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

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Karst Sub-basin Delineation near Turnhole Bend, Mammoth Cave National Park

Jake Tholen

IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
BACHELOR’S OF HYDROGEOLOGY

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Dr. Patricia Kambesis
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Lee Honors College
Department of Geosciences
Western Michigan University
Kalamazoo, Michigan
May 2017
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.
(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
Several streams flow in different directions and indicate the possibility that Lee Cave is not contained within a single karst basin.

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.
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.

Figure 4: Graphic displaying approximate locations of injection points (blue downward-pointing arrows) and known springs (red upward-pointing arrows).
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.
| Date       | Time | Temperature | pH | Conductivity | Alkalinity | TDS | Calcium | Magnesium | Sodium | Chloride | Potassium | Turbidity | Fluorescence | Suspended Solids
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References


