4/28/1992 (12-31 ft/hr)
Maximum PVR = 1.21 Only one recovery interval noted. Dye also reported at Big Spring (CR1). Source:Aley, 1992. Monitoring points: CR1, EP32, EP11A, EP11B.						
Gravel Spring (Oregon County, Missouri) Trace						
Or 009	Gravel Spring {EP58} (0.66 miles)	McCormack Hollow (IP59)	Fluorescein (5 pounds)	3/29/1972 (12:30)	Carbon Packet Visual	First: 3/29/1972 to 4/4/1972 (>24 ft/hr)
Aley (1975, p. A-23) reports "very strongly positive" recovery but no background analysis. Monitoring points: EP58.						
Greer Spring (Oregon County, Missouri) Traces						
Or 010	Greer Spring {EP1A-EP1B} (3.49 miles)	Simpson Pond (IP14)	Fluorescein (10 pounds)	5/26/1972 (11:45)	Carbon Packet Visual	First: 5/26/1972 to 6/1/1972 Peak: 5/26/1972 to 6/1/1972 (>124 ft/hr)
"Moderately Positive" having an estimated velocity of "137 ft/hr with a maximum/minimum range of 238-35 ft/hr." Source: Fletcher, 1972D, p. 2. A trace (Or 059) conducted from a nearby losing stream during this study suggests that this trace is questionable (see text). Monitoring Points: EP1A , EP1B and "numerous suspected risings" (Fletcher 1972D, p. 1).						
Or 014	Greer Spring {EP1A, EP1B} (27.14 miles)	Nuttle Spring Branch (IP19)	Fluorescein (15 pounds)	11/9/1972 (9:45)	Carbon Packet Visual	First: 11/15/72 to 11/27/72 (330-980 ft/hr)
"Moderately Positive" but only one recovery interval noted. Source: Aley, 1975, p. A-20. Monitoring points: EP1.						
Or 022	Greer Spring {EP1A, EP1B } (34.73 miles)	Eleven Point River at U.S. Route 63 (IP22)	Fluorescein (15 pounds)	9/9/1975 (06:00)	Carbon Packet Visual	First: 9/11/1975 to 9/22/1975 Peak: 9/22/1975 to 10/2/1975 (First: 577-3396 ft/hr) (Peak: 329-577 ft/hr)
"Moderately strong" trace. Source: Tryon, 1975B, p 1. Monitoring points: EP1A, EP1B, CR1, SR1.						
Or 040	Greer Spring {EP1A, EP1B } (30.76 miles)	Sims Creek (IP40)	Rhodamine WT™ (2 pounds)	5/22/2002 (14:30)	Water Sample Fluorescence Spectrometer	First: 5/30/2002 @ 9:03 Peak: 5:30/2002 @ 21:03 (First: 857 ft/hr) (Peak: 818 ft/hr)
Time-of travel study. Source: USGS unpublished files and Mike Kleeschulte (personal correspondence, USGS, retired, 2016). Monitoring points: EP1, CR1.						

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<table>
<tr><th>MGS ID #</th><th>Recovery Point {ID#} (length)</th><th>Injection Point (ID #)</th><th>Tracer (Amount)</th><th>Injection Date (time)</th><th>Recovery Method Analysis Method</th><th>Recovery Dates (Velocity Range)</th></tr>
<tr><td>Or 041</td><td>Greer Spring {EP1A, EP1B } (8.05 miles)</td><td>Paty Spring (IP39)</td><td>Rhodamine WT™</td><td>3/12/2003 (10:30)</td><td>Carbon Packet Fluorescence Spectrometer</td><td>First: 3/13/2003 to 3/28/2003
Peak: 3/13/2003 to 3/28/2003
(>110 ft/hr)</td></tr>
<tr><td colspan="7">Maximum PVR = 1.7 This trace is the result of re-interpreting USGS files using the PVR method. Source: Unpublished USGS files and this study. Monitoring Points: EP1, CR1.</td></tr>
<tr><td>Or 046</td><td>Greer Spring {EP1A, EP1B } (8.31 miles)</td><td>Tributary of Spring Creek (IP38)</td><td>Fluorescein (4 pounds)</td><td>11/2/2004</td><td>Water Sample Fluorescence Spectrometer</td><td>First: 11/17/2004
Peak: 11/20/2004
(First: 122 ft/hr)
(Peak: 102 ft/hr)</td></tr>
<tr><td colspan="7">Maximum PVR = 6.5 Source: USGS unpublished files and Mike Kleeschulte (personal correspondence, USGS, retired, 2016). Monitoring points: EP1, CR1.</td></tr>
<tr><td>Or 038</td><td>Greer Spring {EP1A, EP1B} (37.63 miles)</td><td>Rattlesnake Spring Branch (IP84)</td><td>Eosine (9 pounds)</td><td>2/26/2014 (09:00)</td><td>Carbon Packet Fluorescence Spectrometer</td><td>First (EP1A): 3/26/2014
First (EP1B): 3/27/2014
Peak: 3/27/2014 to 4/1/2014
(First: 284-294 ft/hr)
(Peak: 243-285 ft/hr)</td></tr>
<tr><td colspan="7">Maximum PVR = 13.88 Dye also recovered at Mammoth (SR1) and Blue springs (NF5). Source: this study. Monitoring points: EP1A, EP1B, EP4, EP12, EP13, EP15, EP26, EP46, SR1, NF1, NF2, NF3, NF5, NF6, NF12, NF13, NF15, CR1, BC1.</td></tr>
<tr><td>Or 027</td><td>Greer Spring {EP1A, EP1B} (33.93 miles)</td><td>Upper Dry Creek (IP17)</td><td>Rhodamine WT™ (3 gallons)</td><td>3/26/2014 (13:05)</td><td>Carbon Packet Fluorescence Spectrometer</td><td>First: 4/15/2014 to 4/22/2014
Peak: 4/15/2014 to 4/22/2014
(277-374 ft/hr)</td></tr>
<tr><td colspan="7">Maximum PVR = 10.22 Dye also recovered at Mammoth Spring (SR1). Source: this study. Monitoring points: EP1A, EP1B, EP4, EP12, EP13, EP15, EP26, EP46, SR1, NF1, NF2, NF3, NF5, NF6, NF12, NF13, NF15, CR1, BC1.</td></tr>
<tr><td>Or 042</td><td>Greer Spring {EP1A, EP1B} (16.26 miles)</td><td>Eleven Point River near Lost Hill (IP46)</td><td>Eosine (5 pounds)</td><td>10/28/2014 (17:00)</td><td>Carbon Packet Fluorescence Spectrometer</td><td>First: 11/3/2014 to 11/13/2014
Peak: 11/3/2014 to 11/13/2014
(227-611 ft/hr)</td></tr>
<tr><td colspan="7">Maximum PVR = 18.23 Dye was never recovered at any point on the Eleven Point River above Greer Spring. Source: this Study. Monitoring points: EP1A, EP1B, EP2, EP3, EP5, EP6, EP12, EP14, EP15, EP 26, EP42, EP46, SR1, CR1, BC1, NF1, NF2, NF5.</td></tr>
<tr><td>Or 045</td><td>Greer Spring {EP1A, EP1B} (11.00 miles)</td><td>Cave Spring on Spring Creek (IP49)</td><td>Fluorescein (5 pounds)</td><td>1/21/2015 (10:25)</td><td>Carbon Packet Fluorescence Spectrometer</td><td>First: 2/10/2015 to 2/18/2015
Peak: 2/18/2015 to 2/24/2015
(First: 86-121 ft/hr)
(Peak: 71-86 ft/hr)</td></tr>
<tr><td colspan="7">Maximum PVR = 7.58 Source: this study. Monitoring points: EP1A, EP1B, EP2, EP3, EP5, EP6, EP12, EP14, EP15, EP 26, EP42, EP46, SR1, CR1, BC1, NF1, NF2, NF5.</td></tr>
</table>

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MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Or 047	Greer Spring {EP1A, EP1B} (24.28 miles)	Upper Kenaga Hollow (IP65)	Rhodamine WT™ (2 gallons)	5/18/2015 (11:19)	Carbon Packet Fluorescence Spectrometer	First: 5/26/2015 to 6/2/2015 Peak: 6/2/2015 to 6/9/2015) (First: 358-673 ft/hr) (Peak: 244-358 ft/hr)
Maximum PVR = 10.58 Source: this study. Monitoring points: EP1A, EP1B, EP6, EP12, EP14, EP 26, EP42, SR1, CR1.						
Or 048	Greer Spring {EP1A, EP1B} (32.46 miles)	Dean Davis Conservation Area (IP66)	Fluorescein (10 pounds)	6/18/2015 (12:12)	Carbon Packet Fluorescence Spectrometer	First: 6/30/2015 to 7/7/2015 Peak: 7/7/2015 to 7/14/2015 (First: 378-601 ft/hr) (Peak: 276-378 ft/hr)
Maximum PVR = 8.49 Source: this study. Monitoring points: EP1A, EP1B, EP6, EP12, EP14, EP15, EP 26, EP42, SR1, CR1, BC1, NF1, NF26, NF5.						
Or 049	Greer Spring {EP1A, EP1B} (15.98 miles)	Birch Creek downstream of Birch Tree sewage discharge (IP67)	Eosine (10 pounds)	8/4/2015 (13:30)	Carbon Packet Fluorescence Spectrometer	First: 8/18/2015 to 8/25/2015 Peak: 8/18/2015 to 8/25/2015 (169-254 ft/hr)
Maximum PVR 1.87 Main dye recovery at Big Spring (Carter County - CR1). This trace could be the result of surface flow into a losing reach of Spring Creek downstream of the injection. Source: this study. Monitoring points: EP1A, EP1B, EP6, EP12, EP 26, CR1.						
Or 060	Greer Spring {EP1A, EP1B} (15.7 miles)	Middle Fork 11 Point River upstream of Blue Hole Spring (IP69)	Fluorescein (2 pounds	9/9/2015 (11:45)	Carbon Packet Fluorescence Spectrometer	First: 9/22/2015 to 9/29/2015 Peak: 9/22/2015 to 9/29/2015 (173-268 ft/hr)
Maximum PVR = 2.7 Principal recovery at Bill Mac Spring (EP6) and downstream in the Eleven Point River. Tentative recovery at Greer Spring (EP1A, EP1B) requires verification. Source: this study. Monitoring points: EP6, CR1, EP1A, EP1B, EP12, EP14, EP26, SR1, SR9.						
Or 054	Greer Spring {EP67} (20.32 miles	Middle Fork Channel upstream of Fanchon (IP73)	Eosine (10 pounds)	2/9/2016 (16:00)	Carbon Packet Fluorescence Spectrometer	First: 2/29/2016 to 3/14/2016 Peak: 2/29/2016 to 3/14/2016 (132-225 ft/hr)
Maximum PVR = 1.16 Small recovery likely the result of dye recovery at Bill Mac Spring (EP6) flowing into a losing reach downstream that recharges Greer Spring (EP67). Should be replicated. Dye also recovered at Bill Mac Spring (EP6), Mammoth Spring (SR1), Rookery Tree Complex (EP 61-63) unreported spring upstream of Bluff Spring (EP64) and unreported spring upstream of Howell County Road 3850 (EP70). Source: this study. Monitoring points: EP1, EP6, EP12, EP26, EP60, EP61, EP62, EP63, EP64, EP67, EP70, EP71, SR1.						

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MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Hay Hollow Creek Springs (Douglas County, Missouri) Trace						
Do 007	Hay Hollow Creek Springs {NF27} (1.27 miles)	Hay Hollow Creek (IP62)	Fluorescein (6 pounds)	4/14/1981	Carbon Packet Visual	First: 4/14/1981 to 4/29/1981 (>19 ft/hr)
Only one recovery interval noted. Source: Tryon, 1981B, p. 1. Monitoring points: NF27, NF5.						
Hodgson Mill Spring (Ozark County, Missouri) Traces						
See "Rainbow/North Fork/Hodgson Mill Complex" below.						
Hurricane Creek (Oregon County, Missouri) Traces						
Or 002	Hurricane Creek near Kelly Hollow {EP102} (0.94 miles)	Hurricane Creek Johnson Spring confluence (IP5)	Fluorescein (1 pound)	8/8/1967	Carbon Packet Visual	First: 8/8/1967 to 8/15/1967 (>30 ft/hr)
"Very strongly positive" but no background analysis reported. Source: Aley, 1975, p A-23. Monitoring points: EP102.						
Or 003	Hurricane Creek Weir {EP28} (0.86 miles)	Hurricane Creek near north section line of section 34 (IP58)	Fluorescein (3 pounds)	11/6/1968 (11:30)	Carbon Packet Visual	First: 11/8/1968 to 11/18/1968 Peak: 11/8/1968 to 11/18/1968 (16-94 ft/hr)
"Very strongly positive'' but only one recovery interval noted. Source: Aley, 1975, p, A-23. Monitoring points: EP28.						
Mammoth Spring (Fulton County, Arkansas) Traces						
Or 001	Mammoth Spring {SR1} (6.82 miles)	Cave at Grand Gulf (IP1)	Fluorescein (0.5 pound)	10/16/1967 (20:00)	Carbon Packet Fluorometer	First: 10/17/1967 to 10/18/1967 Peak: 10/20/1967 (First: 750-1500 ft/hr) (Peak: 375 ft/hr)
Source: Aide, 1968. Has been replicated by trace Or 029 during this study. Monitoring points: SR1						
Or 007	Mammoth Spring {SR1} (14.54 miles)	Granny Meyers Spring (IP7)	Fluorescein (10 pounds)	12/16/1970 (14:45)	Carbon Packet Visual	First: 12/30/1970 to 1/12/1971 Peak: 12/30/1970 to 1/12/1971 (First: 119-230 ft/hr)
"Moderately positive" recovery. Source: Aley, 1975, p. A-21. Has been replicated by trace Or 039 during this study. Monitoring points: SR1.						

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MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Or 012	Mammoth Spring {SR1} (24.93 miles)	Renfrow Spring Sink (IP15)	Fluorescein (10 pounds)	6/14/1972 (13:55)	Carbon Packet Visual	First: 6/22/1972 to 7/5/1972 Peak: 6/22/1972 to 7/12/1972 (First: 262-692 ft/hr) (Peak: 200-692 ft/hr)
Moderately positive recovery. Source: Fletcher, 1972, p. 1. Monitoring points: SR1 and "numerous suspected risings."						
Or 013	Mammoth Spring {SR1} (32.44 miles)	Upper Dry Creek (IP17)	Fluorescein (10 pounds)	8/14/1972 (11:00)	Carbon Packet Visual	First: 8/28/1972 to 9/8/1972 Peak: 8/28/1972 to 9/8/1972 (285-508 ft/hr)
"Weakly positive" with only one recovery interval noted. Source: Aley, 1975, p. A-21. Replication attempt during this study showed an additional recovery at Greer Spring (EP1A, 1B). See Or 028. Monitoring points: SR1.						
Or 024	Mammoth Spring {SR1} (22.27 miles)	Sinkhole in West Plains Sewage Lagoon (IP85)	Fluorescein (10 pounds)	5/18/1978	Carbon Packet Visual	First: 5/26/1978 to 5/30/1978 Peak: 5/30/1978 to 6/5/1978 (First: 408-612 ft/hr) (Peak: 272-408 ft/hr)
This injection overlapped another (see Do 003 trace to Big Spring –Douglas County, and Oz 014 to Blue Spring – Ozark County) by Vandike (1979) that also likely resurfaced at Mammoth Spring. Source: Dean, 1978. Monitoring points: SR1, SR2, SR3, SR4, SR5, SR6, SR7, SR8, SR9.						
Or 029	Mammoth Spring {SR1} (6.82 miles)	Cave at Grand Gulf (IP1)	Rhodamine WT ™ (3 gallons)	10/9/2013 (10:50)	Water Fluorometer Carbon Packet Fluorescence Spectrometer	Water First: 10/13/2013 @ 16:13 Peak: 10/17/2013 @ 4:58 (First: 355 ft/hr) (Peak: 193 ft/hr) Carbon Packet First: 10/9/2013 to 10/16/2013 Peak: 10/16/2013 to 10/26/2013 (First: >210 ft/hr) (Peak: 115-210 ft/hr)
Maximum PVR = 15.86 Source: this study. Monitoring points: SR1, EP1A, EP1B, EP2, EP3, EP5.						
Or 035	Mammoth Spring {SR1} (25.29 miles)	Upper Mustion Creek (IP43)	Fluorescein (10 pounds)	2/14/2014 (13:00)	Carbon Packet Fluorescence Spectrometer	First: 2/25/2014 to 3/6/2014 Peak: 3/6/2014 to 3/11/2014 (First: 278-504 ft/hr) (Peak: 223-278 ft/hr)
Maximum PVR = 217.32 Source: this Study. Monitoring points: SR1, CR1, EP1A, EP1B, EP2, EP3, EP12, EP13, EP15, NF1, NF2, NF3, NF5, NF6, NF13, NF15, BC1.						

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MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Or 037	Mammoth Spring {SR1} (35.18 miles)	Rattlesnake Spring Branch (IP84)	Eosine (9 pounds)	2/26/2014 (09:00)	Carbon Packet Fluorescence Spectrometer	First: 3/18/2014 to 3/27/2014 Peak: 3/27/2014 to 4/1/2014 (First: 266-384 ft/hr) (Peak: 227-266 ft/hr)
Maximum PVR = 9.16 Dye also recovered at Greer (EP1A, 1B) and Blue springs (NF5). Source: this study. Monitoring points: SR1, CR1, EP1A, EP1B, EP2, EP3, EP12, EP13, EP15, NF1, NF3, NF5, NF6, NF12, NF13, NF15, NF26, BC1.						
Or 028	Mammoth Spring {SR1} (32.74 miles)	Upper Dry Creek (IP17)	Rhodamine WT™ (3 gallons)	3/26/2014 (13:05)	Carbon Packet Fluorescence Spectrometer	First: 4/15/2014 to 4/22/2014 First: 4/15/2014 to 4/22/2014 (266-360 ft/hr)
Maximum PVR = 8.44 Dye also recovered at Greer Spring (EP1A, 1B). Source: this study. Monitoring points: SR1, CR1, EP1A, EP1B, EP2, EP3, EP12, EP13, EP15, NF1, NF3, NF5, NF6, NF12, NF13, NF15, NF26, BC1.						
Or 039	Mammoth Spring {SR1} (14.54 miles)	Granny Meyers Spring (IP7)	Eosine (5 pounds)	7/23/2014 (15:56)	Carbon Packet Fluorescence Spectrometer	First: 8/5/2014 to 8/12/2014 Peak: 8/12/2014 to 8/19/2014 (First: 119-160 ft/hr) (Peak: 94-119 ft/hr)
Maximum PVR = 29.92 Replication of an earlier trace (Or 007). Source: this study. Monitoring points: SR1, CR1, EP1A, EP1B, EP2, EP3, EP12, EP13, EP15, NF1, NF2, NF3, NF5, NF6, NF13, NF15, BC1.						
Or 055	Mammoth Spring {SR1} (22.36 miles)	Middle Fork Channel upstream of Fanchon (IP73)	Eosine (10 pounds)	2/9/2016 (16:00)	Carbon Packet Fluorescence Spectrometer	First: 2/29/2016 to 3/14/2016 Peak: 2/29/2016 to 3/14/2016 (146-249 ft/hr)
Maximum PVR = 3.32 Also recovered at Bill Mac Spring (EP6), Greer Spring (EP67), Rookery Tree Complex (EP 61-63) unreported spring upstream of Bluff Spring (EP64) and unreported spring upstream of Howell County Road 3850 (EP70). Source: this study. Monitoring points: EP1, EP6, EP12, EP26, EP60, EP61, EP62, EP63, EP64, EP67, EP70, EP71, SR1.						
Mill Creek Spring (Carter County, Missouri) Traces						
Cr 018	Mill Creek Spring {CR2} (4.52 miles)	Peck Ranch Losing Stream (IP30)	Fluorescein (6 pounds)	8/1/1984 (14:00)	Carbon Packet Fluorescence Spectrometer	First: 8/6/1984 to 8/13/1984 (84-205 ft/hr)
"Strongly positive" but with only one recovery interval noted. Additional recovery at Big Spring (Carter County - CR1). Source: Aley and Aley, 1987, p A3. Monitoring points: CR2, CR1, CR3, CR4, CR5, CR6.						

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MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Cr 020	Mill Creek Spring {CR2} (12.50 miles)	Losing Reach of Sycamore Creek (IP31)	Fluorescein (6 pounds)	3/19/1985 (14:45)	Carbon Packet Visual	First: 3/25/1985 to 4/11/1985 (120-470 ft/hr)
"Moderately positive" but with only one recovery interval noted. Dye recovered at Big (Carter County - CR1) and Plum springs (CR7) as well. Source: Aley and Aley, 1987, p. A3. Monitoring points: CR2, CR1, CR7, CR3.						
Cr 028	Mill Creek Spring {CR2} (6.1 miles)	East Fork of Nordic Hollow (IP32)	Fluorescein (6 pounds)	6/25/1985 (12:30)	Carbon Packet Fluorescence Spectrometer	First: 7/9/1985 to 8/8/1985 (32-100 ft/hr)
"Strongly positive" but with only one recovery interval noted. Source: Aley and Aley, 1987, p. A3. Monitoring points: CR2, CR1, CR3, CR4.						
Mitchell Spring (Oregon County, Missouri) Trace						
Or 023	Mitchell Spring {EP23} (1.15 miles)	Schoolhouse Hollow (IP63)	Fluorescein (5 pounds)	12/28/1976	Carbon Packet Visual	First: 12/28/1976 to 3/10/1977 (4 ft/hr)
Only one recovery interval. Source: Tryon, 1977. Monitoring points: EP23, EP5.						
Morgan Spring (Oregon County, Missouri) Traces						
See "Blue/Morgan Complex" above.						
North Fork Spring (Ozark County, Missouri) Traces						
See "Rainbow/North Fork/Hodgson Mill Complex" below.						
Plum Spring (Carter County, Missouri) Trace						
Cr 021	Plum Spring {CR7} (7.56 miles)	Losing Reach of Sycamore Creek (IP31)	Fluorescein (6 pounds)	3/19/1985 (14:45)	Carbon Packet Visual	First: 3/25/1985 to 4/16/1985 (60-287 ft/hr)
"Very weakly positive" with only one recovery interval. Dye reportedly recovered at Big (Carter County - CR1) and Mill Creek (CR2) springs as well. Source: Aley and Aley, 1987, p. A5. Monitoring points: CR7, CR1, CR2, CR3.						
Rainbow/North Fork/Hodgson Mill Complex (Ozark County, Missouri) Traces *(Includes all traces to Rainbow, North Fork and Hodgson Mill springs)*						
Oz 001	Hodgson Mill Spring {BC1} (5.52 miles)	Dora Sinkhole (IP9)	Lycopodium spores (10 pounds)	7/22/71 (12:00)	Nylon Net Visual	9/2/1971 to 9/15/1971
Tracer flushed with 1200 gallons of water and recovered only at Hodgson Mill Spring (BC1). There was no monitoring for lycopodium spores before 9/2/1971 or after 9/15/1971. Trace was replicated at the same time with fluorescein (see Oz 002 below). Source: Aley, 1972. Monitoring points: BC1, NF1, NF2, NF5.						

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Oz 002	Hodgson Mill Spring {BC1} (5.52 miles)	Dora Sinkhole (IP9)	Fluorescein (7 pounds)	7/22/71 (12:00)	Carbon Packet Visual	First: 8/3/1971 to 8/11/1971 Peak: 8/11/1971 to 8/16/1971 (First: 61-101 ft/hr) (Peak: 49-61 ft/hr)
Tracer flushed with 1200 gallons of water and recovered only at Hodgson Mill Spring (BC1). Trace was replicated at the same time with Lycopodium spores (see Oz 001 above). Source: Aley, 1972. Monitoring Points: BC1, NF1, NF2, NF5.						
Oz 006	North Fork Spring {NF2} (6.31 miles)	The Sinks (IP24)	Fluorescein (6 pounds)	8/17/1977 (15:30)	Carbon Packet Visual	First: 8/31/1977 to 9/7/1977 (67-100 ft/hr)
Also reported recovery at Rainbow (NF1) and Blue (Ozark County - NF5) springs. Source: Vandike, 1979. Monitoring points: NF2, NF1, NF5.						
Oz 007	Rainbow Spring {NF1} (6.46 miles)	The Sinks (IP24)	Fluorescein (6 pounds)	8/17/1977 (15:30)	Carbon Packet Visual	First: 8/31/1977 to 9/7/1977 (68-103 ft/hr)
Also reported recovery at North Fork (NF2) and Blue (Ozark County - NF5) springs. Source: Vandike, 1979. Monitoring points: NF1, NF2, NF5.						
Oz 009	Rainbow Spring {NF1} (10.95 miles)	Brassfield Sink (IP25)	Fluorescein (15 pounds)	11/2/1977 (16:00)	Carbon Packet Visual	First: 12/3/1977 to 12/10/1977 (64-78 ft/hr)
Source: Vandike, 1979. This study suggests that this trace is questionable. Monitoring points: NF1						
Oz 011	Rainbow Spring {NF1} (1.69 miles)	Collins Spring Branch (IP27)	Optical Brightener (1 gallon)	4/23/1978 (15:10)	Cotton Ball Visual	First: 4/23/1978 to 4/30/1978 (>54 ft/hr)
Source: Vandike, 1979. Monitoring points: NF1.						
Oz 012	Rainbow Spring {NF1} (11.45 miles)	Rattlesnake Spring Branch (IP84)	Fluorescein (8 pounds)	5/7/1978 (16:30)	Carbon Packet Visual	First: 5/15/1978 to 5/24/1978 (150-322 ft/hr)
Also reported recovery at Big Spring (NF5) but unable to replicate during this study. Injection overlapped one by Dean (1978). Source: Vandike, 1979. Monitoring points: NF1, NF2, NF6.						
Oz 016	North Fork Spring {NF2} (34.55 miles)	Wolf Creek (IP33)	Fluorescein (10 pounds)	4/18/1986 (11:00)	Carbon Packet Fluorescence Spectrometer	First: 4/18/1986 to 5/2/1986 Peak: 4/18/1986 to 5/2/1986 (>541 ft/hr)
Maximum PVR = 13.0. Also reported recovery at Rainbow (NF1) and Hodgson Mill (BC1) springs. Source: Williams, 1986. Monitoring points: BC1, NF1, NF2, NF5, NF6, NF15, BVC1, BVC2, GR1, NF7, BC2, BC3, BC4, BC6, BC7, BC8, BC9, BC10.						

Appendix A
Summary of Water Traces to Selected Springs

MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Oz 017	Rainbow Spring {NF1} (34.81 miles)	Wolf Creek (IP33)	Fluorescein (10 pounds)	4/18/1986 (11:00)	Carbon Packet Fluorescence Spectrometer	First: 4/18/1986 to 5/2/1986 Peak: 4/18/1986 to 5/2/1986 (>545 ft/hr)
Maximum PVR = 14.3 Also reported recovery at North Fork (NF2) and Hodgson Mill (BC1) springs. Source: Williams, 1986. Monitoring points: NF1, BC1, NF2, NF5, NF6, NF15, BVC1, BVC2, GR1, NF7, BC2, BC3, BC4, BC6, BC7, BC8, BC9, BC10.						
Oz 018	Hodgson Mill Spring {BC1} (33.12 miles)	Wolf Creek (IP33)	Fluorescein (10 pounds)	4/18/1986 (11:00)	Carbon Packet Fluorescence Spectrometer	First: 4/18/1986 to 5/2/1986 Peak: 5/2/1986 to 5/14/1986 (First: >519 ft/hr) (Peak: 280-519 ft/hr)
Maximum PVR = 10.22 Also reported recovery at North Fork (NF2) and Rainbow (NF1) springs. Source: Williams, 1986 Monitoring points: NF1, BC1, NF2, NF5, NF6, NF15, BVC1, BVC2, GR1, NF7, BC2, BC3, BC4, BC6, BC7, BC8, BC9, BC10.						
Oz 019	Rainbow Spring {NF1} (34.52 miles)	Fry Creek (IP34)	Rhodamine WT™ (2 gallons)	8/19/1987 (14:00)	Carbon Packet Fluorescence Spectrometer	First: 9/11/1987 to 9/16/1987 Peak: 9/11/1987 to 9/16/1987 (272-331 ft/hr)
Maximum PVR = 32.36 Also reported recovery at North Fork (NF2) and Hodgson Mill (BC1) springs. Source: Williams, 1987 Monitoring points: NF1, NF2, BC1.						
Oz 020	Hodgson Mill Spring {BC1} (32.72 miles)	Fry Creek (IP34)	Rhodamine WT™ (2 gallons)	8/19/1987 (14:00)	Carbon Packet Fluorescence Spectrometer	First: 9/11/1987 to 9/12/1987 Peak: 9/11/1987 to 9/16/1987 (First: 301-314 ft/hr) (Peak: 258-314 ft/hr)
Maximum PVR = 21.9 Also reported recovery at North Fork (NF2) and Rainbow (NF1) springs. Source: Williams, 1987. Monitoring points: BC1, NF1, NF2.						
Oz 021	North Fork Spring {NF2} (34.26 miles)	Fry Creek (IP34)	Rhodamine WT™ (2 gallons)	8/19/1987 (14:00)	Carbon Packet Fluorescence Spectrometer	First: 9/11/1987 to 9/16/1987 Peak: 9/16/1987 to 9/22/1987 (First: 270-329 ft/hr) (Peak: 222-270 ft/hr)
Maximum PVR = 34.03 Also reported recovery at Rainbow (NF1) and Hodgson Mill (BC1) springs. Source: Williams, 1987. Monitoring points: NF2, NF1, BC1.						
Oz 024	Rainbow Spring {NF1} (27.62 miles)	Summer Spring Branch (IP35)	Rhodamine WT™ (1 gallon)	11/2/1988 (13:30)	Carbon Packet Fluorescence Spectrometer	First: 11/10/1988 to 11/17/1988 Peak: 11/10/1988 to 11/17/1988 (407-766 ft/hr)
Also reported recovery at North Fork (NF2) and Hodgson Mill (BC1) springs. Source: Brown, 1989. Monitoring points: BC1, NF1, NF2, BC11, BC12, BC13, BC14, BC15.						

Appendix A
Summary of Water Traces to Selected Springs

MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Oz 025	North Fork Spring {NF2} (27.36 miles)	Summer Spring Branch (IP35)	Rhodamine WT™ (1 gallon)	11/2/1988 (13:30)	Carbon Packet Fluorescence Spectrometer	First: 11/10/1988 to 11/17/1988 Peak: 11/10/1988 to 11/17/1988 (403-758 ft/hr)
Also reported recovery at Rainbow (NF1) and Hodgson Mill (BC1) springs. Source: Brown, 1989. Monitoring points: BC1, NF1, NF2, BC11, BC12, BC13, BC14, BC15.						
Oz 026	Hodgson Mill Spring {BC1} (26.19 miles)	Summer Spring Branch (IP35)	Rhodamine WT™ (1 gallon)	11/2/1988 (13:30)	Carbon Packet Fluorescence Spectrometer	First: 11/10/1988 to 11/17/1988 Peak: 11/10/1988 to 11/17/1988 (386-726 ft/hr)
Also reported recovery at Rainbow (NF1) and North Fork (NF2) springs. Source: Brown, 1989. Monitoring points: BC1, NF1, NF2, BC11, BC12, BC13, BC14, BC15.						
Oz 027	Rainbow Spring {NF1} (38.74 miles)	Lick Fork of the Gasconade (IP36)	Fluorescein (10 pounds)	11/2/1988 (11:30)	Carbon Packet Fluorescence Spectrometer	First: 11/10/1988 to 11/17/1988 Peak: 11/10/1988 to 11/17/1988 (567-1063 ft/hr)
Also reported recovery at North Fork (NF2) and Hodgson Mill (BC1) springs. Source: Brown, 1989. Monitoring points: BC1, NF1, NF2, BC11, BC12, BC13, BC14, BC15, GR2, GR3, GR4, GR5.						
Oz 028	Hodgson Mill Spring {BC1} (37.20 miles)	Lick Fork of the Gasconade (IP36)	Fluorescein (10 pounds)	11/2/1988 (11:30)	Carbon Packet Fluorescence Spectrometer	First: 11/10/1988 to 11/17/1988 Peak: 11/10/1988 to 11/17/1988 (545-1020 ft/hr)
Also reported recovery at North Fork (NF2) and Rainbow (NF1) springs. Source: Brown, 1989. Monitoring points: BC1, NF1, NF2, BC11, BC12, BC13, BC14, BC15, GR2, GR3, GR4, GR5.						
Oz 029	North Fork Spring {NF2} (38.47 miles)	Lick Fork of the Gasconade (IP36)	Fluorescein (10 pounds)	11/2/1988 (11:30)	Carbon Packet Fluorescence Spectrometer	First: 11/10/1988 to 11/17/1988 Peak: 11/10/1988 to 11/17/1988 (563-1055 ft/hr)
Also reported recovery at Rainbow (NF1) and Hodgson Mill (BC1) springs. Source: Brown, 1989. Monitoring points: BC1, NF1, NF2, BC11, BC12, BC13, BC14, BC15, GR2, GR3, GR4, GR5.						
Oz 035	Rainbow Spring {NF1} (24.07 miles)	Upper Fox Creek (IP45)	Eosine (5 pounds)	8/19/2014 (18:33)	Carbon Packet Fluorescence Spectrometer	First: 8/27/2014 to 9/2/2014 Peak: 9/2/2014 to 9/9/2014 (First: 380-674 ft/hr) (Peak: 255-380 ft/hr)
Maximum PVR = 98.65 Also recovered at North Fork (NF2) and Hodgson Mill (BC1) springs and the North Fork at NF26. Source: this study. Monitoring points: BC1, NF1, NF5, NF6, NF9, NF10, NF15, NF21, NF26.						

Appendix A
Summary of Water Traces to Selected Springs

MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Oz 036	Hodgson Mill Spring {BC1} (23.30 miles)	Upper Fox Creek (IP45)	Eosine (5 pounds)	8/19/2014 (18:33)	Carbon Packet Fluorescence Spectrometer	First: 8/27/2014 to 9/2/2014 Peak: 9/2/2014 to 9/9/2014 (First: 368-651 ft/hr) (Peak: 246-368 ft/hr)
Maximum PVR = 88.29 Also recovered at North Fork (NF2) and Rainbow (NF1) springs and in the North Fork at NF26. Source: this study. Monitoring points: BC1, NF1, NF5, NF6, NF9, NF10, NF15, NF21, NF26.						
Oz 037	North Fork Spring {NF26} (23.72 miles)	Upper Fox Creek (IP45)	Eosine (5 pounds)	8/19/2014 (18:33)	Carbon Packet Fluorescence Spectrometer	First: 8/27/2014 to 9/2/2014 Peak: 9/2/2014 to 9/9/2014 (First: 375-664 ft/hr) (Peak: 251-375 ft/hr)
Maximum PVR = 27.69 Also recovered at Hodgson Mill (BC1) and Rainbow (NF1) springs as well as the North Fork at NF26. Source: this study. Monitoring points: BC1, NF1, NF5, NF6, NF9, NF10, NF15, NF21, NF26.						
Oz 038	Hodgson Mill Spring {BC1} (4.77 miles)	Upper Bollinger Branch (IP64)	Sulpho-Rhodamine B (2 pounds)	4/14/2015 (14:00)	Carbon Packet Fluorescence Spectrometer	First: 4/21/2015 to 4/27/2015 Peak: 4/27/2015 to 5/5/2015 (First: 80-148 ft/hr) (Peak: 50-80 ft/hr)
Maximum PVR = 9.49 Injection was downstream of discharge from Dora School lagoon. This was a semi-replication of Oz 001 above. Source: this study. Monitoring points: BC1, NF1, NF5, NF6, NF15, NF21, NF26.						
Rookery Tree Complex (Oregon County, Missouri) Traces						
Or 052	Rookery Tree Complex {EP61-63} (4.14 miles)	Middle Fork Channel upstream of Fanchon (IP71)	Rhodamine WT™ (2 gallons)	9/9/2015 (10:20)	Carbon Packet Fluorescence Spectrometer	First: 12/9/2015 to 12/16/2015 Peak: 12/9/2015 to 12/16/2015 (>9 ft/hr)
Maximum PVR = 3.42 Incomplete dye recovery curve with no background packets. Also recovered at Bill Mac Spring (EP6) and unreported spring (EP64) upstream of Bluff Spring. Source: this study. Monitoring points: EP1, EP6, EP12, EP60, EP61, EP62, EP63, EP64, EP67, EP70, EP71, SR1.						
Or 057	Rookery Tree Complex {EP61-63} (4.11 miles)	Middle Fork Channel upstream of Fanchon (IP73)	Eosine (10 pounds)	2/9/2016 (16:00)	Carbon Packet Fluorescence Spectrometer	First: 2/9/2016 to 2/17/2016 Peak: 2/17/2016 to 2/29/2016 (First: >118 ft/hr) (Peak: 46-118 ft/hr)
Maximum PVR = 361.05 Also recovered at Bill Mac Spring (EP6), Greer Spring (EP01), Mammoth Spring (SR01) and two previously unreported springs (EP64 and EP71) upstream of the Rookery Tree Complex. Source: this study. Monitoring points: EP1, EP6, EP12, EP60, EP61, EP62, EP63, EP64, EP67, EP70, EP71, SR1.						

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Summary of Water Traces to Selected Springs

MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Three Mile Spring (Oregon County, Missouri) Trace						
Or 008	Three Mile Spring {EP57} (1.56 miles)	Sheep Ranch Hollow (IP56)	Fluorescein (5 pounds)	5/26/1971 (14:00)	Carbon Packet Visual	First: 6/1/1971 to 6/9/1971 Peak: 6/1/1971 to 6/16/1971 (First: 25-58 ft/hr) (Peak: 16-58 ft/hr)
"Very strongly positive." This spring may be referred to as Wolfpen Hollow Spring # 2 in trace Or 061. Source: Aley, 1975, p. A-23. Monitoring points: EP57.						
Topaz Springs (Douglas County, Missouri) Traces						
Do 005	Topaz Spring upstream of Mill {NF9} (4.35 miles)	Clifty Creek (IP28)	Fluorescein (6 Pounds)	5/6/1981	Carbon Packet Visual	First: 5/19/1981 to 6/23/1981 (20-74 ft/hr)
Dye reported at both Topaz springs. Source: Tryon, 1981A, p. 1. Monitoring points: NF9, NF10, NF21.						
Do 006	Topaz Spring at Mill {NF9, 10} (4.35 miles)	Clifty Creek (IP28)	Fluorescein (6 Pounds)	5/6/1981	Carbon Packet Visual	First: 5/19/1981 to 6/23/1981 (20-74 ft/hr)
Dye reported at both Topaz springs. Source: Tryon, 1981A, p. 1. Monitoring points: NF9, NF10, NF21.						
Turnbull Cave Spring (Douglas County, Missouri) Trace						
Do 004	Turnbull Cave Spring {NF23} (1.11 Miles)	Roaring Spring Branch (IP60)	Fluorescein (10 Pounds)	7/6/1978 (09:00)	Carbon Packet Visual	First: 7/7/1978 to 7/8/1978 (115-217 ft/hr)
Source: Vandike, 1979. Monitoring points: NF23.						
Turner Mill Spring (Oregon County, Missouri) Trace						
Or 015	Turner Mill Spring {EP10} (2.79 miles)	Rough Hollow (IP57)	Fluorescein (3 Pounds)	3/7/1973 (15:15)	Carbon Packet Visual	First: 3/7/1973 to 3/9/1973 Peak: 3/9/1973 to 3/13/1973 (First: >329 ft/hr) (Peak: 105-329 ft/hr)
"Moderately positive" recovery. Source: Fletcher,1973, p. 1. Monitoring points: EP10, CR1.						

Appendix A
Summary of Water Traces to Selected Springs

MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Or 067	Turner Mill Spring {EP10} (1.65 miles)	Katie Sisco Hollow (IP75)	Rhodamine WT™ (2 pounds)	1/3/1992 (11:30)	Carbon Packet Fluorescence Spectrometer	First: 1/3/1992 to 1/10/1992 Peak: 1/3/1992 to 1/10/1992 (>52 ft/hr)
Maximum PVR =101.00 Source: Aley, 1992. Monitoring points: EP11B, EP67, EP68, EP10, EP29, EP72, EP73, EP74, EP75, EP76.						
Unreported Spring in Eleven Point Between Long Hollow and Greer Spring Branch Trace						
Or 065	Unreported Spring {EP85} (1.96 miles)	Long Hollow (IP79)	Fluorescein (1 pound)	2/25/1992 (13:55)	Carbon Packet Fluorescence Spectrometer	First: 3/3/1992 to 4/1/1992 (12-62 ft/hr)
Maximum PVR = 27.63 Location of spring is undetermined. No background analysis reported. Source: Aley, 1992. Monitoring points: EP67, EP77, EP83, EP84 EP85.						
Unreported Spring in Eleven Point Upstream of Injection Hollow Trace						
Or 064	Unreported Spring {EP79} (0.25 mile)	Downstream of Injection Hollow Spring (IP77)	Fluorescein (1 pound)	1/3/1992 (16:30)	Carbon Packet Fluorescence Spectrometer	First: 1/3/1992 to 1/17/1992 Peak: 1/3/1992 to 1/17/1992 (>4 ft/hr)
Maximum PVR = 89.00 Location of spring is undetermined. No background analysis reported. Source: Aley, 1992. Monitoring points: EP67, EP29, EP74, EP75, EP77, EP78, EP103, EP79, EP81, EP82, EP85, EP79.						
Unreported Spring in Lower Little Hurricane Creek Trace						
Or 058	Unreported Spring {EP69} (3.75 miles)	Upper Little Hurricane Creek (IP72)	Rhodamine WT™ (2 gallons)	1/12/2016 (13:40)	Carbon Packet Fluorescence Spectrometer	First: 1/12/2016 to 2/9/2016 (>42 ft/hr)
Maximum PVR = 3.59 Also recovered at Dennig Complex (EP11A and EP11B). Incomplete dye recovery curve. Actual resurgence point unidentified but is upstream of the recovery point. Background packets and first recoveries were in the 11 Point River downstream. Source: this study. Monitoring points: EP67, EP6, EP65, EP66, EP69, EP11A EP11B, SR1.						
Unreported Spring in Middle Fork Upstream of Bluff Spring Trace						
Or 056	Unreported Spring {EP71} (3.92 miles)	Middle Fork Channel upstream of Fanchon (IP73)	Eosine (10 pounds)	2/9/2016 (16:00)	Carbon Packet Fluorescence Spectrometer	First: 2/9/2016 to 2/17/2016 Peak: 2/17/2016 to 2/29/2016 (First: >112 ft/hr) (Peak: 44-112 ft/hr)
Maximum PVR = 32.01 Actual resurgence point unidentified but is upstream of the recovery point. Also recovered at Bill Mac Spring (EP6), Greer Spring (EP01), Mammoth Spring (SR01) and another unreported spring upstream. Source: this study. Monitoring points: EP1, EP6, EP12, EP60, EP61, EP62, EP63, EP67, EP70, EP71, SR1.						

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MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Unreported Spring in Middle Fork Upstream of Howell County Road 3850 Trace						
HI 001	Unreported Spring {EP70} (2.55 miles)	Middle Fork Channel upstream of Fanchon (IP73)	Eosine (10 pounds)	2/9/2016 (16:00)	Carbon Packet Fluorescence Spectrometer	First: 2/29/2016 to 3/14/2016 Peak: 3/14/2016 to 3/29/2016 (First: 17-28 ft/hr) (Peak: 12-17 ft/hr)
Maximum PVR = 4.91 Actual resurgence point unidentified but is upstream of the recovery point. Also recovered at Bill Mac Spring (EP6), Greer Spring (EP01), Mammoth Spring (SR01) and another unreported spring downstream. Source: this study. Monitoring points: EP1, EP6, EP12, EP60, EP61, EP62, EP63, EP64, EP67, EP70, EP71, SR1.						
Warm Fork Spring (Oregon County, Missouri) Trace						
Or 044	Warm Fork Spring {SR9} (2.08 miles)	Warm Fork at Oregon County Road 333 (IP47)	Fluorescein (1 Pound)	1/21/2015 (07:50)	Carbon Packet Fluorescence Spectrometer	First: 1/21/2015 to 1/27/2015 Peak: 1/21/2015 to 1/27/2015 (>72 ft/hr)
Maximum PVR = 48.54 Warm Fork was dry between injection and recovery throughout trace. Source: this study. Monitoring points: SR9, SR1, EP2, EP3, EP5.						
Wilder Spring (Ozark County, Missouri) Trace						
Oz 030	Wilder Spring {NF4} (5.08 miles)	Collins Dairy (IP37)	Fluorescein, (3 gallons)	10/23/2007 (12:12)	Carbon Packet Fluorescence Spectrometer	First: 11/12/2007 to 11/19/2007 Peak: 11/26/2007 to 12/4/2007 (First: 41-56 ft/hr) (Peak: 27-33 ft/hr)
Maximum PVR =49.59 Dye also recovered at Althea Spring (NF3). Source: Crews, 2008. Monitoring points: NF4, NF3, NF11, NF13, NF14, NF16, NF17, NF18, BB1, BB2.						
Oz 031	Wilder Spring {NF4} (5.08 miles)	Collins Dairy (IP37)	Rhodamine WT ™ (3 gallons)	10/23/2007 (12:12)	Carbon Packet Fluorescence Spectrometer	First: 11/12/2007 to 11/19/2007 Peak: 11/26/2007 to 12/4/2007 (First: 41-56 ft/hr) (Peak: 27-33 ft/hr)
Maximum PVR = 9.69 Dye also recovered at Althea Spring (NF3) Source: Crews, 2008. Monitoring points: NF4, NF3, NF11, NF13, NF14, NF16, NF17, NF18, BB1, BB2.						
Oz 039	Wilder Spring {NF4} (8.14 miles)	Spring Creek Near Pottersville (IP68)	Eosine (5 pounds)	9/1/2015 (10:55)	Carbon Packet Fluorescence Spectrometer	First: 9/15/2015 to 9/22/2015 Peak: 9/22/2015 to 9/29/2007 (First: 84-126 ft/hr) (Peak: 63-84 ft/hr)
Maximum PVR = 162.46 Dye recovery curve data from NF13 but maximum recovery was at Wilder Spring (NF4) which is presumed to be the main resurgence point. Source: this study. Monitoring Points: NF1, NF26, NF3, NF4, NF13, NF15 BC1.						

Appendix A
Summary of Water Traces to Selected Springs

MGS ID #	Recovery Point {ID#} (length)	Injection Point (ID #)	Tracer (Amount)	Injection Date (time)	Recovery Method Analysis Method	Recovery Dates (Velocity Range)
Wolfpen Hollow Spring #1 (Oregon County, Missouri) Trace						
Or 062	Wolfpen Hollow Spring #1 {EP99} (2.81 miles)	McCormack Hollow near Pig Spring (IP53)	Fluorescein (1.5 pounds)	6/28/1995 (15:30)	Carbon Packet Fluorescence Spectrometer	First: 7/6/1995 to 7/12/1995 Peak: 7/12/1995 t0 7/24/1995 (First: 45-79 ft/hr) (Peak: 24-45 ft/hr)
Maximum PVR > 80 Dye also recovered in smaller amounts at Wolfpen Hollow Spring #2 (EP100) and Big Spring (Carter County - CR1) though the author lists the Big Spring connection as a "possible recovery." Source: Imes, 1996, p. 1. Monitoring points: CR1, EP1, EP8, EP10, EP11, EP29, EP33, EP99, EP100, EP101, EP102.						
Wolfpen Hollow Spring #2 (Oregon County, Missouri) Trace						
Or 061	Wolfpen Hollow Spring #2 {EP100} (3.46 miles)	McCormack Hollow near Pig Spring (IP53)	Fluorescein, (1.5 pounds)	6/28/1995 (15:30)	Carbon Packet Fluorescence Spectrometer	First: 7/12/1995 to 7/24/1995 Peak: 7/12/1995 to 7/24/1995 (29-55 ft/hr)
Maximum PVR = 1.87 Dye recovered with slightly higher PVR at Big Spring (Carter County - CR1) though the author lists the Big Spring connection as a "possible recovery." Much larger amounts were recovered at Wolfpen Hollow Spring #1. Source: Imes, 1996, p. 1. Monitoring points: CR1, EP1, EP8, EP10, EP11, EP29, EP33, EP99, EP100, EP101, EP102.						

Appendix B

Explanation

Appendix B provides location data for monitoring points, referenced by watershed abbreviation and a sequential number. All location data (including altitudes) are approximate. Location data for older traces have limited precision due to the lack of large scale topographic maps at the time of the work. Global positioning system (GPS) information has been used to locate approximate latitude and longitude (degrees, minutes and seconds) of all injection and monitoring points. This information is generally of higher precision for points located during this study due to the ready availability of GPS measurement devices. Figure 108 is a generalized location map for all monitoring points. Figure 109 is focused on monitoring points in northern Oregon and eastern Howell counties. Legal locations are included when possible for all traces.

Figure 107 shows the standard method for locating legacy monitoring points. This system uses six by six mile numbered townships and ranges as the basis for describing land location. Townships are numbered from south to north beginning at a point in Arkansas. Ranges are numbered from the Fifth Principal Meridian which passes through the state of Missouri from north to south. Ranges are numbered to the east and west from this meridian. Nearly the entire study area is located in areas west of the Fifth Principal Meridian. These six mile by six mile areas are further divided into sections, which are normally about a mile on each side. Exceptions exist where townships and ranges are more or less than six miles on a side, and sections are more or less than one mile on a side. Sections within a given township and range are numbered from 1 to 36 as shown below. Sections are further divided into ¼ sections, ¼, ¼ sections and ¼, ¼, ¼ sections. These are distinguished by the letters A, B, C, and D which represent the northeast, northwest, southwest, and southeast quarters respectively as shown below. In appendix B legal locations are expressed from most specific to least specific. In other words, they are expressed in the following order: ¼, ¼, ¼ section (as A-D), ¼, ¼ section (also as A-D), ¼ section (A-D as well) followed by the section number (1-36), township number (N for north) and range number (E for east and W for West). Thus a site in the northwest ¼ of the southeast ¼ of the northeast ¼ of section 13, township (T) 23 north, range (R) 4 west is expressed as “BDA sec 13, 23N 4W” for brevity (see illustration below).

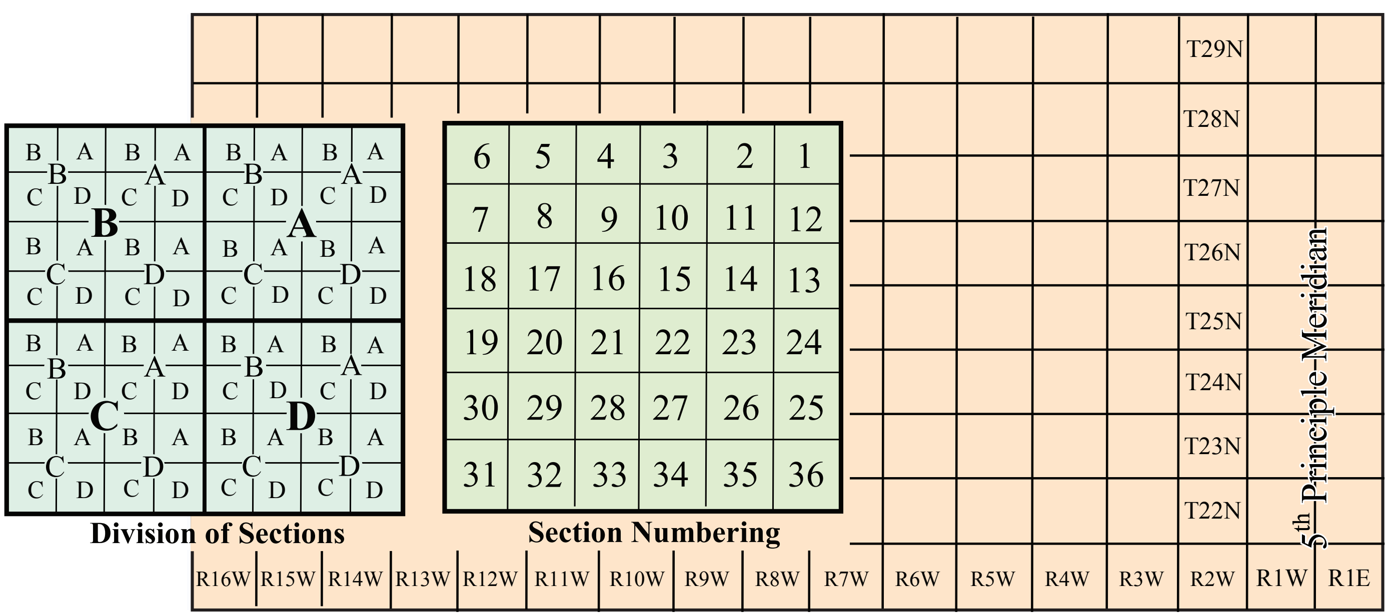

Figure 107. Legal location of points in Appendices B and C.

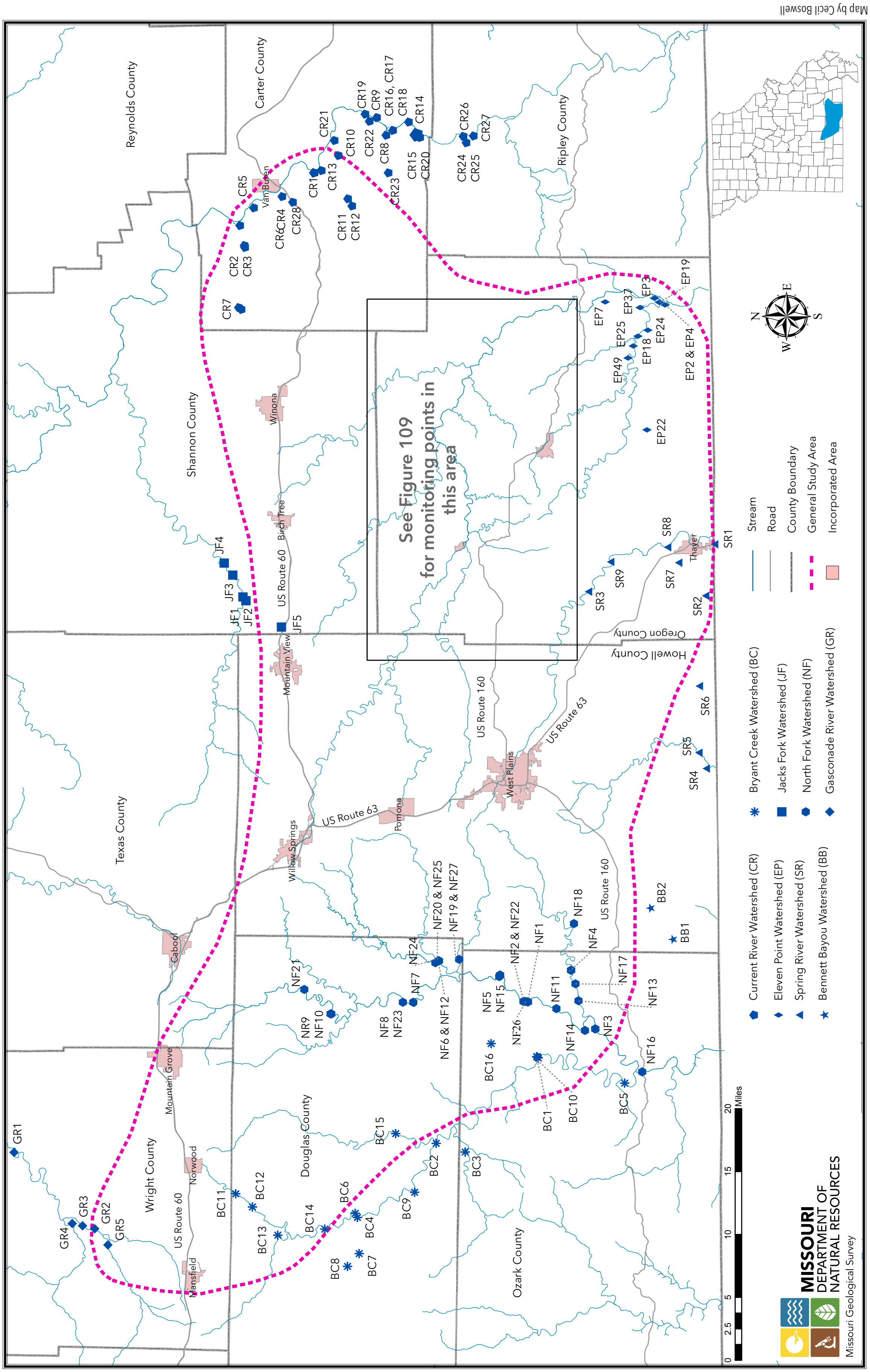

Figure 108. Monitoring points in the Big Four Region.

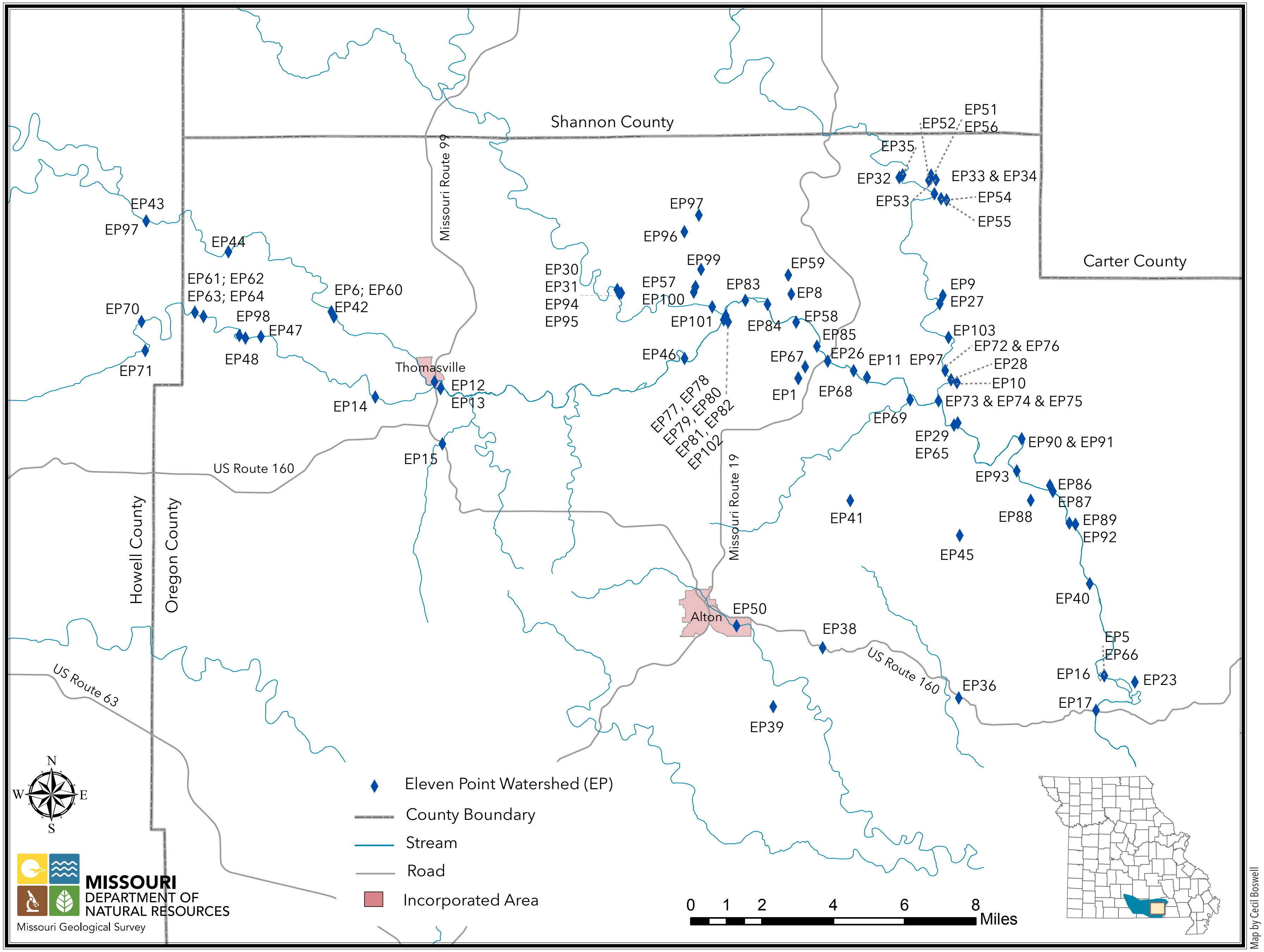

Figure 109. Monitoring points in northern Oregon and eastern Howell counties.

Appendix B

Selected Monitoring Points used for Traces in Appendix A

Locations are Approximate

ID Number	Point Name	Remarks	County	Legal Description	Latitude Longitude	Altitude in Feet
Gasconade River Watershed						
GR1	Gasconade River	At Missouri Route E.	Wright, Missouri	DAA Sec 18 30N-13W	37° 18' 48" 92° 23' 55"	1065'
GR2	Lick Fork	At Walls Ford Road.	Wright, Missouri	CAB Sec 7 29N-14W	37° 13' 15" 92° 30' 35"	1150'
GR3	Lick Fork	At Sellers Ford Road South half of 2 mile long section.	Wright, Missouri	Sec 6 29N-14W	37° 14' 05" 92° 30' 19"	1135'
GR4	Woods Fork	Just below Casador Lake North half of 2 mile long section.	Wright, Missouri	Sec 6 29N-14W	37° 14' 48" 92° 30' 14"	1145'
GR5	Lick Fork	At Missouri Route 5.	Wright, Missouri	DCB Sec 13 29N-15W	37° 12' 15" 92° 31' 58"	1170'
Bryant Creek Watershed						
BC1	Hodgson Mill Spring	Private property.	Ozark, Missouri	BCD Sec 34 24N-12W	36° 42' 34" 92° 15' 59"	655'
BC2	Bryant Creek	Douglas County Road N-345 downstream from Columbus Spring.	Douglas, Missouri	DBA Sec 29 25N-13W	36° 49' 36" 92° 23' 25"	730'
BC3	Rock Bridge Spring	Spring Creek at Missouri Route N.	Ozark, Missouri	CCB Sec 4 24N-13W	36° 47' 33" 92° 24' 07"	740'
BC4	Bryant Creek	Above losing reach on Bryant Creek at Douglas County Road C-230.	Douglas, Missouri	CCC Sec 21 26N-14W	36° 55' 10" 92° 29' 21"	820'
BC5	Bryant Creek	Upstream from Tecumseh at Ozark County Road 308.	Ozark, Missouri	BCD Sec 5 22N-12W	36° 36' 31" 92° 18' 17"	575'
BC6	Hunter Creek	Above losing reach on Bryant Creek.	Douglas, Missouri	DCD Sec 20 26N-14W	36° 55' 04" 92° 29' 43"	820'
BC7	White Creek at County Road 14-210	Downstream from Hoffmeister Spring.	Douglas, Missouri	CAA Sec 26 26N-15W	36° 54' 57" 92° 32' 49"	880'
BC8	Crystal Spring		Douglas, Missouri	BDA Sec 22 26N-15W	36° 55' 46" 92° 33' 55"	890'
BC9	Bryant Creek	At Douglas County Road 14-335.	Douglas, Missouri	BAD Sec 15 25N-14W	36° 51' 06" 92° 27' 33"	770'
BC10	Bryant Creek	At Missouri Route 181 just upstream of Hodgson Mill Spring.	Ozark, Missouri	CCD Sec 34 24N-12W	36° 42' 29" 92° 16' 04"	640'
BC11	Summers Barn Spring	Private property near Douglas County Road 117	Douglas, Missouri	ADB Sec 3 27N-14W	37° 03' 29" 92° 27' 36"	1105'
BC12	Dry Creek below unnamed spring	Private property near Douglas County Road 117.	Douglas, Missouri	DAC Sec 9 27N-14W	37° 02' 20" 92° 28' 46"	1040'
BC13	Bryant Creek at Missouri Route U		Douglas, Missouri	DBC Sec 19 27N-14W	37° 00' 35" 92° 31' 12"	950'
BC14	Bryant Creek at Missouri Route 76		Douglas, Missouri	DCA Sec 7 26N-14W	36° 57' 20" 92° 30' 42"	860'
BC15	Fox Creek at Missouri Route 14		Douglas, Missouri	DDC Sec 4 25N-13W	36° 52' 23" 92° 22' 29"	775'

Appendix B
Selected Monitoring Points used for Traces in Appendix A
Locations are Approximate

ID Number	Point Name	Remarks	County	Legal Description	Latitude Longitude	Altitude in Feet
BC16	Bollinger Spring Branch	At County Road 192.	Ozark, Missouri	CBA Sec 14 24N, 12W	36° 45' 44" 92° 14' 50"	840'
North Fork Watershed						
NF1	Rainbow Spring	AKA Double Spring. Private property.	Ozark, Missouri	AAA Sec 32 24N-11W	36° 43' 11" 92° 11' 14"	655'
NF2	North Fork Spring	AKA Gravel Spring.	Ozark, Missouri	CBC Sec 28 24N-11W	36° 43' 28" 92° 11' 14"	655'
NF3	Althea Spring	AKA Patrick Spring. Owned by MDC.	Ozark, Missouri	DDA Sec 25 23N-12W	36° 38' 32" 92° 13' 38"	610'
NF4	Wilder Spring	AKA Breakup Mill. Private property.	Ozark, Missouri	DDB Sec 14 23N-11W	36° 40' 09" 92° 08' 35"	700'
NF5	Blue Spring	Owned by USFS.	Ozark, Missouri	BCC Sec 14 24N-11W	36° 45' 04" 92° 08' 56"	680'
NF6	Big Spring	Owned by USFS.	Douglas, Missouri	DBB Sec 26 25N-11W	36° 49' 17" 92° 07' 40"	740'
NF7	North Fork	Upstream from Twin Bridges at Douglas County Road AA-279.	Douglas, Missouri	DAA Sec 18 25N-11W	36° 51' 06" 92° 11' 12"	750'
NF8	Turnbull Cave Spring	Private property.	Douglas, Missouri	BDA Sec 7 25N-11W	36° 51' 49" 92° 11' 12"	780'
NF9	Topaz Mill Spring upstream of mill	AKA Topaz Mill Spring #1. Private property.	Douglas, Missouri	CAD Sec 12 26N-12W	36° 56' 47" 92° 12' 09"	860'
NF10	Topaz Mill Spring	AKA Topaz Mill Spring #2. Private property.	Douglas, Missouri	CAD Sec 12 26N-12W	36° 56' 50" 92° 12' 08"	850'
NF11	North Fork at River of Life	Private property.	Douglas, Missouri	ADB Sec 8 23N-11W	36° 41' 12" 92° 11' 52"	630'
NF12	Spring Creek upstream from Big Spring	Owned by USFS.	Douglas, Missouri	BBD Sec 26 25N-11W	36° 49' 19" 92° 07' 41"	735'
NF13	Duncan Ford on Spring Creek	At Ozark County Road H-349.	Ozark, Missouri	BBB Sec 21 23N-11W	36° 39' 40" 92° 11' 12"	640'
NF14	North Fork River at Blair Bridge	Owned by USFS.	Ozark, Missouri	DCA Sec 24 23N-12W	36° 39' 14" 92° 13' 45"	620'
NF15	North Fork River upstream from Blue Spring	Owned by USFS.	Ozark, Missouri	ADD Sec 15 24N-11W	36° 45' 09" 92° 09' 04"	680'
NF16	North Fork at Tecumseh	At US Route 160.	Ozark, Missouri	CBA Sec 16 22N-12W	36° 35' 18" 92° 17' 20"	560'
NF17	Fogey Spring Branch	Owned by USFS.	Ozark, Missouri	ADC Sec 15 23N-11W	36° 39' 52" 92° 09' 44"	680'
NF18	Cureall Spring	Private property.	Howell, Missouri	DBC Sec 16 23N-10W	36° 39' 56" 92° 04' 34"	860'
NF19	Tabor Creek	Near Ozark County Road 14-361.	Ozark, Missouri	CAC Sec 35 25N-11W	36° 47' 54" 92° 07' 33"	740'
NF20	Dry Creek	At Ozark County Road 14-292.	Ozark, Missouri	DDC Sec 23 25N-11W	36° 49' 25" 92° 07' 36"	740'

Appendix B
Selected Monitoring Points used for Traces in Appendix A
Locations are Approximate

ID Number	Point Name	Remarks	County	Legal Description	Latitude Longitude	Altitude in Feet
NF21	North Fork Upstream from Topaz Springs	At Douglas County Road E-276. Private property.	Douglas, Missouri	BAD Sec 32 27N-11W	36˚ 58' 38" 92˚ 10' 00"	910'
NF22	North Fork upstream from North Fork Spring	Private property.	Ozark, Missouri	DAD Sec 29 24N-11W	36˚ 43' 30" 92˚ 11' 15"	655'
NF23	Turnbull Cave Spring	Private property.	Douglas, Missouri	BDA Sec 7 25N-11W	36˚ 57' 49" 92˚ 11' 12"	780'
NF24	Spring Creek upstream from Dry Creek	At Douglas County Road 14-292.	Douglas, Missouri	BCC Sec 23 25N-11W	36˚ 49' 33" 92˚ 07' 49"	740'
NF25	Dry Creek upstream from Big Spring West	At Douglas County Road 181-292.	Douglas, Missouri	ABB Sec 26 25N-11W	36˚ 49' 24" 92˚ 07' 37"	740'
NF26	North Fork River upstream of Rainbow Spring and downstream of North Fork Spring	Private property.	Ozark, Missouri	BCC Sec 28 24N-11W	36˚ 43' 19" 92˚ 11' 13"	655'
NF27	Hay Hollow Creek Springs	Douglas County Road 14-361 crossing immediately downstream of springs.	Douglas, Missouri	CAC Sec 35 25N-11W	36˚ 47' 54" 92˚ 07' 33"	740'
Eleven Point Watershed						
EP1	Greer Spring Upper-EP1A Lower-EP1B	Owned by USFS.	Oregon, Missouri	EP1A ACC Sec 36 25N-4W EP1B BDC Sec 36 25N-4W	EP1A 36˚ 47' 12" 91˚ 20' 55" EP1B 36˚ 47' 12" 91˚ 20' 52"	EP1A 585 EP1B 575'
EP2	Blue Spring	Owned by USFS.	Oregon, Missouri	CBD Sec 16 22N-2W	36˚ 33' 24" 91˚ 11' 20"	375'
EP3	Morgan Spring	AKA Thomasson Mill Spring. Owned by USFS.	Oregon, Missouri	BDA Sec 16 22N-2W	36˚ 33' 44" 91˚ 10' 58"	380'
EP4	Sullivan Spring	Owned by USFS.	Oregon, Missouri	DBD Sec 16 22N-2W	36˚ 33' 23" 91˚ 11' 20"	380'
EP5	Boze Mill Spring	Owned by USFS.	Oregon, Missouri	CBC Sec 9 23N-2W	36˚ 39' 46" 91˚ 11' 42"	435'
EP6	Bill Mac Spring	Private property.	Oregon, Missouri	ABB Sec 26 25N-6W	36˚ 48' 52" 91˚ 34' 57"	660'
EP7	Sibkey Spring	Private property.	Oregon, Missouri	CBD Sec 28 23N-2W	36˚ 37' 09" 91˚ 11' 14"	430'
EP8	McCormack Lake Spring	Owned by USFS. Location imprecise.	Oregon, Missouri	BBC Sec24 25N-4W	36˚ 49' 15" 91˚ 21' 03"	560'
EP9	Johnson Spring	Owned by USFS. Location imprecise.	Oregon, Missouri	CDB Sec 22 25N-3W	36˚ 49' 09" 91˚ 16' 27"	560'
EP10	Turner Mill Spring	Owned by USFS.	Oregon, Missouri	DDD Sec 3 24N-3W	36˚ 47' 01" 91˚ 16' 04"	520'

Appendix B
Selected Monitoring Points used for Traces in Appendix A
Locations are Approximate

ID Number	Point Name	Remarks	County	Legal Description	Latitude Longitude	Altitude in Feet
EP11	Dennig Spring Upper EP11A Lower EP11B	AKA Huff Springs or Graveyard Springs. Multiple outlets owned by USFS.	Oregon, Missouri	EP11A DCC Sec 32 25N-3W EP11B ACC Sec 32 25N-3W	EP11A 36° 47' 11" 91° 18' 48" EP11B 36° 47' 07" 91° 18' 44"	510'
EP12	Eleven Point River at Thomasville	Owned by USFS.	Oregon, Missouri	CCC Sec 32 25N-5W	36° 47' 15" 91° 31' 56"	630'
EP13	Middle Fork Eleven Point River at Thomasville	Owned by USFS.	Oregon, Missouri	AAA Sec 5 24N-5W	36° 47' 03" 91° 31' 47"	620'
EP14	Middle Fork Eleven Point River upstream of Thomasville	Owned by USFS.	Oregon, Missouri	DBB Sec 6 24N-5W	36° 46' 54" 91° 33' 44"	650'
EP15	Barren Fork at U.S. Route 160	Private property.	Oregon, Missouri	BAA Sec 8 24N-5W	36° 45' 43" 91° 31' 42"	655'
EP16	Eleven Point River upstream of Boze Mill	Owned by USFS.	Oregon, Missouri	CBC Sec 9 23N-2W	36° 39' 46" 91° 11' 53"	430'
EP17	Eleven Point River at Riverton	Owned by USFS.	Oregon, Missouri	CAD Sec 17 23N-2W	36° 38' 55" 91° 12' 02"	415'
EP18	Frederick Creek at Missouri Route Y	Private property.	Oregon, Missouri	BAA Sec 12 22N-3W	36° 34' 56" 91° 14' 13"	425'
EP19	Eleven Point River at Missouri Route 142	Owned by USFS.	Oregon, Missouri	CAB Sec 21 22N-2W	36° 33' 01" 91° 11' 35"	380'
EP20	Eleven Point River in Arkansas	Owned by USFS.	Randolph, Arkansas	BBC Sec 22 21N-2W	36° 27' 15" 91° 10' 51"	340'
EP21	Eleven Point River at Arkansas Route 93	Owned by USFS.	Randolph, Arkansas	AAB Sec 1 20N-2W	36° 25' 07" 91° 08' 19"	320'
EP22	Gum Spring at Oregon County Road 228	Private property.	Oregon, Missouri	DAC Sec 11 22N-4W	36° 34' 25" 91° 22' 17"	635'
EP23	Mitchell Spring	Owned by USFS.	Oregon, Missouri	DDD Sec 9 23N-2W	36° 39' 37" 91° 10' 50"	440'
EP24	Sand Spring	Private property.	Oregon, Missouri	BDC Sec 7 22N-2W	36° 34' 14" 91° 13' 45"	430'
EP25	Frederick Creek at Jobe at Oregon County Road 225	Private property.	Oregon, Missouri	BCC Sec 1 22N-3W	36° 35' 16" 91° 15' 04"	450'
EP26	Eleven Point River at Greer Crossing on Missouri Route 19	Owned by the USFS.	Oregon, Missouri	BCB Sec 31 25N-3W	36° 47' 35" 91° 19' 59"	520
EP27	Hurricane Creek above Johnson Spring	Owned by USFS. Imprecise location.	Oregon, Missouri	CAC Sec 22 25N-3W	36° 48' 57" 91° 16' 32"	560'
EP28	Hurricane Creek at the Weir	Owned by USFS.	Oregon, Missouri	BCD Sec 34 25N-3W	36° 47' 04" 91° 16' 15"	510'
EP29	11 Point River Upstream of Turner Mill	Owned by USFS.	Oregon, Missouri	BDD Sec 3 24N-3W	36° 45' 58" 91° 16' 11"	490'
EP30	Spring Creek above Cooper Spring		Oregon, Missouri	ACB Sec19 25N-4W	36° 49' 26" 91° 26' 20"	610'

Appendix B
Selected Monitoring Points used for Traces in Appendix A
Locations are Approximate

ID Number	Point Name	Remarks	County	Legal Description	Latitude Longitude	Altitude in Feet
EP31	Spring Creek below Cooper Spring		Oregon, Missouri	DCB Sec 19 25N-4W	36˚ 49’ 18” 91˚ 26’ 16”	600’
EP32	Falling Spring	USFS property.	Oregon, Missouri	DBB Sec 4 25N-3W	36˚ 52’ 03” 91˚ 17’ 42”	650’
EP33	Barrett Spring	AKA Blowing Spring in earlier study.	Oregon, Missouri	DBC Sec 3 25N-3W	36˚ 51’ 38” 91˚ 16’ 39”	640’
EP34	Mack Estavella	Intermittent spring with imprecise location.	Oregon, Missouri	Sec 32 25N-3W	?	?
EP35	Hurricane Creek upstream from Falling Spring		Oregon, Missouri	DBB Sec 4 25N-3W	36˚ 52’ 07” 91˚ 17’ 36”	650’
EP36	Many Springs	Private property.	Oregon, Missouri	BCB Sec 14 23N-3W	36˚ 39’ 17” 91˚ 16’ 11”	640’
EP37	Frederick Creek	At Oregon County Road 243.	Oregon, Missouri	CBB Sec 9 22N-2W	36˚ 34’ 45” 91˚ 11’ 47”	420’
EP38	Williams Spring		Oregon, Missouri	CDC Sec 6 23N-3W	36˚ 40’ 34” 91˚ 20’ 17”	720’
EP39	Cave Spring	Private property.	Oregon, Missouri	AAD Sec 14 23N-4W	36˚ 39’ 09” 91˚ 21’ 49”	680’
EP40	Powder Mill Spring		Oregon, Missouri	BBA Sec 32 24N-2W	36˚ 42’ 01” 91˚ 12’ 09”	450’
EP41	Cisco Spring		Oregon, Missouri	ADD Sec 18 24N-3W	36˚ 44’ 09” 91˚ 19’ 22”	840’
EP42	Eleven Point River above Bill Mac Spring	Private property.	Oregon, Missouri	CCD Sec 23 25N-6W	36˚ 49’ 00” 91˚ 35’ 02”	660’
EP43	Eleven Point River at Missouri Route W		Howell, Missouri	ADA Sec 11 25N-7W	36˚ 51’ 17” 91˚ 40’ 37”	746’
EP44	Eleven Point River downstream of Missouri Route W	Private property.	Oregon, Missouri	CAB Sec 17 25N-6W	36˚ 50’ 30” 91˚ 38’ 08”	710’
EP45	Panther Spring		Oregon, Missouri	CBC Sec 23 24N-3W	36˚ 43’ 15” 91˚ 16’ 04”	680’
EP46	Eleven Point River at Cane Bluff	Owned by USFS.	Oregon, Missouri	CBB Sec 33 25N-4W	36˚ 47’ 43” 91˚ 24’ 19”	560’
EP47	Middle Fork Eleven Point River at Nobbe Spring	Private property.	Oregon, Missouri	DBC Sec 28 25N-6W	36˚ 48’ 25” 91˚ 37’ 11”	730’
EP48	Middle Fork Eleven Point River downstream of Blue Hole Spring	Private property.	Oregon, Missouri	CAD Sec 29 25N-6W	36˚ 48’ 23” 91˚ 37’ 39”	735’
EP49	Frederick Creek at Frey Ford	At Oregon County Road 223 crossing.	Oregon, Missouri	DCB Sec 2 22N-3W	36˚ 35’ 39” 91˚ 16’ 03”	460’
EP50	Piney Creek	Near city of Alton wastewater treatment facility.	Oregon, Missouri	DAA Sec 3 23N-4W	36˚ 41’ 10” 91˚ 22’ 53”	720’
EP51	Ditch Spring	AKA Intermittent Spring.	Oregon, Missouri	CBB Sec 3 25N-3W	36˚ 52’ 05” 91˚ 16’ 45”	660’

Appendix B
Selected Monitoring Points used for Traces in Appendix A
Locations are Approximate

ID Number	Point Name	Remarks	County	Legal Description	Latitude Longitude	Altitude in Feet
EP52	Cave Spring	Near New Liberty School.	Oregon, Missouri	ADA Sec 4 25N-3W	36° 51’ 58” 91° 16’ 48”	650’
EP53	Hollow Creek	Near New Liberty.	Oregon, Missouri	CAB Sec 3 25N-3W	36° 51’ 59” 91° 16’ 36”	880’
EP54	Carter Shop Hollow	Near New Liberty.	Oregon, Missouri	ADC Sec 3 25N-3W	36° 51’ 29” 91° 16’ 17”	680’
EP55	Carter Shop Hollow Spring	Near New Liberty.	Oregon, Missouri	BDC Sec 3 25N-3W	36° 51’ 31” 91° 16’ 27”	700’
EP56	Dripping Spring	Near New Liberty.	Oregon, Missouri	CBB Sec 3 25N-3W	36° 52’ 05” 91° 16’ 43”	700’
EP57	Three Mile Spring	Location approximate. May be the same location as Wolfpen Hollow Spring #2.	Oregon, Missouri	CDB Sec 21 25N-4W	36° 49’ 20” 91° 24’08”	575
EP58	Gravel Spring		Oregon, Missouri	ACB Sec 25 25N-4W	36° 48’ 33” 91° 20’ 55”	540’
EP59	McCormack Spring		Oregon, Missouri	CCC Sec 13 25N-4W	36° 49’ 43” 91° 21’ 8”	620’
EP60	Eleven Point River below Bill Mac Spring	Private property.	Oregon, Missouri	BAB Sec 26 25N-6W	36° 48’ 54” 91° 34’ 56”	650’
EP61	Rookery Tree Spring	Private property.	Oregon, Missouri	BBA Sec 30 25N-6W	36° 48’ 56” 91° 38’ 54”	770’
EP62	Bluff Spring	Private property.	Oregon, Missouri	CDC Sec 19 25N-6W	36° 49’ 02” 91° 39’ 10”	770’
EP63	Steepshead Spring	Private property.	Oregon, Missouri	AAB Sec 30 25N-6W	36° 48’ 57” 91° 39’ 07”	770’
EP64	Middle Fork Eleven Point River above Bluff Spring	Private property.	Oregon, Missouri	CDC Sec 19 25N-6W	36° 49’ 02” 91° 39’ 12”	775’
EP65	Eleven Point River at Turner Access South	Owned by MDC.	Oregon, Missouri	CDD Sec 3 24N-3W	36° 45’ 58” 91° 16’ 11”	490’
EP66	Eleven Point River at Boze Mill Access	Owned by MDC.	Oregon, Missouri	BCC Sec 9 23N-2W	36° 39’ 46” 91° 11’ 46”	435’
EP67	Greer Spring at Cabin	Owned by the USFS.	Oregon, Missouri	AAC Sec 36 25N-4W	36° 47’ 28” 91° 20’ 40”	555’
EP68	Graveyard Spring	Owned by the USFS. Name assigned during this study. Older names are uncertain.	Oregon, Missouri	CAD Sec 31 25N-3W	36° 47’ 21” 91° 19’ 12”	520’
EP69	Little Hurricane Creek	Owned by the USFS.	Oregon, Missouri	BCA Sec 4 25N-3W	36° 46’ 37” 91° 17’ 30”	510’
EP70	Middle Fork Eleven Point River at County Road 3850	Private property.	Howell, Missouri	CAA Sec 26 25N-7W	36° 48’ 49” 91° 40’ 49”	840’
EP71	Middle Fork Eleven Point River at County Road 1420	Private property.	Howell, Missouri	AAA Sec 35 25N-7W	36° 48’ 07” 91° 40’ 42”	850’
EP72	Hurricane Creek at Oregon County Road 154	Location approximate.	Oregon, Missouri	CAC Sec 34 25N-3W	36° 47’ 17” 91° 16’ 25”	524’
EP73	Hurricane Creek at mouth	Location approximate.	Oregon, Missouri	DDB Sec 3 24N-3W	36° 46’ 36” 91° 16’ 38”	496’
EP74	Eleven Point River upstream of Hurricane Creek	Location approximate.	Oregon, Missouri	DDB Sec 3 24N-3W	36° 46’ 35” 91° 16’ 38”	496’

Appendix B
Selected Monitoring Points used for Traces in Appendix A
Locations are Approximate

ID Number	Point Name	Remarks	County	Legal Description	Latitude Longitude	Altitude in Feet
EP75	Eleven Point River 330' downstream of Hurricane Creek	Location approximate.	Oregon, Missouri	DDB Sec 3 24N-3W	36˚ 46' 35" 91˚ 16' 34"	496'
EP76	MacBates Spring	Location approximate.	Oregon, Missouri	BAC Sec 34 25N-3W	36˚ 47' 19" 91˚ 16' 25"	523'
EP77	Deadman Spring	Location approximate.	Oregon, Missouri	ABB Sec 27 25N-4W	36˚ 48' 45" 91˚ 23' 02"	556'
EP78	Eleven Point River upstream of Deadman Spring	Location approximate.	Oregon, Missouri	DBB Sec 27 25N-4W	36˚ 48' 45" 91˚ 23' 03"	560'
EP79	Eleven Point River upstream of Injection Hollow	Location approximate.	Oregon, Missouri	BCD Sec 28 25N-4W	36˚ 48' 39" 91˚ 23' 08"	560'
EP80	Injection Hollow Spring	Location approximate.	Oregon, Missouri	BAA Sec 33 25N-4W	36˚ 48' 36" 91˚ 22' 59"	580'
EP81	Spring upstream of Chaney Cave	Location approximate.	Oregon, Missouri	AD Sec 28 25N-4W	36˚ 48' 42" 91˚ 23' 04"	555'
EP82	Roadbank Spring upstream of Chaney Cave	Location approximate.	Oregon, Missouri	CD Sec 28 25N-4W	36˚ 48' 39" 91˚ 23' 07"	558'
EP83	Minick Spring	Location approximate.	Oregon, Missouri	AD Sec 22 25N-4W	36˚ 49' 07" 91˚ 22' 27"	550'
EP84	Eleven Point River at mouth of Long Hollow	Location approximate.	Oregon, Missouri	DAC Sec 23 25N-4W	36˚ 49' 01" 91˚ 21' 47"	544'
EP85	Eleven Point River upstream of Greer Branch	Location approximate.	Oregon, Missouri	CDD Sec 25 25N-4W	36˚ 47' 58" 91˚ 20' 18"	525'
EP86	Overflow Cave	Location approximate.	Oregon, Missouri	BBD Sec 18 24N-2W	36˚ 44' 19" 91˚ 13' 13"	440'
EP87	Bliss Spring Branch	Location approximate.	Oregon, Missouri	CBA Sec 18 24N-2W	36˚ 44' 33" 91˚ 13' 14"	445'
EP88	Barn Hollow Spring	Location approximate.	Oregon, Missouri	CBB Sec 18 24N-2W	36˚ 44' 33" 91˚ 13' 49"	458'
EP89	Whites Creek near mouth	Location approximate.	Oregon, Missouri	DCB Sec 20 24N-2W	36˚ 43' 30" 91˚ 12' 33"	456'
EP90	Tumbling Shoal Creek mouth	Location approximate.	Oregon, Missouri	BAA Sec 12 24N-3W	36˚ 45' 36" 91˚ 14' 06"	468'
EP91	Eleven Point River upstream of Tumbling Shoal Creek	Location approximate.	Oregon, Missouri	BAA Sec 12 24N-3W	36˚ 45' 37" 91˚ 14' 08"	469'
EP92	Eleven Point River upstream of Whites Creek	Location approximate.	Oregon, Missouri	CCB Sec 20 24N-2W	36˚ 43' 29" 91˚ 12' 41"	457'
EP93	Bay Spring	Location approximate.	Oregon, Missouri	DCD Sec 12 24N-3W	36˚ 44' 50" 91˚ 14' 18"	460'
EP94	Bluff Spring above Cooper Cave	Location approximate.	Oregon, Missouri	BCB Sec 19 25N-4W	36˚ 49' 26" 91˚ 26' 19"	606'
EP95	Spring Creek 200 yards below Cooper Cave	Location approximate.	Oregon, Missouri	DCB Sec 19 25N-4W	36˚ 49' 18" 91˚ 26' 17"	599'

Appendix B
Selected Monitoring Points used for Traces in Appendix A
Locations are Approximate

ID Number	Point Name	Remarks	County	Legal Description	Latitude Longitude	Altitude in Feet
EP96	Bockman Cave Spring	Location approximate.	Oregon, Missouri	CBC Sec 9 25N-4W	36° 50' 49" 91° 24' 16"	680'
EP97	Willow Tree Cave Spring	Location approximate.	Oregon, Missouri	BCA Sec 9 25N-4W	36° 51' 13" 91° 23' 49"	720'
EP98	Middle Fork Eleven Point River above Blue Hole Spring	Private property.	Oregon, Missouri	CCA Sec 29 25N-6W	36° 48' 37" 91° 37' 50"	760'
EP99	Wolfpen Hollow Spring #1	Location approximate.	Oregon, Missouri	BCD Sec 16 25N-4W	36° 49' 54" 91° 23' 45"	620'
EP100	Wolfpen Hollow Spring #2	Location approximate. May be same location as Three Mile Creek Spring.	Oregon, Missouri	BDB Sec 21 25N-4W	36° 49' 25" 91° 23' 59"	577'
EP101	Wolfpen Hollow Spring #3	Location approximate.	Oregon, Missouri	BCD Sec 21 25N-4W	36° 48' 58" 91° 23' 26"	630'
EP102	Hurricane Creek near Kelly Hollow	Location approximate.	Oregon, Missouri	DAC Sec 27 25N-3W	36° 48' 07" 91° 16' 18"	550'
EP103	Eleven Point River at mouth of Injection Hollow	Location approximate.	Oregon, Missouri	BCD Sec 28 24N-4W	36° 48' 39" 91° 23' 08"	557'
Jacks Fork Watershed						
JF1	Jam Up Creek at Jam Up Cave		Shannon, Missouri	CAD Sec 4 27N-6W	37° 02' 21" 91° 36' 26"	790'
JF2	Jacks Fork near Mouth of Jam Up Creek		Shannon, Missouri	DBD Sec 4 27N-6W	37° 02' 19" 91° 36' 21"	790'
JF3	Jacks Fork at Rymers Landing		Shannon, Missouri	DBD Sec 35 28N-6W	37° 03' 10" 91° 34' 14"	770'
JF4	Jacks Fork at Bunker Hill Ranch		Shannon, Missouri	CCD Sec 25 28N-6W	37° 03' 45" 91° 33' 12"	760'
JF5	Haley Well	Private property.	Shannon, Missouri	CCA Sec 19 27N-6W	36° 59' 51" 91° 38' 47"	735'
Spring River Watershed						
SR1	Mammoth Spring	Part of Mammoth Spring State Park, Arkansas.	Fulton, Arkansas	DDC Sec 5 21N-5W	36° 29' 52" 91° 32' 09"	505'
SR2	Bussell Branch English Creek at Missouri Route 142		Oregon, Missouri	ADB Sec 3 21N-6W	36° 30' 33" 91° 36' 35"	620'
SR3	Warm Fork at Oregon County Road 333	Upstream of Warm Fork Spring.	Oregon, Missouri	DBB Sec 23 23N-6W	36° 38' 39" 91° 36' 04"	660'
SR4	West Fork Spring River at Missouri Route 142		Howell, Missouri	AAD Sec 5 21N-8W	36° 30' 40" 91° 51' 22"	730'
SR5	South Fork Spring River at Missouri Route 142		Howell, Missouri	ABB Sec 3 21N-8W	36° 31' 10" 91° 50' 01"	730'

Appendix B
Selected Monitoring Points used for Traces in Appendix A
Locations are Approximate

ID Number	Point Name	Remarks	County	Legal Description	Latitude Longitude	Altitude in Feet
SR6	Myatt Creek at Missouri Route 142		Howell, Missouri	BAB Sec 4 21N-7W	36˚ 31' 04" 91˚ 44' 18"	660'
SR7	Two Mile Creek		Oregon, Missouri	CBB Sec 30 22N-5W	36˚ 32' 23" 91˚ 33' 43"	580'
SR8	Warm Fork at Missouri Route 19		Oregon, Missouri	BCB Sec 20 22N-5W	36˚ 33' 08" 91˚ 32' 22"	520'
SR9	Warm Fork at Oregon County Road 323	Downstream of Warm Fork Spring.	Oregon, Missouri	BBA Sec 31 23N-5W	36˚ 37' 04" 91˚ 33' 32"	610'
Current River Watershed						
CR1	Big Spring	Part of Ozark National Scenic Riverways.	Carter, Missouri	CCA Sec 6 26N-1E	36˚ 57' 03" 90˚ 59' 30"	433'
CR2	Mill Creek Spring		Carter, Missouri	DBD Sec 6 27N-1W	37˚ 02' 02" 91˚ 05' 56"	555'
CR3	Mill Creek upstream from Mill Creek Spring	Location approximate.	Carter, Missouri	ABD Sec 6 27N-1W	37˚ 02' 04" 91˚ 05' 55"	540'
CR4	Pike Creek at Missouri Route M	Location approximate.	Carter, Missouri	DCD Sec 23 27N-1W	36˚ 59' 22" 91˚ 01' 36"	460'
CR5	House Creek at Missouri Route M	Location approximate.	Carter, Missouri	BAD Sec 10 27N-1W	37˚ 01' 21" 91˚ 02' 32"	480'
CR6	Mill Creek at Missouri Route M	Location approximate.	Carter, Missouri	DDB Sec 4 27N-1W	37˚ 02' 20" 91˚ 04' 02"	480'
CR7	Plum Spring	Location approximate.	Carter, Missouri	DDD-Sec 32 28N-2W	37˚ 02' 32" 91˚ 11' 06"	760'
CR8	Hooper Hollow at Carter County Road 217	Location approximate.	Carter, Missouri	AAC-Sec 34 26N-1E	36˚ 52' 06" 90˚ 56' 31"	420'
CR9	Spring Hollow	Location approximate.	Carter, Missouri	BDD Sec 26 26N-1E	36˚ 52' 43" 90˚ 55' 00"	435'
CR10	Chilton Creek at Missouri Route Z	Location approximate.	Carter, Missouri	CDD-Sec 8 26N-1E	36˚ 55' 25" 90˚ 58' 11"	460'
CR11	Chilton Creek lower	Location approximate.	Carter, Missouri	CCD-Sec 14 26N-1W	36˚ 54' 50" 91˚ 01' 56"	630'
CR12	Chilton Creek upper	Location approximate.	Carter, Missouri	DAA-Sec 22 26N-1W	36˚ 54' 34" 91˚ 02' 34"	700'
CR13	Chub Hollow at Missouri Route Z	Location approximate.	Carter, Missouri	DCD-Sec 6 26N-1E	36˚ 56' 37" 90˚ 59' 27"	455'
CR14	Current River upstream of Phillips Spring	Location approximate.	Carter, Missouri	DBA-Sec 11 26N-1E	36˚ 50' 31" 90˚ 55' 25"	398'
CR15	Phillips Spring	Location approximate.	Carter, Missouri	DDC-Sec 10 25N-1E	36˚ 50' 01" 90˚ 56' 33"	395'
CR16	Current River upstream of Panther Spring	Location approximate.	Carter, Missouri	BDD-Sec 34 26N-1E	36˚ 51' 49" 90˚ 56' 11"	406'
CR17	Panther Spring	Location approximate.	Carter, Missouri	CDD-Sec 34 26N-1E	36˚ 51' 40" 90˚ 56' 10"	405'
CR18	Current River downstream of Panther Spring	Location approximate.	Carter, Missouri	AAA-Sec 3 25N-1E	36˚ 51' 37" 90˚ 56' 07"	405'

Appendix B
Selected Monitoring Points used for Traces in Appendix A
Locations are Approximate

ID Number	Point Name	Remarks	County	Legal Description	Latitude Longitude	Altitude in Feet
CR19	Current River at Cataract Landing	Location approximate.	Carter, Missouri	BCC-Sec 24 26N-1E	36° 53’ 31” 90° 54’ 41”	426’
CR20	Spring Creek near mouth	Location approximate.	Carter, Missouri	CAB-Sec 15 25N-1E	36° 49’ 46” 90° 56’ 46”	396’
CR21	Log Hollow at Missouri Route Z	Location approximate.	Carter, Missouri	BBC-Sec 10 26N-1E	36° 55’ 41” 90° 56’ 53”	450’
CR22	Lick Log Hollow at Carter County Road 217	Location approximate.	Carter, Missouri	BCA-Sec 26 26N-1E	36° 53’ 14” 90° 55’ 17”	418’
CR23	Bear Camp Hollow	Location approximate.	Carter, Missouri	BBA-Sec 6 25N-1E	36° 52’ 00” 90° 59’ 46”	605’
CR24	Twin Spring West	Location approximate.	Ripley, Missouri	BDD-Sec 33 25N-1E	36° 46’ 36” 90° 57’ 20”	395’
CR25	Twin Spring East	Location approximate.	Ripley, Missouri	ADD-Sec 33 25N-1E	36° 46’ 34” 90° 57’ 19”	400’
CR26	Big Barren Creek near mouth	Location approximate.	Ripley, Missouri	AAC-Sec 34 25N-1E	36° 46’ 46” 90° 56’ 46”	392’
CR27	Tucker Bay Spring	Location approximate.	Ripley, Missouri	ADB-Sec 3 24N-1E	36° 46’ 03” 90° 56’ 45”	378’
CR28	Goodnight Spring at Onyx Cave	Location approximate	Carter, Missouri	DBC-Sec 26 27N-1W	36° 58’ 39” 91° 02’ 07”	520’
Bennett Bayou Watershed						
BB1	Bennetts Bayou at YY Hwy		Howell, Missouri	ACB Sec 30 22N-10W	36° 33’ 07” 92° 06’ 00”	770'
BB2	Big Spring		Howell, Missouri	DCB Sec 16 22N-10W	36° 34’ 38” 92° 03’ 18”	875’
Beaver Creek Watershed						
BVC1	Beaver Creek	At Douglas County Road 437.	Douglas, Missouri	ACC Sec 27 25N-17W	36° 49’ 27” 92° 47’ 50”	900’
BVC2	Beaver Creek	At Sam Day Road.	Taney, Missouri	BAC Sec 21 24N-18W	36° 44’ 58” 92° 56’ 29”	765’

Appendix C

Explanation

Appendix C provides location data for dye injection points. Injection points are numbered sequentially with an "IP" designation. All location data (including altitudes) are approximate. Location data for older traces have limited precision due to the lack of large scale topographic maps at the time of the work. Global positioning system (GPS) information has been used to locate approximate latitude and longitude (degrees, minutes and seconds) of all injection and monitoring points. This information is generally of higher precision for points located during this study due to the ready availability of GPS measurement devices. Figure 110 is a generalized map of all known injection points in the study area.

Legal locations are included when possible for all traces. That was the standard method for locating legacy injection points. Refer to figure 107 for details about legal location determination in Appendix C.

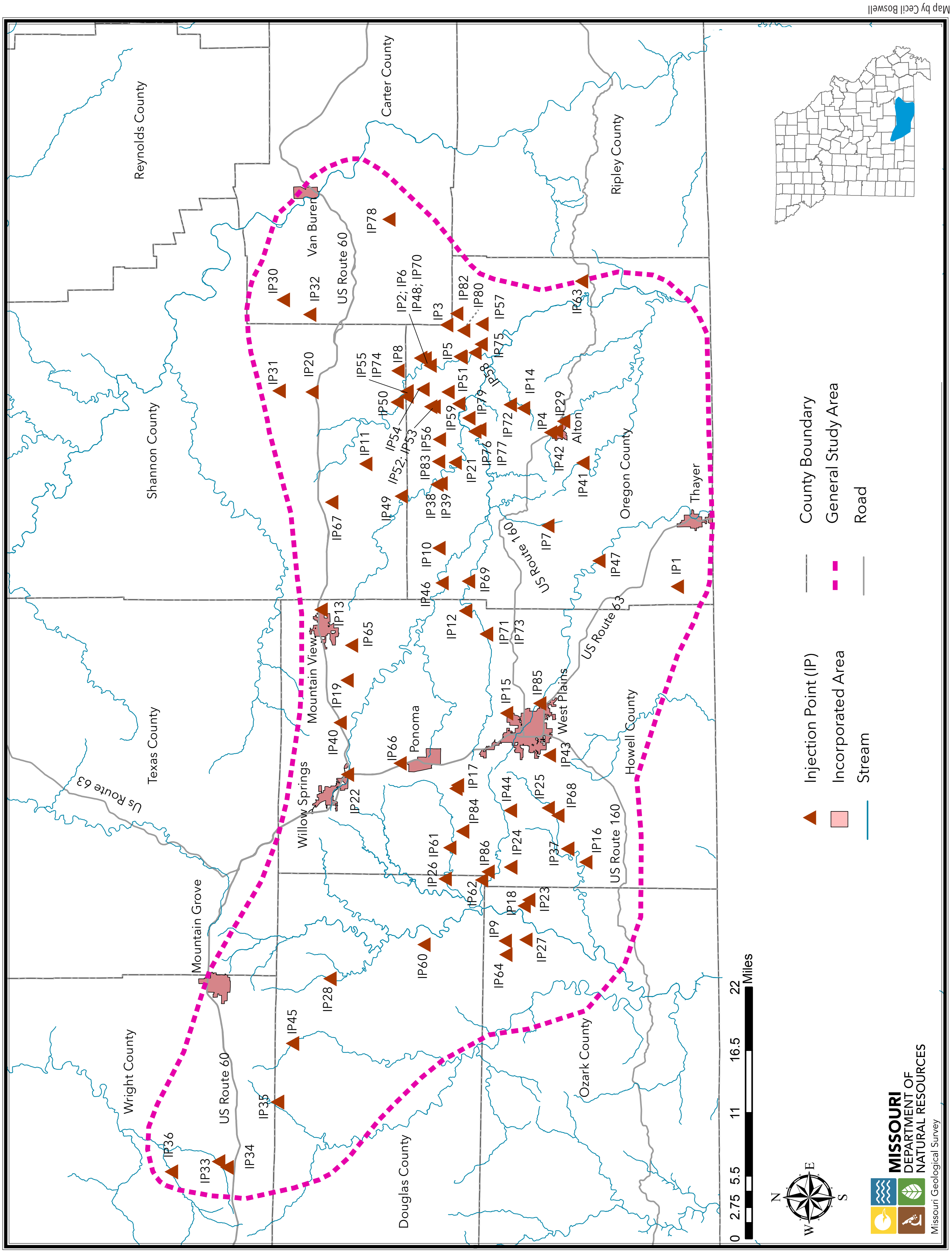

Figure 110. Injection points in the Big Four Region.

Appendix C
Injection Points used for Traces in Appendix A
Locations are Approximate

Injection Number	Injection Point	Remarks	Watershed	County	Legal Description	Latitude Longitude	Elev. MSL
IP1	Grand Gulf Cave	State Park leased from the LAD Foundation.	Spring River	Oregon, Missouri	CCD Sec 20 22N-6W	36˚ 32' 41" 91˚ 38' 40"	550'
IP2	Blowing Spring Estavelle	Owned by USFS.	Eleven Point River	Oregon, Missouri	CC Sec 3 25N-3W	36˚ 51' 33" 91˚ 16' 45"	630'
IP3	Goldmine Hollow	Just upstream of Kelly Hollow.	Eleven Point River	Oregon, Missouri	AAD Sec 13 25N-3W	36˚ 49' 57" 91˚ 13' 30"	700'
IP4	Alton Sinkhole	Private property once used as a dump.	Eleven Point River	Oregon, Missouri	AAA Sec 33 24N-4W	36˚ 42' 13" 91˚ 23' 54"	760'
IP5	Johnson Spring Branch	Location imprecise.	Eleven Point River	Oregon, Missouri	CAC Sec 22 25N-3W	36˚ 48' 58" 91˚ 16' 32"	550'
IP6	Leslie Spr. Swallow Hole	Location imprecise.	Eleven Point River	Oregon, Missouri	BBA Sec 9 25N-3W	36˚ 51' 16" 91˚ 17' 18"	610'
IP7	Granny Meyers Spring Branch	Small spring branch above losing stream segment on private property.	Eleven Point River	Oregon, Missouri	BCC Sec 29 24N-5W	36˚ 42' 30" 91˚ 32' 42"	850'
IP8	Wildcat Spring Branch	Location imprecise.	Eleven Point River	Shannon, Missouri	ADA Sec 29 26N-3W	36˚ 53' 43" 91˚ 17' 46"	740'
IP9	Dora Sink	Private property.	North Fork	Ozark, Missouri	BDC Sec 8 24N-11W	36˚ 46' 07" 92˚ 11' 58"	920'
IP10	Stillhouse Spring	Apparently mis-located in earlier references.	Eleven Point River	Oregon, Missouri	ADC Sec 11 25N-6W	36˚ 50' 50" 91˚ 34' 36"	820'
IP11	Dowler Sink	Location imprecise	Eleven Point River	Shannon, Missouri	BDA Sec 12 26N-5W	36˚ 56' 19" 91˚ 26' 33"	975'
IP12	Middle Fork of the 11 Point River	Losing stream located on private property.	Eleven Point River	Howell, Missouri	AAD Sec 26 25N-7W	36˚ 48' 52" 91˚ 40' 38"	835'
IP13	Jam Up Creek	Downstream of Mountain View sewage discharge	Jacks Fork	Howell, Missouri	CCB Sec 24 27N-7W	36˚ 59' 53" 91˚ 40' 20"	1080'
IP14	Simpson Pond	Leaking pond on private property.	Eleven Point River	Oregon, Missouri	BBC Sec 13 24N-4W	36˚ 44' 13" 91˚ 21' 32"	780'
IP15	Renfrow Spring Sinkhole	Sinkhole on private property with a small spring in the wall.	Spring River	Howell, Missouri	CCB Sec 10 24N-8W	36˚ 45' 50" 91˚ 50' 23"	1040'
IP16	Cureall Spring Branch	Private property.	North Fork	Howell, Missouri	ABC Sec 16 23N-10W	36˚ 39' 55" 92˚ 04' 34"	860'

Appendix C
Injection Points used for Traces in Appendix A
Locations are Approximate

Injection Number	Injection Point	Remarks	Watershed	County	Legal Description	Latitude Longitude	Elev. MSL
IP17	Upper Dry Creek	Springs on private property feed a stream that normally loses all flow on USFS property.	North Fork	Howell, Missouri	BCA Sec 20 25N-9W	36° 49’ 46” 91° 57’ 28”	1080’
IP18	McGarr Spring Branch		North Fork	Ozark, Missouri	BDB Sec 23 24N-11W	36° 44’ 40” 92° 08’ 38”	800’
IP19	Nuttle Spring Branch	Small spring in losing stream on private property.	Eleven Point River	Howell, Missouri	ADD Sec 35 27N-8W	36° 57’ 58” 91° 47’ 03”	1150’
IP20	South Branch of Pike Creek in Winona	Losing stream downstream of sewage discharge.	Current River	Shannon, Missouri	ACC Sec 18 27N-3W	37° 00’ 18” 91° 19’ 38”	900’
IP21	Spring Creek at the Mouth of Jenny Hollow	Published written description does not agree with published legal description.	Eleven Point River	Oregon, Missouri	DAA Sec 24 25N-5W	36° 49’ 30” 91° 26’ 34”	610’
IP22	11 Point at Hwy 63	Losing stream with flow loss occurring on private property.	Eleven Point River	Howell, Missouri	CDD Sec 33 27N-9W	36° 58’ 01” 91° 56’ 00”	1170’
IP23	Amber Spring		North Fork	Ozark, Missouri	DAD Sec 23 24N-11W	36° 44’ 18” 92° 08’ 04”	825’
IP24	The Sinks	Twin sinkholes on USFS property.	North Fork	Howell, Missouri	ABA Sec 17 24N-10W	36° 45’ 40” 92° 04’ 58”	880’
IP25	Brassfield Sink	Private property.	North Fork	Howell, Missouri	BDA Sec 31 24N-9W	36° 42’ 45” 91° 59’ 25”	990’
IP26	Still Spring	Downstream of Still Spring at Dry Creek.	North Fork	Douglas, Missouri	ABD Sec 13 25N-11W	36° 50’ 40” 92° 06’ 02”	780’
IP27	Collins Spring Branch	Injection at confluence with Creek Pond Hollow.	North Fork	Ozark, Missouri	DDB Sec 20 24N-11W	36° 44’ 35” 92° 11’ 51”	800’
IP28	Clifty Creek	Below Douglas County Road 76-149.	North Fork	Douglas, Missouri	BAD Sec 28 27N-12W	36° 59’ 31” 92° 15’ 25”	1000’
IP29	Alton Sewage Lagoon	Lagoon now replaced with treatment plant.	Eleven Point River	Oregon, Missouri	CBB Sec 2 23N-4W	36° 41’ 10” 91° 22’ 49”	720’
IP30	Peck Ranch Losing Stream		Current River	Carter, County	CBB Sec 4 27N-2W	37° 02’ 22” 91° 10’ 49”	740’
IP31	Upper Sycamore Creek	Just downstream of Missouri Route 19.	Current River	Shannon, Missouri	DCC Sec 31 28N-3W	37° 02’ 49” 91° 19’ 28”	1010’
IP32	East Fork of Nordic Hollow	Called Vermillion Hollow on Stegall Mountain Quad.	Current River	Carter, Missouri	CDA Sec 18 27N-2W	37° 00’ 23” 91° 12’ 17”	770’

Appendix C
Injection Points used for Traces in Appendix A
Locations are Approximate

Injection Number	Injection Point	Remarks	Watershed	County	Legal Description	Latitude Longitude	Elev. MSL
IP33	Wolf Creek	Downstream from Mansfield sewage discharge.	Gasconade	Wright, Missouri	CBA Sec 11 28N-15W	37° 08’ 06” 92° 32’ 43”	1270’
IP34	Fry Creek		Gasconade	Wright, Missouri	CCC Sec 11 28N-15W	37° 07’ 25” 92° 33’ 18”	1295’
IP35	Summer Spring Branch		Bryant Creek	Douglas, Missouri	DAA Sec 3 27N 14W	37° 03’ 34” 92° 27’ 05”	1160’
IP36	Lick Fork Gasconade River	1.5 miles upstream from Missouri Route 5.	Gasconade	Wright, Missouri	BBA Sec 22 29N-15W	37° 11’ 41” 92° 33’ 40”	1190’
IP37	Losing Stream at Dairy	Private property.	North Fork	Howell, Missouri	BAB Sec 10 23N-10W	36° 41’ 18” 92° 03’ 17”	920’
IP38	Tributary to Spring Creek	Between Johnson Hollow and Paty Hollow.	Eleven Point River	Oregon, Missouri	CBC Sec 11 25N-5W	36° 50’ 53” 91° 28’ 37”	740’
IP39	Paty Spring		Eleven Point River	Oregon, Missouri	ABB Sec 14 25N-5W	36° 50’ 36” 91° 28’ 30”	720’
IP40	Sims Creek	At U.S. Route 60 crossing.	Eleven Point River	Howell, Missouri	DBB Sec 32 27N-8W	36°58‘ 33” 91°51’01”	1120’
IP41	Upper Frederick Creek	Losing reach downstream of small springs. Private property.	Eleven Point River	Oregon, Missouri	DDC Sec 7 23N-4W	36°39’46” 91°26’47”	815’
IP42	Piney Creek between Missouri Route 19 and U.S. Route 160	Losing reach upstream of U.S. Route 160. Private property.	Eleven Point River	Oregon, Missouri	BBC Sec 34 24N-4W	36° 41’ 44” 91° 23’ 45”	740’
IP43	Upper Mustion Creek	Losing stream on private property downstream from South Fork.	Spring River	Howell, Missouri	BCA Sec 36 24N-9W	36° 42’ 38” 91°54’25”	1075’
IP44	Upper Tabor Creek	Losing stream on private property north of Missouri Route CC below a small spring.	North Fork	Howell, Missouri	DCD Sec 7 24N-9W	36° 45' 38" 91° 59' 36"	1075’
IP45	Upper Fox Creek	Private property downstream of Missouri Route ZZ	Bryant Creek	Douglas, Missouri	ABC Sec 10 27N-13W	37° 02' 24" 92° 21' 30"	1035’
IP46	11 Point near Lost Hill	Private property downstream of Missouri Route W.	Eleven Point River	Oregon, County	AAB Sec 17 25N-6W	36° 50’ 38” 91° 37’ 57”	710’
IP47	Warm Fork	At Oregon County Road 333.	Spring River	Oregon, Missouri	DBB Sec 23 23N-6W	36° 38’ 39” 91° 36’ 04”	655’

Appendix C
Injection Points used for Traces in Appendix A
Locations are Approximate

Injection Number	Injection Point	Remarks	Watershed	County	Legal Description	Latitude Longitude	Elev. MSL
IP48	New Liberty Garbage Dump		Eleven Point River	Oregon, Missouri	ACB Sec 3 25N-3W	36˚ 51' 59" 91˚ 16' 36"	860'
IP49	Cave Spring on Spring Creek	Near edge of USFS property.	Eleven Point River	Shannon, Missouri	CCB Sec 27 26N-5W	36˚ 53' 38" 91˚ 29' 41"	780'
IP50	Hurricane Creek	Near Pond Hollow.	Eleven Point River	Shannon, Missouri	CAB Sec 25 26N-4W	36˚ 53' 50" 91˚ 20' 44"	730'
IP51	Davis Pond	Injection into leaking pond.	Eleven Point River	Oregon, Missouri	ABC Sec 18 25N-3W	36˚ 49' 56" 91˚ 19' 51"	900'
IP52	Horse Trail Spring		Eleven Point River	Oregon, Missouri	DDA Sec 11 25N-4W	36˚ 51' 02" 91˚ 21' 13"	750'
IP53	Pig Spring		Eleven Point River	Oregon, Missouri	AAA Sec 11 25N-4W	36˚ 51' 17" 91˚ 21' 10"	800'
IP54	Road Ditch		Eleven Point River	Oregon, Missouri	DDB Sec 6 25N-3W	36˚ 51' 51" 91˚ 19' 34"	900'
IP55	Intermittent Stream	Just upstream of Missouri Route 19.	Eleven Point River	Oregon, Missouri	BAA Sec 36 26N-4W	36˚ 53' 05" 91˚ 20' 13"	750'
IP56	Sheep Ranch Hollow		Eleven Point River	Oregon, Missouri	BCC Sec 9 25N-4W	36˚ 50' 40" 91˚ 24' 20"	635'
IP57	Rough Hollow		Eleven Point River	Oregon, Missouri	BBC Sec 31 25N-2W	36˚ 47' 16" 91˚ 13' 28"	820'
IP58	Hurricane Creek	Near north section line of Section 34.	Eleven Point River	Oregon, Missouri	BBA Sec34 25N-3W	36˚ 47' 50" 91˚ 16' 11"	520'
IP59	McCormack Hollow	Downstream of McCormack Lake	Eleven Point River	Oregon, Missouri	ABC Sec 24 25N-4W	36˚ 49' 08" 91˚ 20' 59"	575'
IP60	Roaring Spring		North Fork	Douglas, Missouri	ADD Sec 1 25N-12W	36˚ 52' 19" 92˚ 12' 14"	860'
IP61	Dribble Cave Spring		North Fork	Howell, Missouri	DDC Sec 16 25N-10W	36˚ 50' 16" 92˚ 03' 04"	880'
IP62	Hay Hollow Creek	Below the Braddock damsite.	North Fork	Douglas, Missouri	CBD Sec 36 25N-11W	36˚ 47' 53" 92˚ 06' 11"	780'
IP63	Schoolhouse Hollow		Eleven Point River	Oregon, Missouri	BCC Sec 11 23N-2W	36˚ 39' 37" 91˚ 09' 36"	520'
IP64	Upper Bollinger Branch	Near junction of Missouri Routes 181 and CC.	Bryant Creek	Ozark, Missouri	BCC Sec 7 24N-11W	36˚ 46' 05" 92˚ 13' 15"	975'
IP65	Upper Kenaga Hollow	Downstream of Howell County Road 2900.	Eleven Point River	Howell, Missouri	AAA Sec 5 26N-7W	36˚ 57' 37" 91˚ 43' 46"	1120'
IP66	Dean Davis Cons. Area	Inside the failed lake basin owned by MDC.	Eleven Point River	Howell, Missouri	DCA Sec 27 26N-9W	36˚ 54' 00" 91˚ 55' 01"	1195'
IP67	Birch Creek	Downstream from city sewage discharge.	Eleven Point River	Howell, Missouri	BCA Sec 28 27N-5W	36˚ 58' 57" 91˚ 30' 08"	965'

Appendix C
Injection Points used for Traces in Appendix A
Locations are Approximate

Injection Number	Injection Point	Remarks	Watershed	County	Legal Description	Latitude Longitude	Elev. MSL
IP68	Spring Creek	Upstream from Pottersville.	North Fork	Howell, Missouri	DBB Sec 6 23N-9W	36˚ 42' 01" 92˚ 00' 07"	950'
IP69	Middle Fork Channel	Upstream from Blue Hole Spring on private property.	Eleven Point River	Oregon, Missouri	CCA Sec 29 25N-6W	36˚ 48' 36" 91˚ 37' 49"	750'
IP70	Barrett Spring Branch	Owned by USFS.	Eleven Point River	Oregon, Missouri	DBC Sec 3 25N-3W	36˚ 51' 38" 91˚ 16' 38"	630'
IP71	Middle Fork Channel	Upstream of Fanchon. Private property.	Eleven Point River	Howell, Missouri	BAA Sec 3 24N-7W	36˚ 47' 18" 91˚ 42' 52"	885'
IP72	Little Hurricane Creek Trib.	Private property.	Eleven Point River	Oregon, Missouri	AAC Sec 12 24N-4W	36˚ 45' 12" 91˚ 21' 10"	730'
IP73	Middle Fork Channel	Upstream of Fanchon #2. Private property.	Eleven Point River	Howell, Missouri	CCC Sec 34 25N-7W	36˚ 47' 20" 91˚ 42' 52"	885'
IP74	Small Spring in Hurricane Creek	Private property.	Eleven Point River	Oregon, Missouri	ABB Sec 31 26N-3W	36˚ 53' 04" 91˚ 19' 46"	750'
IP75	Katie Sisco Hollow	Owned by USFS.	Eleven Point River	Oregon, Missouri	BAC Sec 35 25N-3W	36˚ 47' 21" 91˚ 15' 23"	650'
IP76	Injection Hollow	Owned by USFS.	Eleven Point River	Oregon, Missouri	CDA Sec 33 25N-4W	36˚ 47' 45" 91˚ 23' 27"	650'
IP77	Downstream of Injection Hollow Spring	Owned by USFS.	Eleven Point River	Oregon, Missouri	ABA Sec 33 25N-4W	36˚ 47' 57" 91˚ 23' 39"	580'
IP78	Van Winkle Sawdust Pile	Location approximate.	Current River	Carter Missouri	ABC Sec 22 26N-1W	36˚ 54' 12" 91˚ 03' 23"	820'
IP79	Long Hollow	Location approximate.	Eleven Point River	Oregon, Missouri	CDA Sec 27 25N-4W	36˚ 48' 23" 91˚ 22' 21"	690'
IP80	Ozark Trail	Location approximate.	Eleven Point River	Oregon, Missouri	AAB Sec 25 25N-3W	36˚ 48' 40" 91˚ 14' 04"	700'
IP81	Hurricane Creek west of U.S. Hwy 19	Location approximate.	Eleven Point River	Oregon, Missouri	BBC Sec 31 26N-3W	36˚ 52' 39" 91˚ 19' 59"	790'
IP82	Sinkhole in Sitton Valley	Location approximate.	Eleven Point River	Oregon, Missouri	BCB Sec 20 25N-2W	36˚ 49' 14" 91˚ 12' 21"	940'
IP83	Sinkhole in Jenny Hollow	Location approximate.	Eleven Point River	Oregon, Missouri	CDC Sec 7 25N-4W	36˚ 50' 38" 91˚ 26' 08"	795'
IP84	Rattlesnake Spring Branch	Losing stream in an upper reach of Dry Creek. Spring is on USFS property.	North Fork	Howell, Missouri	BAA Sec 27 25N-10W	36˚ 49' 17" 92˚ 01' 31"	990'

Appendix C
Injection Points used for Traces in Appendix A
Locations are Approximate

Injection Number	Injection Point	Remarks	Watershed	County	Legal Description	Latitude Longitude	Elev. MSL
IP85	Collapse in West Plains Sewage Lagoon	Lagoon is now replaced by a new treatment facility owned by the city of West Plains.	Spring River	Howell, Missouri	ADA Sec 27 24N-8W	36˚ 43' 18" 91˚ 49' 30"	930'
IP86	Siloam Spring	About 0.75 mile downstream of Siloam Spring.	North Fork	Howell, Missouri	BDB Sec 5 24N-10W	36˚ 47' 23" 92˚ 05' 23"	860'

MISSOURI NATURAL RESOURCES

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