Dye Trace Study of Karst Groundwater Flow at Mystery Spring and Wildcat Culvert in Lexington, Fayette County, Kentucky

Daniel P. Martin will graduate in December 2018 with a B.S. in Geology and an Honors minor. In addition to contributing to this article, he has also presented the same research at the Kentucky Academy of Science and conducted other research with several professors in the Geology Department and College of Honors. Daniel currently works as a conservation educator at the Newport Aquarium and hopes to further his education in the field of conservation research and environmental advocacy.

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Abstract

The main purpose of this study was to test connectivity from a sinkhole by William T. Young Library on the University of Kentucky's campus to Mystery Spring (1.5 miles away) near RJ Corman Railroad in Town Branch, and measure groundwater velocity thereto. A secondary aspect of the study was to measure travel time from a storm drain at the bottom of the aforementioned campus sinkhole to "Wildcat Culvert" which discharges into Town Branch (100 meters downstream of Mystery Spring), and to observe if the two were connected.

A map of the groundwater flow patterns in the area was published in 1996 based on mostly unpublished dye trace research. The last known work on Mystery Spring was conducted in 1989 by James Currens at Kentucky Geological Survey. In 1994, the William T. Young Library was built near the subject sinkhole that involved the construction of over 200 concrete and steel pylons, potentially disrupting the previous groundwater flow. In order to determine whether the construction affected karst conduits in the area, we conducted a second dye trace study in July of 2018 recreating, in many ways, the unpublished study from 1989.

90 grams of dye was injected into the two locations noted near the library (the sinkhole and a storm drain at the bottom of the razed sinkhole) and charcoal receptors, as well as an infrared probe, were placed at the predicted outflow points. Probe results at Mystery Spring were inconclusive but dye appeared in the charcoal receptors within 14 hours after injection at concentrations of 2.1 ppb. Eosine dye began appearing in visible quantities within 2 hours of the injection (6:00 p.m. on July 6th) at the outflow, "Wildcat Culvert," which is connected to the storm drain. No connection was observed between the sinkhole and the storm drain.

Keywords: dye trace, karst, groundwater flow dynamics

Introduction

In areas underlain by carbonates, dissolution of carbonate rocks may occur, resulting in groundwater flow dynamics that may be quite different than flow dynamics associated with granular flow. Granular flow patterns are typical of many non-carbonate areas and are characterized by subsurface flow through homogeneous grains and pore spaces, meaning flow spreads through the subsurface at a relatively even rate in all directions (isotropic). In carbonate areas, sinkholes, conduits, sinking streams, and other karst features direct groundwater flow anisotropically, which means the flow pattern is distributed unevenly. This type of flow is largely defined by dissolved void spaces and fractures. According to Kentucky Geological Survey, 38% of Kentucky has karst at or near the surface, including much of the city of Lexington (Geology of Kentucky).

In karst systems, the groundwater flow pattern makes the tracking and cleanup of chemical spills and other pollutants difficult. Dye trace studies, in which a quantity of visually- and chemically-distinct dye is added to a water system and chemical receptors are planted in bodies of water nearby to detect the presence of dye as it moves through the groundwater system, are beneficial in efforts to map the groundwater flow in karst areas.

In 1989, an unpublished study was conducted at a sinkhole (by what would later become the building site of William T. Young Library on the University of Kentucky campus in Lexington, Kentucky) by injecting dye into the sinkhole and placing chemical receptors at nearby bodies of water, establishing a subsurface groundwater flow pattern for the area (Currens et al., 1996). Upon completion of this survey, a karst dye trace map of the region was drafted using the data. The construction of the William T. Young Library in 1994 resulted in over 200 steel and concrete pylons being sunk into the ground to ensure the stability of the library's foundation (Jester et al., 1998). While these pylons were emplaced to prevent damage to the building's foundations from karst features, the construction had the potential to disrupt the previous groundwater flow, potentially rendering invalid the 1989 dye trace study. In theory, groundwater could have been directed to another basin, surface outlet, or a storm drain at the bottom of the razed sinkhole. The purpose of this study was (1) to examine whether the construction of the library had altered the groundwater flow of the region by disturbing the conduits generated by the karst features in the area, (2) test the time of travel of travel between the sinkhole and springs, as well as a sinkhole storm drain and Wildcat Culvert, and (3) test connectivity between the sinkhole and storm drain. In order to study the groundwater flow of the area, a dye trace was performed following parameters similar to those used in the 1989 study. Knowledge of these flow

Geology

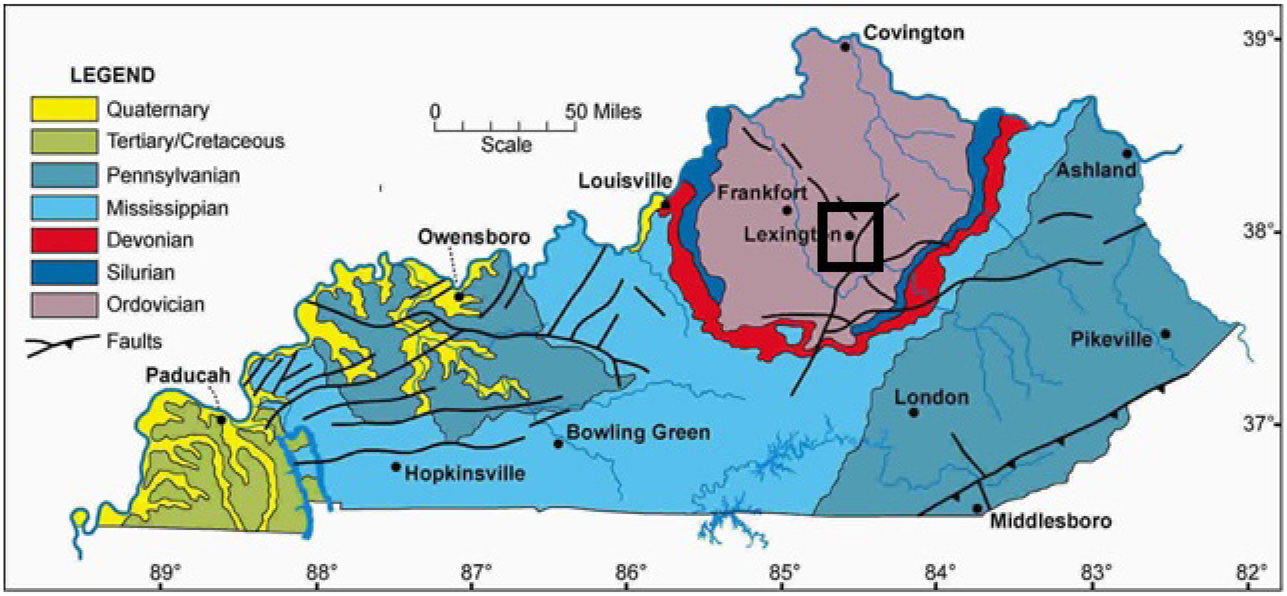

Figure 1. A geologic map of the state of Kentucky (Geology of Kentucky). The study area is outlined in black.

patterns are important for potential remediation in the event of a contamination spill.

Geologic Background

Lexington is located in the central Kentucky region (Figure 1). The location near the William T. Young Library on the University of Kentucky's campus in Lexington, Kentucky is shown in Figure 2. Dye receptors were deployed along Mystery Spring on the west side of Lexington (Figure 3) and a nearby basin, McConnell Spring, to test for interbasin spillover. The primary rock units present in this area of Kentucky are Ordovician in age and are structurally defined on a large scale by the Cincinnati Arch, an anticlinal structure created by the orogeny of the Appalachian Mountains, to the east. The creation of the arch uplifted older Ordovician rock units where they were exposed by erosion (McDowell 2001).

Lexington lies on the axis of the Cincinnati Arch. The rock units in the Lexington area were deposited during the upper part of the Middle Ordovician, the most prominent being the Lexington Limestone. Around 320 feet at its thickest section, the Lexington Limestone is primarily composed of fossiliferous limestone layers high in phosphates, with shale members also present. The formation was deposited in a shallow marine environment. It is divided into 12 distinct members: the Curdsville Limestone, Logana, Grier Limestone, Brannon, Perryville Limestone, Tanglewood Limestone, Millersburg, Greendale Lentil, Stamping Ground, Devils Hollow, and Strodes Creek Members, as seen in Figure 4.

At the dye injection site, the Tanglewood and Brannon Members are the primary surface units. The Tanglewood is a fossiliferous calcarenite that is well sorted and cross bedded with rounded phosphate grains. The Brannon consists of interbedded calcarenite and shale with few fossils and some fragments of chert. In some areas, ball and pillow structures are present on the upper beds of the unit (Cressman 2001). The layer between the Brannon and Tanglewood, the Perryville, is not present at the dye injection site. Along Town Branch at the dye receptor sites, the Brannon and Grier members of the Lexington Limestone are exposed. All of the receptor sites were located on Grier rock units (Kentucky). The Grier member is primarily a fossiliferous calcarenite with evidence of bioturbation and some shale beds (Cressman, 1973). The bedrock in the area dips at a range of 3 degrees to 5 degrees, and local tectonic activity from the nearby Kentucky River and Lexington Fault systems have created further conduits for groundwater flow in the region. Past dye trace studies in the region have determined groundwater flow velocities of 1.2 miles in 6-9 hours from a sinkhole at Campbell

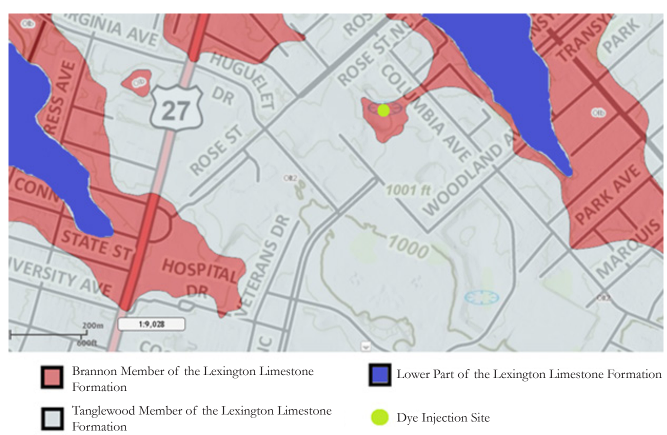

Figure 2. A geologic map of the formations at the dye injection sites near the William T. Young Library on the University of Kentucky campus. The injection side is marked in green. The blue circles on the map denote sinkholes (Kentucky Geologic Map Information Service).

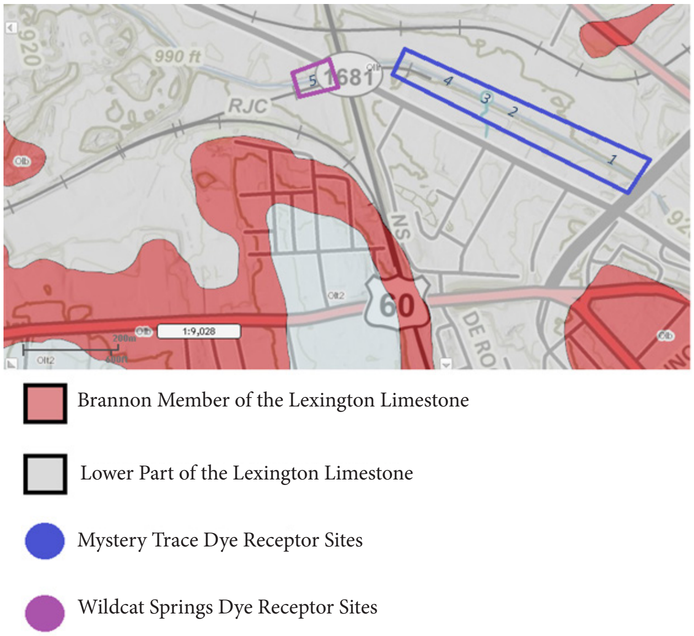

Figure 3. A geologic map of the dye receptor sites along Town Branch, where Mystery Spring and Wildcate Culvert are located. The monitoring locations along the stream are outlined in blue, going from #1 on the right to #5 on the left. Mystery Spring is indicated by the blue line and circle at monitoring point #3, and Wildcat Culvert is #5.

House and McConnell Springs or around 0.16 miles per hour, and 2 miles in 9-11 hours from Campbell House sinkhole to Preston's Cave Spring or around 0.2 miles per hour. The conduit between McConnell Springs and the Campbell House sinkhole exhibited a dye travel time of approximately 0.133 mph (Norris et al., 2016), much faster than the flow rate of non-karst aquifers in Eastern Kentucky which range from 10 feet per day to 0.0001 feet per day (Garrison, 2015).

Methods

Background data were collected from May 24th, 2018 through July 7th, 2018 at Mystery Spring, McConnell Springs, and Town Branch to ensure there was no contamination present in the water system. A dye trace notification was submitted to the State of Kentucky on the 29th of May, 2018.

Charcoal dye receptors and a Cyclops 7 infrared probe were installed in Town Branch. The receptors were installed as a backup to confirm whether dye had passed through the system, and the probe was to quantify dye passing through the system at 1-minute intervals. After this, dye injection into the sinkhole on the west side of William T. Young Library at the University of Kentucky occurred (Friday, July 6th, 2018). On the day of injection, flash rainfall occurred from 3:40pm to 4:00pm temporarily raising flow conditions from near base level to over 200 cubic feet per second (Figure 5). 90 grams of fluorescein dye was injected at 4:17pm into sinkhole (Figure 6). Injection was aided by 125 gallons of water from a water truck hose provided by Facility Services at the University of Kentucky. Water flow began 4:15pm and ended at 4:27pm, with injection occurring at 4:17pm. Fluorescein dye was used because preliminary testing of the predicted outflow location showed negligible levels of background fluorescein contamination. Preexisting fluorescein in the water system would affect the ability to accurately measure the rate of flow and confirm the predicted connection.

Dye was also deployed into a storm drain on the west side of the William T. Young Library at the University of Kentucky on Friday, July 6th, 2018 (see small circle

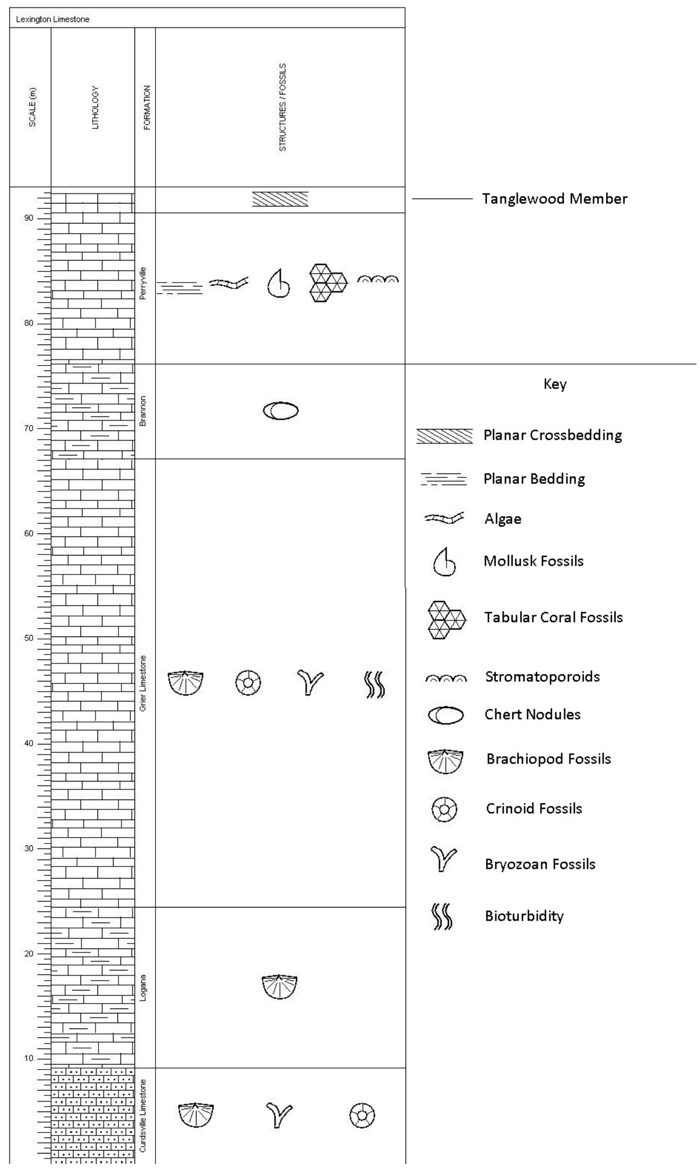

Figure 4. A stratigraphic column of the rock units and formations beneath Lexington, Kentucky (Cressman, 1973).

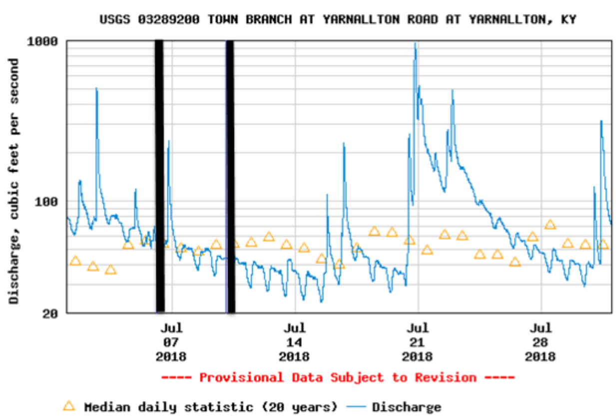

Figure 5. Precipitation measurements from July 2018. The start and end dates for the survey are denoted by black bars.

Figure 6. Fluorescein dye injection on the west side of William T. Young Library at the University of Kentucky on July 6, 2018, performed by a summer research student intern. The black circle in the background marks the location of the storm drain at the bottom of the sinkhole. The foreground ellipse denotes the sinkhole.

in Figure 6), without the aid of the water hose because sufficient water flow was observed in storm drain. 90 grams of eosine dye were poured into the drain grate at 4:30pm. Eosine dye was used in this instance because one of the purposes of this study was to test whether or not the storm drain to Wildcat culvert spilled over into the Mystery Spring.

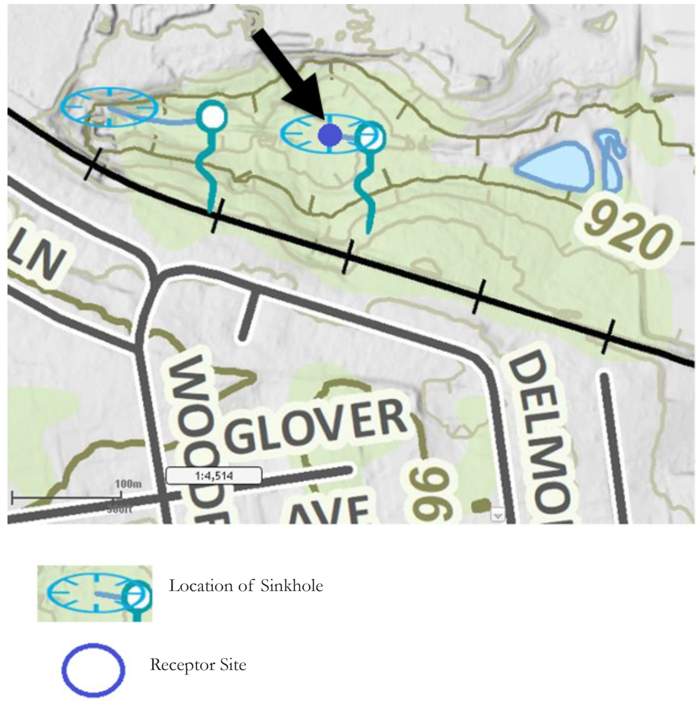

Figure 7. A map of McConnell Springs. Receptors were placed at this site (black arrow) to ensure no inter-basin spillover from Mystery Spring.

To collect dye travel time data from the sinkhole to Mystery Spring, a Cyclops 7 infrared probe was installed at Mystery Spring on Friday, July 7th, 2018. Data were also collected using activated charcoal dye receptors at designated points #1, #2, #3, and #4 at Mystery Spring, point #5 at Town Branch, and point #1 at McConnell Springs (Figures 3 and 7). Samples were collected from McConnell Springs to ensure no interbasin spillover between Mystery and McConnell Springs (Figure 8). A grab water sample was collected from sample point #5, Wildcat Culvert in Town Branch, at 6pm on July 6th, 2018, after dye was visually observed exiting Wildcat Culvert.

Cyclops readings were collected in one-minute intervals until July 8th, with the first reading measured at 11:40am on July 7th, 2018. Charcoal dye receptors at sample points #1 and #3 were collected from July 7th, 2018 through August 16th, 2018. Dye receptors were exchanged daily for three days, then sampling interval reduced to once weekly. Receptors at point #2, #4, and #5 were collected from July 7th, 2018 to July 10th, 2018. The receptor at sample point #1 in McConnell Springs was exchanged on July 7th, 2018. All collected samples were analyzed in the hydrology lab at the Kentucky Geological Survey located on the campus of the University of Kentucky using a Varian Cary Eclipse Fluorescence Spectrophotometer.

Care was taken to ensure a lack of contamination of the charcoal dye receptor packets. Surgical gloves were utilized during collection and installation of the packets and discarded after each packet was installed, and after

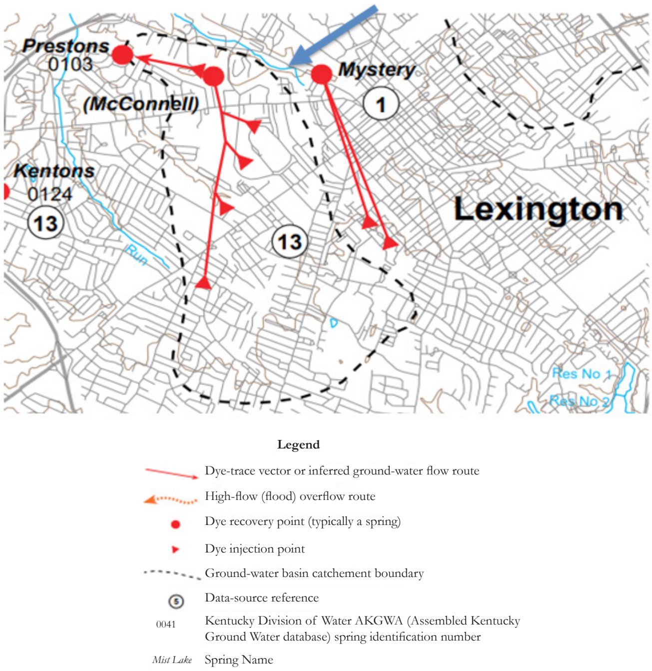

Figure 8. A section of mapped karst groundwater basins in Lexington, Kentucky, emphasizing Mystery and McConnell Springs (Currens and Ray, 1996). The blue arrow denotes Town Branch.

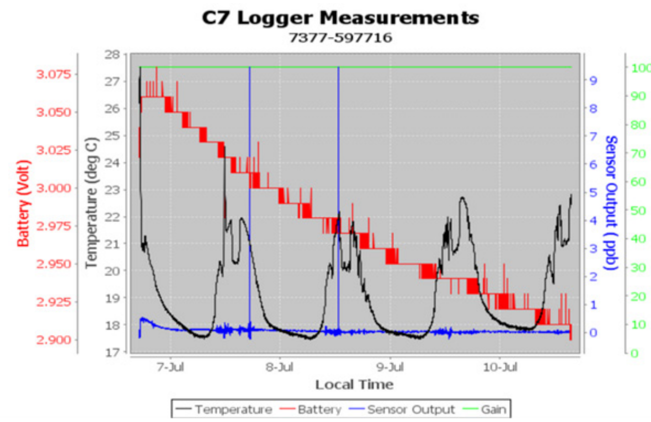

Figure 9. Probe data collected at Mystery Spring from July 7 - 10. The blue spikes are either errors or artifacts from probe removal for readings.

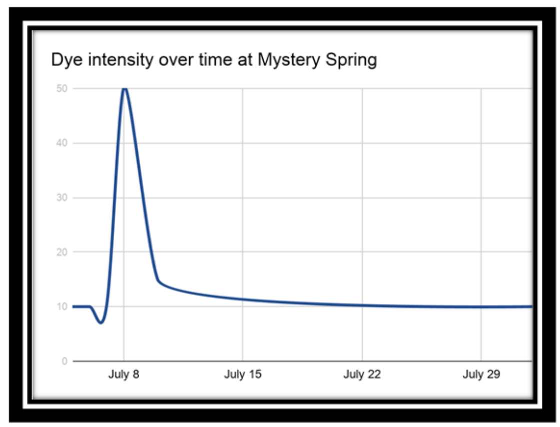

Figure 10. Dye intensity over time at Mystery Spring as measured by charcoal dye receptors and a fluorimeter at the hydrogeology laboratory at the Kentucky Geological Survey. Dye injection occurred on July 6, 2018.

each packet was collected. The individuals responsible for collecting the dye receptor packets were not involved in the testing of the packets for the presence of dye.

The parameters used in this study were similar to those used in the 1989 study. This was done in order to investigate the effect of the construction of the William T. Young Library on the groundwater flow in the area. A lack of dye in the known outflow of the sinkhole would indicate a change in the groundwater flow potentially caused by the construction of the library.

Results

Prior to the study, charcoal dye receptors were deployed for two weeks in Town Branch to test for background dye in the system. No appreciable background dye was detected. After the injection in the campus sinkhole, fluorescein dye appeared within 14 hours at Mystery Spring. Though probe data were monitored following the injection, no obvious spike in the visible spectrum, as would be produced by the presence of fluorescein dye, was detected (Figure 9). See Figure 10 for a chart outlining dye intensity over time at Mystery Spring using charcoal dye receptor data.

Eosine dye injected into the campus storm drainage visibly appeared at the dye receptor sites in Wildcat Culvert at 6pm on Friday, July 7th, 2018, which was less than two hours after injection (Figure 3).

Discussion

The study was successful in determining a connection between the campus sinkhole and Mystery Spring through charcoal dye receptors. However, lack of probe data means dye travel time information was not accurately determined from this study, though when charcoal dye receptors were exchanged on day two at 14 hours, dye had appeared. This suggests a travel time from the campus sinkhole to Mystery Spring (1.5 miles away) of approximately 9-14 hours.

As to why measurable amounts of dye were not observed by the probe, it is possible that the construction of the William T. Young Library on the University of Kentucky campus affected the flow of groundwater in the karst conduits connecting the two sites, but it is more probable that the amounts of fluorescein dye and water used at injection were not in high enough concentrations to be detected in water. Dye passed through the conduit system, but further study will be needed for accurate time of travel data. For a future study, we suggest tripling the amount of dye injected (270 grams).

Prior to the dye trace, it was communicated by Facility Services at the University of Kentucky that a connection exists between the storm drainage injection site and Wildcat Culvert, but travel time in these flow conditions had not been tested. Our results indicate that a spill on campus that travels to the storm drain could travel to Town Branch in less than two hours.

Conclusion

Karst dye trace studies are important because they provide connectivity and time of travel information that could be helpful in the event of a contaminant spill. If contaminants were to appear in Mystery Spring, without a confirmation of the origin of the springs feeding the body of water, it would be difficult to locate, contain, and purify the source of the contaminant. Therefore, due to incomplete data on travel times, and, to some degree conduit connectivity in the area, it would be beneficial to conduct further research into the groundwater flow patterns and travel times of conduits in the Lexington region.

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