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JeTara Brown
*Tennessee State University*, jtlbrown@yahoo.com

Thomas Byl
*Tennessee State University, United States Geological Survey*

Rick S. Toomey
*Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park*, rick_toomey@nps.gov

Lonnie Sharpe Jr.
*Tennessee State University*

# Quantitative Dye Studies to Evaluate the Spill Response System for Mammoth Cave National Park


JeTara Brown[1], Thomas Byl[1,3], Rickard S. Toomey, III[2], Lonnie Sharpe, Jr.[1]

[1] Tennessee State University
[2] Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park
[3] United States Geological Survey


## Introduction

Mammoth Cave National Park is located in south-central Kentucky (Figure 1) has been designated an International Biosphere Reserve since 1990. The Park is home to the world's largest cave with over 400 miles of passages and a cave ecosystem that is linked to the surface through groundwater recharge. Groundwater quality in the Mammoth Cave region of Kentucky is critical to the cave's ecosystem, tourism, and the health of the Green River. Despite its vulnerability, groundwater is used as a vital resource to many communities around the world, including the United States. In fact, ground water is used as a source of water supply by about one-half the population of the United States. An estimated 11 percent of karst springs in Kentucky are used for domestic water supplies. This means over 10,000 homes rely on groundwater as their water supply source. These people have a critical interest in protecting the quality of the water they are drinking. Mammoth Cave National Park itself has a biodiversity of 43 mammals, 15 reptiles, 19 amphibians and 3 fish which all rely on the groundwater for survival.

The National Park Service controls the main part of the cave and encourages tourism while protecting the unique and fragile ecosystem in the cave. With over 500,000 visits per year, it is natural for accidents and spills to occur on the surface. Spills commonly come in the form of parking lot runoff due to the transport of auto diesel fuels through stormwater flow and broken sewer lines. Hence the Park's concern for maintaining high quantity contaminants from spills or wrongful release of chemicals. Therefore, it is important to develop a system that prevents the pollutants from harming the fragile cave ecosystem. Unfortunately, the same hydrogeologic processes that formed the cave makes the karst system vulnerable to contamination. Many of the natural storm-drainage flowpaths go directly to distinct sinkholes rather than the filters.

## Resource Management Incidents

On May 27, 2014, a sewer line break occurred on Mammoth Cave Parkway near Green Ferry Road. According to Mammoth Cave National Park's After Action Report, the accident was caused by the failure of


**Figure 1:** Map of Mammoth Cave National Park

a two-inch brass ball valve. The ball valve failed when repairs were being made to resolve a much-smaller sewer leak that resulted from an air-relief valve that failed to shut properly. The air relief valve failure caused a small level of sewage spillage, and then the subsequent ball valve failure resulted in an initial sewage geyser that spouted approximately 20-30 feet high for a short period and then became a steady flow at ground level for over one hour before a repair was made. The Caveland Environmental Authority (CEA) employees and park employees responded by capping the geyser and placing check dams along the flow path. According to the CEA, approximately 5,000 gallons of sewage was spilled and that about 3,000 gallons were recovered.

In addition, a second sewage spill occurred at the same location on April 28, 2015 there was only steady flow of sewage detected. The cause and amount of sewage released has yet to be identified, but it is assumed to have been flowing for a long period of time. The need for containment basins within the park has increased. It is well known that preventing contamination of the groundwater is preferable to remediation. Therefore, the objective of this study was to measure the effectiveness of temporary check dams used to impede transport from a surface sewer leak into the cave.

## Methods and Results

Three quantitative tracer studies were conducted from August 2014 to January 2015 to test the effectiveness of the check dams. The presence and absence of two temporary check dams constructed with pea-gravel were the main variables in the studies. Check dams are relatively small, temporary structures constructed across a swale or channel that are typically constructed out of gravel, rock, sandbags, logs or treated lumber, or sediment retention fiber roll. Check dams can be temporary or permanent structures. Check dams are used to slow the velocity of concentrated water flows, a practice that helps reduce erosion. As stormwater runoff flows through the structure, the check dam catches sediment from the channel itself or from the contributing drainage area. A check dam either filters the water for sediment as it passes through the dam or retains the water, allowing the sediment to settle while the water flows over the dam. Multiple check dams, spaced at appropriate intervals, can be very effective. They are most effective when used with other stormwater, erosion, and sediment-control measures.

For the first test on August 31, 2014 (Figure 2), the rainfall depth was a 2.4 inch rain event. Two check dams were still in place along the surface flow routes. There was a tracer breakthrough in the cave 10 hours after the dye was released. Sixteen hours after the time of the release, approximately half of the recovered dye (center of mass) had moved past the monitoring station at Cataracts. The total amount of dye accounted for was approximately 4 mL out of the 180 mL released, which is less than 3% of the tracer used in this study. These results indicate that the dams did a great job retaining most of the dye on the surface despite the heavy rain.

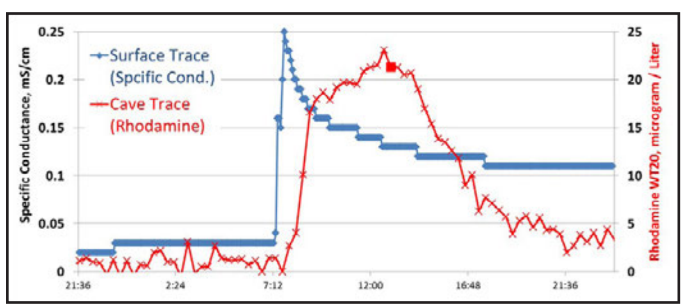


**Figure 2:** Breakthrough Curve for Test 1 conducted August 31, 2014

The second test (Figure 3) was initiated on the evening of October 13, 2014 during a 2.1 inch rain event. Both check dams had been removed for this study to estimate the amount of time it would take for the dye to reach the cave with no obstacles. The breakthrough and center-of-mass were calculated from the results. Breakthrough in the cave occurred 4 hours after the dye was released. The center of mass occurred 10 hours after the release time. The total amount of dye accounted for via concentration and discharge was 262 mL out of the 600 mL released (43%).

During the final tracer test on January 3, 2015 (Figure 4), the rain depth was 0.7 inches. Due to timing, the release of tracer was on the tail end of the storm instead of the rising limb like the other two tracer tests. Breakthrough in the cave occurred only 50 minutes after the time of release. The center of mass was determined to be 15 hours after the time of release. The maximum tracer amount recovered was 288 mL of dye which was 48% of the total amount of dye released.

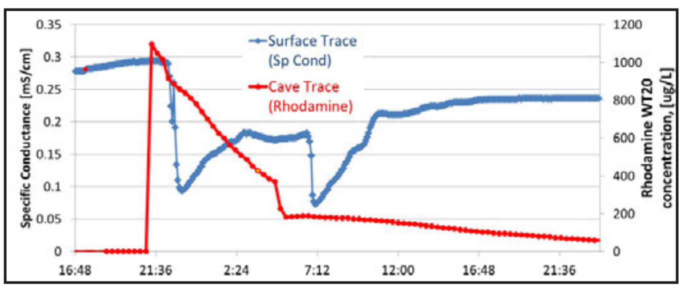


**Figure 3:** Breakthrough Curve for Test 2 conducted October 13, 2014

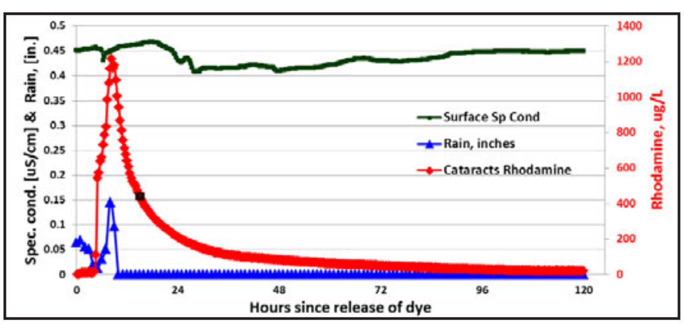


**Figure 4:** Breakthrough Curve for Test 3 conducted January 3, 2015

## Conclusions

Based on these results, we can conclude that the dams increased mean residence time on the surface from approximately 0.83 to16 hours, providing management more time to implement waste recovery. The dams also reduced the quantity of dye entering the cave by 90%. Temporary check dams provide emergency responders with an effective way to impede contaminants from entering the karst groundwater system at Mammoth Cave National Park. The dams are also aesthetically neutral for tourists, seeing that they are not overbearing to where they disturb the natural beauty of the surrounding environment. The limestone pea gravel used in the design is a natural material indigenous to the area geology, blending into its surroundings. More work needs to be done to identify and highlight surface to cave connections using GIS to anticipate sinkholes that are at risk of contaminants. One would also need to continue to test the dams to better understand the life expectancy. In the meantime, monitoring of the site and dam maintenance should be conducted continuously to retain effectiveness.