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Karst Sub-basin Delineation via Dye Trace Study near Turnhole Bend, Mammoth Cave National Park

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IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR'S OF HYDROGEOLOGY

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Abstract

Establishing watershed boundaries is a critical stage in understanding the local water cycle. Drainage basins are typically identified by topographic divides; water flows to successively lower locations along the most direct path available. The karst terrain in Mammoth Cave National Park, however, presents additional challenges in identifying the boundaries of these basins. Underground drainages in the form of caves or conduits often do not correspond with surface topography. These passages can redirect water far from the most immediate surface release.

A dye trace study is designed to identify flow paths from the surface to springs along the Green River. Three surface sites were selected and injected with unique dyes. All three known springs in the area were monitored with activated charcoal filters to detect the re-emergence of dye after establishing background levels. Fluorescence analysis determines which dyes emerged at each spring.

This study seeks to establish the boundaries on a small drainage sub-basin near the Turnhole Bend area of Mammoth Cave National Park. This research will yield a higher level of resolution of hydrologic connectivity than the state-wide map from the Kentucky Geological Survey or the previous efforts of Mammoth Cave National Park.

Introduction

The Kentucky Geological Survey creates predicted boundaries for catchment basins as part of its mapping operations. These boundaries are produced after consideration of local lithology, bedding orientation, known faults, water well data, and previous dye trace results. Predicted sub-basin boundaries established by the Kentucky Geological Survey are shown in Figure 1. The predicted groundwater basins and dye traces shown in Figure 1 derive from Quinlan and Ray

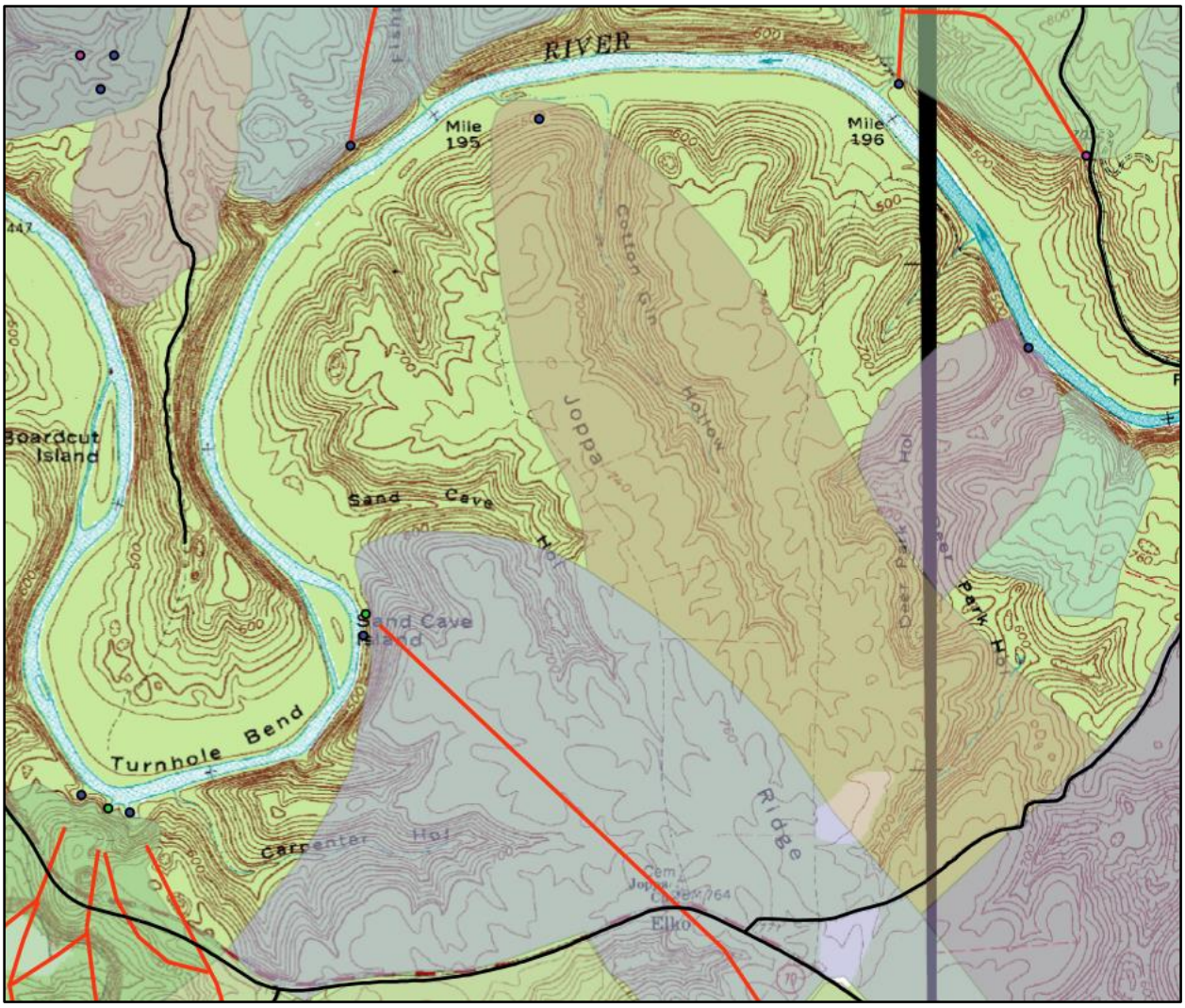

Figure 1: Drainage sub-basin boundaries established by the Kentucky Geological Survey. The large basin displayed in light blue is the Sand Cave Basin. It is the main subject of this study. Previous dye trace results are displayed as red lines. Note that the dye trace within the Sand Cave Basin is a high-flow overflow route from another large basin and does not define the extent of the basin.

(1989), Ray and Currens (1998), and Currens et al. (2011). This study seeks to identify the boundaries of the Sand Cave Basin.

Site Description

Mammoth Cave National Park is located in South Central Kentucky. The park is a globally-significant karst area. It has been deemed a UNESCO (United Nations Educational, Scientific and Cultural Organization) World Heritage Site for its outstanding displays of karst topography, cave mineralogy, and the associated species within. The cave fauna have led to the park's designation as an International Biosphere Reserve. Extensive study and exploration has led to the discovery of over 405 miles of connected cave passages, making Mammoth Cave the longest known cave system in the world.

The primary lithologies in the park are sandstones and limestones. The Ste. Genevieve and Girkin Formations, both predominantly composed of limestone, are exposed within the study site as shown in Figure 2. These two formations are the primary cave-forming units, although some passages descend into the underlying St. Louis limestone. Exposed limestones form areas of high relief within the park. Flat-topped ridges are capped by the Big Clifty member of the Golconda Formation, predominantly composed of sandstone. The presence of a resistant caprock is believed to be a significant factor in the development of exceptionally extensive cave networks like Mammoth Cave. A generalized lithology map is shown in Figure 3.

The study site is defined as the northern portion of Joppa Ridge, located east of Turnhole Bend. It is bound on the North, East, and West sides by the Green River and to the South by Smith Valley. Lee Cave is a major cave system, extending a total length of seven miles within the study

site. Several streams flow in different directions and indicate the possibility that Lee Cave is not contained within a single karst basin.

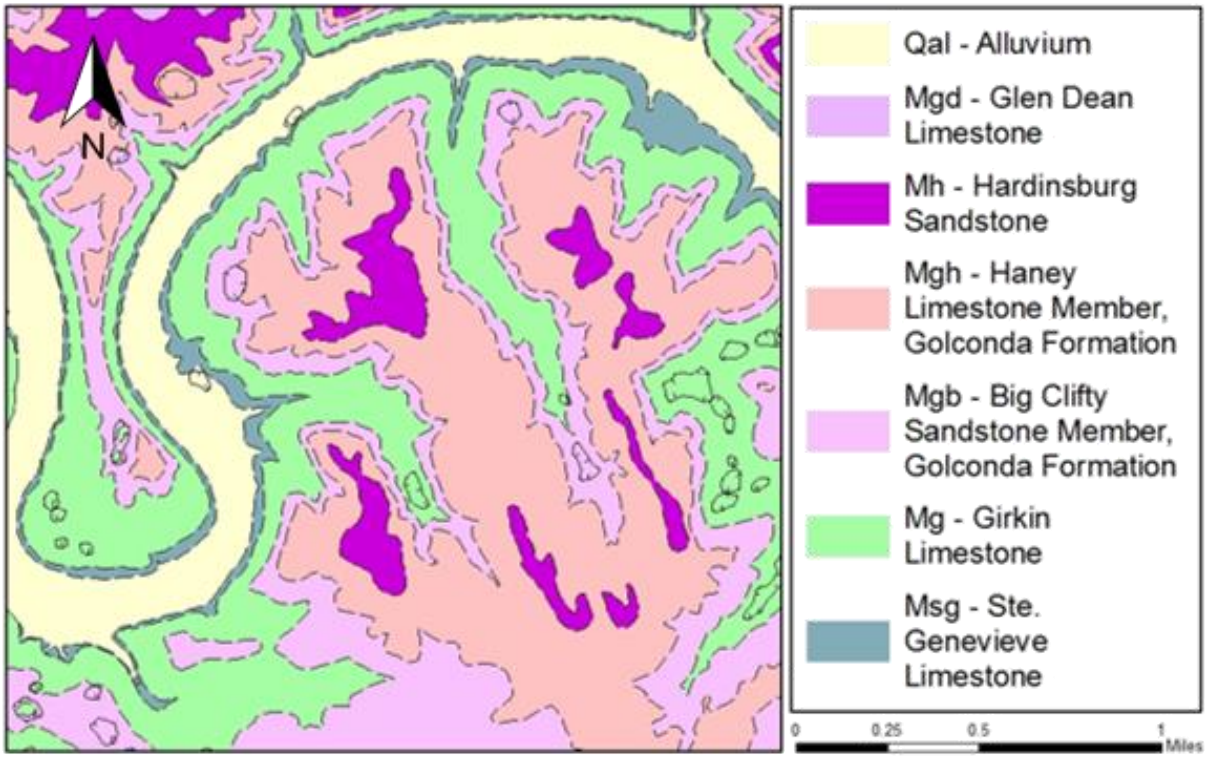

Figure 2: Surficial geology within the study site. The Girkin-Big Clifty contact was inspected for potential injection locations. Sourced from Mammoth Cave National Park GIS Library.

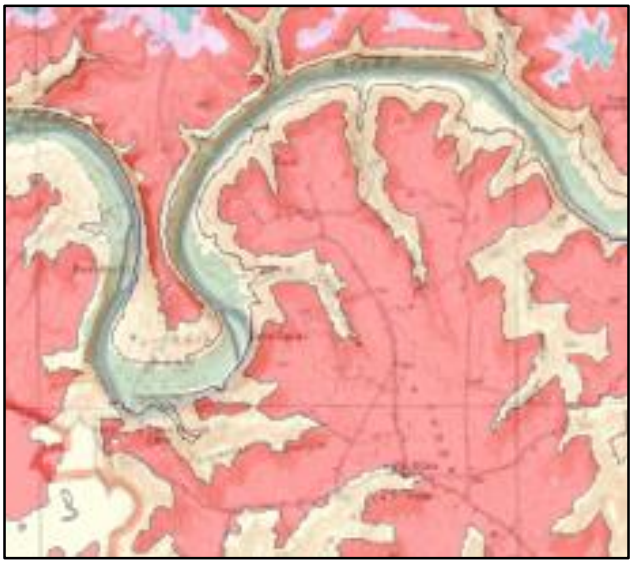

Figure 3: Topographic map with geology overlays displaying areas of sandstone cap (red and pink) and areas of exposed limestone (yellow).

Surface water outlets take the form of springs and cave entrances located along the Green River. Three prominent surface springs are known to exist in the study site (Hess 1976). These sites were confirmed and located via kayak in the current study: Hess 56, Sand Cave Spring, and Turnhole Bend.

Methods

Dye trace studies have been used to establish hydrologic connectivity between injection points and springs (Palmer 2007). This study implemented a qualitative dye trace methodology to map basin boundaries. Environmentally-safe fluorescent dyes were released into surface and cave water flows. Receptors sensitive to these dyes were placed at nearby springs. Laboratory analysis then tested for the presence of dye in the receptor as an indicator of the hydrologic connection.

Dye receptors employed in this study were produced by the Crawford Hydrology Laboratory in a dye-free environment. The fine encasing mesh consists of a fiberglass material coated in vinyl. The receptors measure two inches by four inches. Each contains approximately three grams of activated coconut charcoal. Receptors were attached to their respective sites by paper clip and nylon fishing line or polyester twine. Receptors were attached in the spring flows and exposed for approximately four weeks prior to the dye release to establish background dye levels. Nitrile gloves were used to handle receptors. Gloves were replaced between contacting new or old receptors. Receptors were collected and placed in sealed plastic bags and labelled. Samples were refrigerated if not transported directly to the Crawford Hydrology Laboratory for testing. Background dye monitoring was conducted to determine any presence of dye prior to injection. The selection of individual dyes was conducted in consultation with Crawford Hydrology Laboratory. The Active Dye-Trace List published by the Kentucky Department for Environmental Protection (KYDEP) was reviewed prior to injection to avoid conflict with other dye trace studies. KYDEP was notified of all dye injections conducted in this study.

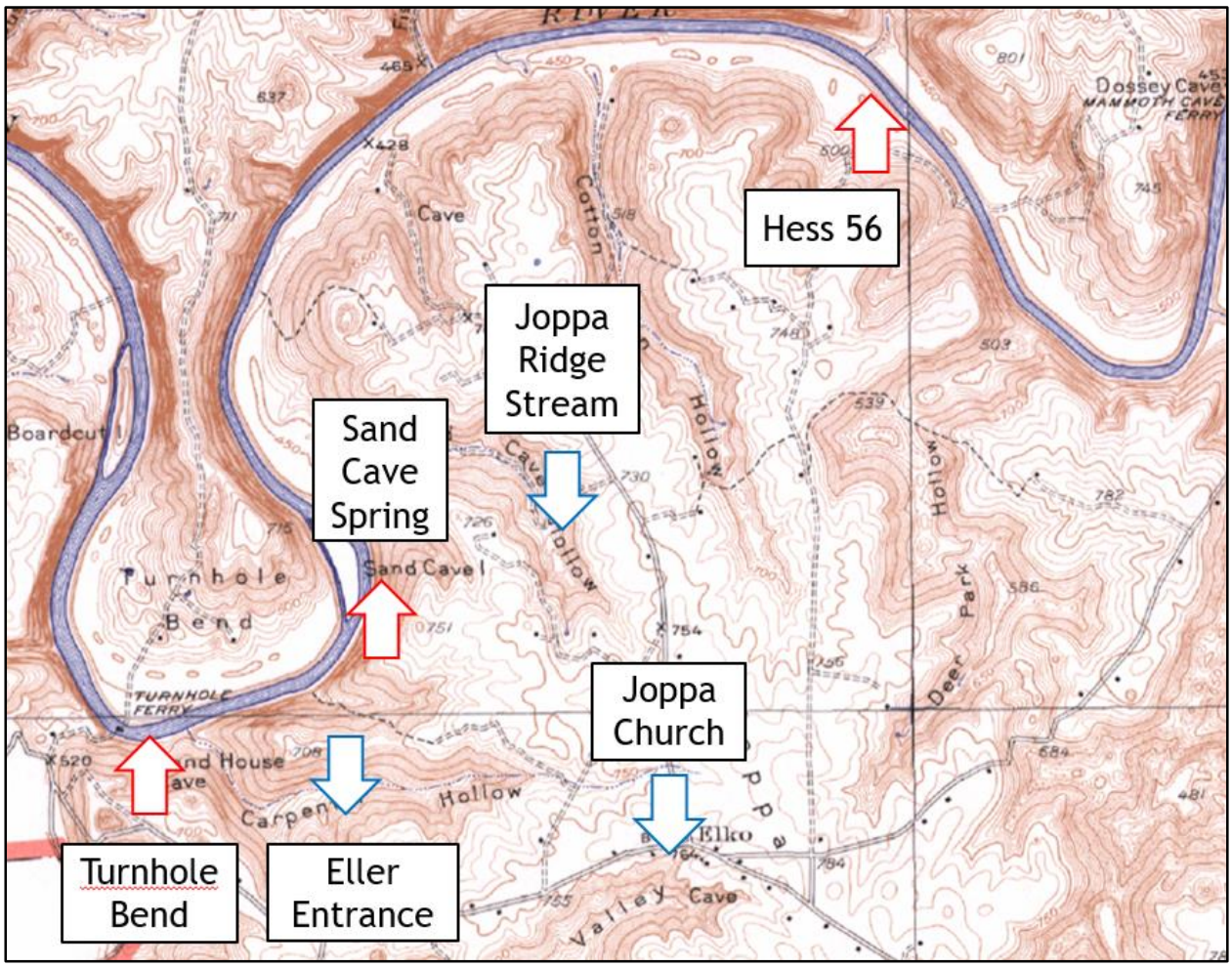

Figure 4: Graphic displaying approximate locations of injection points (blue downward-pointing arrows) and known springs (red upward-pointing arrows).

Dye receptors were collected for background analysis on 11/4/2016 and replaced on 2/10/2017. Dye injections occurred on 2/11/2017 and 2/18/2017. A solution containing 1.5 pounds of eosine dissolved in 1.5 gallons of water was released into a sinking stream on Joppa Ridge on 2/11/2017. A solution containing 2.0 pounds of fluorescein dissolved in 2.0 gallons of water was injected in a drainage culvert near Joppa Ridge Church and flushed with 1000 gallons of water on 2/11/2017. A solution containing 1.5 pounds of sulforhodamine B dissolved into 1.5 gallons of water was released into a stream at the bottom of a pit in the Eller Entrance to Lee Cave on 2/18/2017. Dye receptors were collected for analysis on 2/24/2017, 3/13/2017, and 4/13/2017.

Analysis of background dye conditions revealed detectable levels of fluorescein from Turnhole Bend. Lab results showed a concentration of 0.055 ppb (parts per billion). This was determined to be within an acceptable level for the use of fluorescein as a dye in this study. Background dye conditions were below detection limit for all other dyes used in this study: eosine, rhodamine WT, D&C Red 28, and sulforhodamine. Fluorescein was selected for injection at Joppa Church. Eosine was selected for injection at Joppa Ridge. Sulforhodamine B was selected for injection in Lee Cave.

Results

Fluorescein from the Joppa Church drainage was detected in Sand Cave Spring. Lab analysis conducted on 3/2/2017 of receptors from Sand Cave Spring detected levels of 279.583 and 237.777 ppb fluorescein. Lab analysis conducted on 3/2/2017 of receptors from Sand Cave spring detected levels of 282.603 and 310.273 ppb eosine. These traces are displayed in Figure 5.

Sulforhodamine B was not detected in any of the filters following the injection. It is believed the dye has left the cave system due to significant rainfall events. It is possible that the dye had emerged at Turnhole Bend in concentrations too dilute to be detected. The large volume of water at Turnhole Bend may also produce incomplete mixing. The placement of a dye receptor in such a location would not yield a positive trace. It is also possible that this portion of the cave drains through an unknown spring or springs submerged under the Green River. Any springs of this nature, if they exist, were inaccessible and were not accounted for in this study.

Conclusions and Discussion

Two positive traces were established. Water from the Joppa Ridge and the Joppa Church injection sites drain to the Green River at Sand Cave Spring. This connectivity is representative of base flow conditions. Sulforhodamine B injected at the Eller Lee Cave entrance was not detected at any spring in the two receptor exchanges following dye injection. These results confirm the predictions made by the Kentucky Geological Survey. There is no suggested revision of the boundaries.

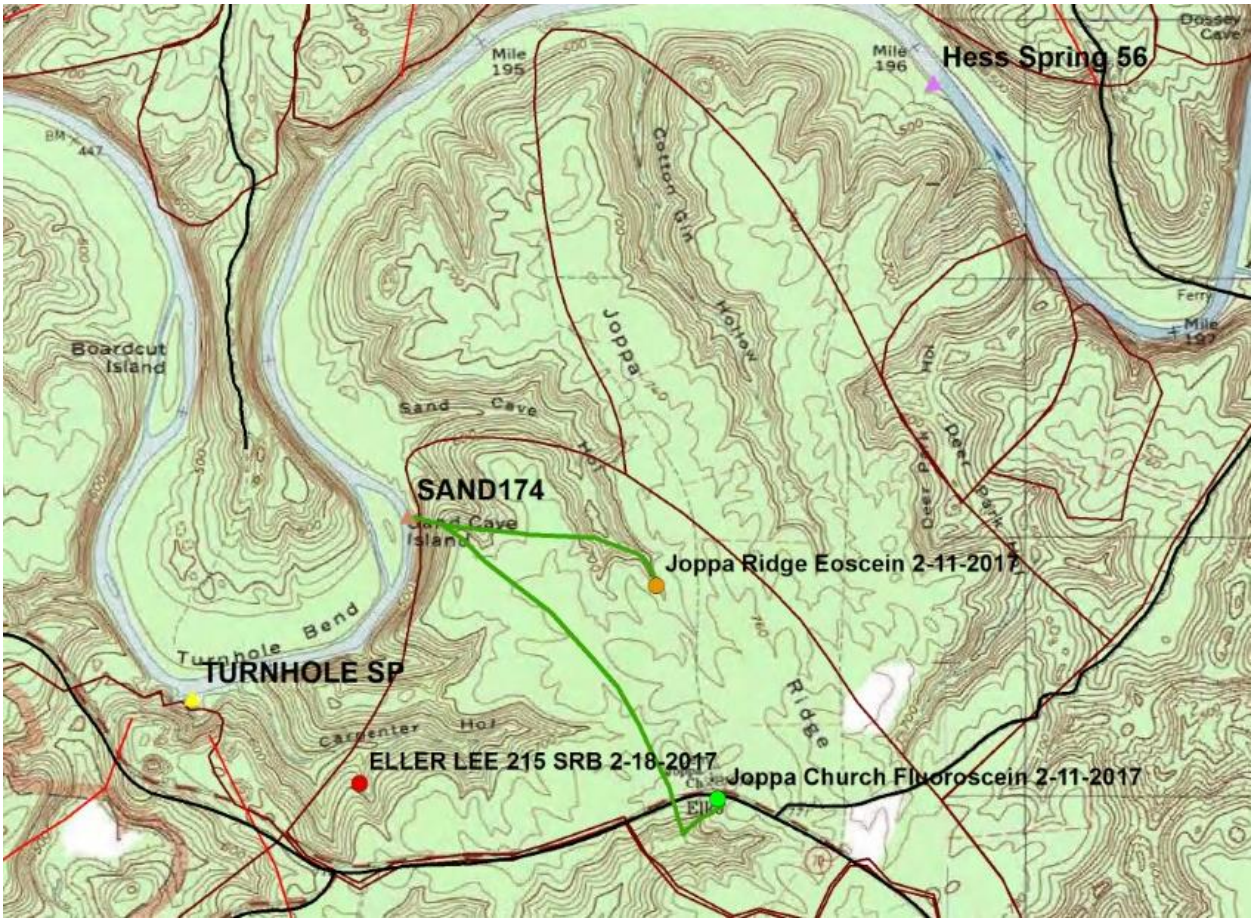

Figure 5: Project results. Brown lines represent predicted sub-basin boundaries. Green lines indicate dye flow paths of positive dye traces established through this project.

Future Work

A renewed dye trace could be conducted with an additional injection of dye at the Eller entrance to Lee Cave. A new background analysis is necessary before resuming any dye traces in the area. Sulforhodamine B is a permissible dye candidate at the Lee Entrance injection site because any remaining sulforhodamine B from this study was released at this site. Quantitative dye traces may be conducted from the Joppa Church and Joppa Ridge injection sites because base flow connectivity to Sand Cave Spring has been established.

Crawford Hydrology Lab *

* *Hydrogeologists, Geologists, Environmental Scientists* *
* *Karst Groundwater Investigations* * *Fluorescent Dye Anal*

LABORATORY REPORT SHEET

FLUORIMETRIC ANALYSIS RESULTS

Turnhole Bend Dye Trace

Analysis requested by:

Jake Tholen

FLUORESCEIN	EOSINE	SULPHORHODAMINE B
Color Index: Acid Yellow 73	**Color Index:** Acid Red 87	**Color Index:** Acid Red 52
Dye Receptor: Activated Charcoal	**Dye Receptor:** Activated Charcoal	**Dye Receptor:** Activated Charcoal
Analysis by: Spectrofluorophotometer	**Analysis by:** Spectrofluorophotometer	**Analysis by:** Spectrofluorophotometer

Charcoal Samples

						FLUORESCEIN PQL in Eluent: 0.005 ppb; PQL in Water: 0.010 ppb; λ in Eluent: 517.4 nm; λ in Water: 510.7 nm			EOSINE PQL in Eluent: 0.005 ppb; PQL in Water: 0.010 ppb; λ in Eluent: 541.3 nm; λ in Water: 536.2 nm			SULPHORHODAMINE B PQL in Eluent: 0.005 ppb; PQL in Water: 0.010 ppb; λ in Eluent: 579.6 nm; λ in Water: 583.5 nm			
Lab ID	Event	Date Collected	Feature Name	TIME	Peakfit	Results	Conc in ppb	Peak Center (nm)	Results	Conc in ppb	Peak Center (nm)	Results	Conc in ppb	Peak Center (nm)	Comments
EL-001-0	BG1	11/04/16	SAND CAVE SPRING #1	1535		ND			ND			ND			
EH-001-0	BG2	02/10/17	SAND CAVE SPRING #1	-		ND			ND			ND			
EH-001-0	03	02/24/17	SAND CAVE SPRING #1	1100	x	+++	279.583	517.5	+++	282.603	540.6	ND			
EH-001-0	04	03/19/17	SAND CAVE SPRING #1	1200		+++	91.722	517.3	+++	60.678	541.6	ND			
EH-001-0	05	04/13/17	SAND CAVE SPRING #1	-		+++	5.525	517.6	+++	7.789	541.2	ND			
EL-003-0	BG1	11/04/16	TURNHOLE BEND #1	1615		IB	0.055	514.2	ND			ND			
EH-003-0	BG2	02/10/17	TURNHOLE BEND #1	-		ND			ND			ND			
EL-003-0	03	02/24/17	TURNHOLE BEND #1	1045		ND			ND			ND			
EL-003-0	05	04/13/17	TURNHOLE BEND #1	-		ND			ND			ND			
EL-003-0	04	03/19/17	TURNHOLE BEND #1	1100		ND			ND			ND			
EL-004-0	BG1	-	HESS 56 #1	-		ND			ND			ND			
EH-004-0	03	02/24/17	HESS 56 #1	1120		ND			ND			ND			
EH-004-0	04	03/19/17	HESS 56 #1	1315		ND			ND			ND			
EH-004-0	05	04/13/17	HESS 56 #1	-		ND			ND			ND			

Approved by: L. Bledsoe **on** 05/18/17

Comments:

IB = Initial Background
B = Background (<10 times background or lowest detection limit)
POR = Peak Out of Range (>5nm, <10nm from dye peak center)
ND = No Detection
NPI=No Peak Indicated
EL - Eluent Low- High Sensitivity Scan
EH - Eluent High- Low Sensitivity Scan

\+ = Positive (10 times background or lowest detection limit)
++ = Very positive (100 times background or lowest detection limit)
+++ = Extremely positive (1000 times background or lowest detection limit)
?+ = Questionable Positive, needs two hits in a row to equal +
Q = Lab Duplicate
QA = Quality Assurance/Quality Contol Laboratory Dye Standards
PeakFit Utilized (Statistical Analysis Peakfitting Software)

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