The Misbehaving Spring: Studying Unique Underground River Flow Patterns with Advanced Middle School Science Students

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Abstract
Scientists have long known that the spring for one of Mammoth Cave's primary underground rivers will sometimes "misbehave." This "misbehavior" takes the form of a stable reverse flow pattern that brings surface water into the cave instead of taking cave water out to the surface. Although interesting, little research has been conducted on this phenomenon, or its possible impacts to the cave ecosystem. In 2009, the Mammoth Cave International Center for Science and Learning and a local middle school science class embarked on a research project that monitors the unique flow pattern of this underground river and its spring. This paper presents a case study of that project and includes information about developing the project with the students, the students' surprising discoveries, and things we learned along the way. We also offer suggestions, based on our experiences, for others interested in working with students to conduct research.

Introduction
Mammoth Cave is the world's longest cave and is the center of one of the world's most highly studied karst regions. However, even with the intense scientific research that has occurred there, Mammoth Cave still holds many mysteries. The River Styx, one of the cave's major underground rivers, is one example of those mysteries.

Under normal circumstances, the River Styx flows underground to the River Styx Spring, through the River Styx Spring, and to the surface, where it joins the Green River (Figure 1, a). Herein is the mystery—sometimes the River Styx will flow backwards. When this happens, surface water from the Green River enters the spring and flows into the River Styx causing it to flow backwards and jump the drainage divide between it and Echo River, another underground river. The water then flows out Echo River Spring, and back into the Green River (Figure 1, b). This reverse flow pattern is a stable one, and appears to be tied to the level of the Green River. Scien-

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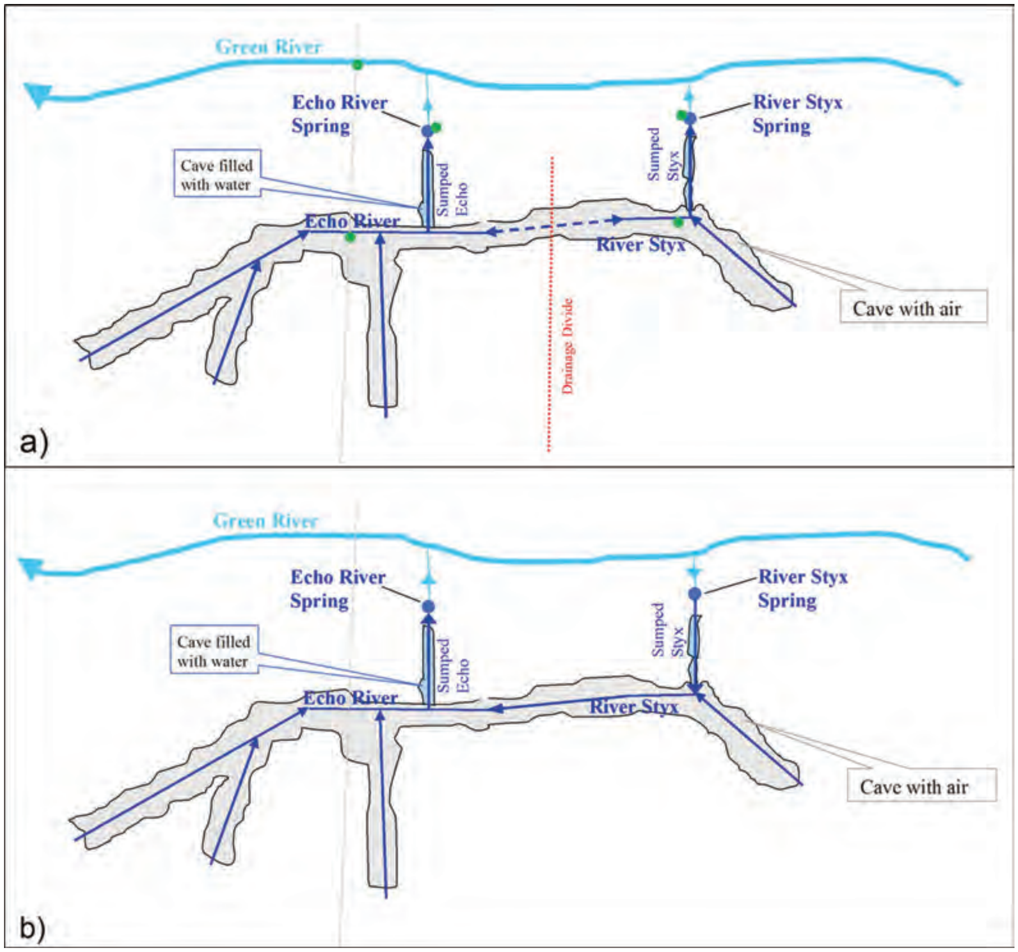

Figure 1. The River Styx flowing in its normal direction (a) and in its reverse flow pattern (b). The green dots in Figure 1a show the locations of the data loggers associated with this project. The drawings are diagrammatic only and are not made to scale.

tists have known about this phenomenon for decades, but have conducted very little research on it.

In the summer of 2009, Ms. Kim Weber, TK Stone Middle School's seventh grade science teacher, contacted the Mammoth Cave International Center for Science and Learning (MCICSL). She was interested in opportunities for her students to conduct research at Mammoth Cave National Park. MCICSL staff suggested the River Styx's reverse flow pattern as a potential study subject. A full understanding of the mysteries behind the River Styx's reverse flow pattern will likely encompass complex geological and hydrological studies. However, even basic information, such as the minimum and maximum water temperatures for the River Styx, or the frequency and duration of the reverse flow pattern, is unknown.

Because most of Mammoth Cave, including its underground rivers, remains a relatively constant temperature year-round, the students could easily begin gathering data on the frequency and duration of the reverse flow patterns by monitoring the water temperature in the River Styx. Under normal flow conditions, the River Styx's water temperature, like the air temperature in the cave, should remain relatively stable throughout the year. However, when the River Styx is in its reverse flow pattern, the Green River brings warm surface water into the cave during the summer, or cold surface water into the cave during the winter. Water temperature, therefore, could serve as a proxy during most of the year for determining which direction the River Styx was flowing. Also, since the students would be monitoring water temperature to determine flow direction, they could easily use that data to determine the minimum and maximum water temperatures during their study period.

Although this basic information is only a small piece of the puzzle, it is a piece that the students could tackle, and one that could provide a valuable starting point for future, more complex studies. Ms. Weber and MCICSL staff were especially excited about this research topic because it meant that the students would be conducting real scientific research, and would be at the forefront of research on the topic. Resource managers, scientists, and educators would all be learning about the reverse flow pattern alongside the students. The students' work has generated a considerable amount of excitement among people interested in Mammoth Cave, and the hydrology of the Mammoth Cave drainage basins.

Materials and methods

In late summer 2009, Ms. Weber, Ms. Trimboli, Education Program Specialist at MCICSL, and Dr. Toomey, Research Director at MCICSL, applied for and received a research permit from Mammoth Cave National Park. This is an ongoing research project and is currently in its second year. The students have been involved in all aspects of the research, including data collection in the field, analyzing the data in the classroom, and presenting their results.

When school began in the fall of 2009, Ms. Weber and Ms. Susan Ryan, TK Stone's Coordinator for Gifted Education, identified the incoming seventh grade students who were considered either gifted or high achieving in science. MCICSL staff went to TK Stone to meet the students and introduce them to the project. The students were divided into two groups, and each group was scheduled to visit the park to work on the project. A similar process was repeated in the fall of 2010 when the next set of incoming seventh grade students arrived.

The field research began in October 2009 when the students arrived to install five sets of HOBO waterproof data loggers. One set of data loggers was installed at each of the following locations: the River Styx (in cave), River Styx Spring (surface), Echo River (in cave), Echo River Spring (surface), and the Green River (surface) (Figure 1, a). Each set of data loggers consisted of two identical data loggers that served as backups for each other. Before being deployed, the data loggers were programmed to record water temperature once every two hours.

Each year the students visit Mammoth Cave two to four times to download data from the data loggers. MCICSL staff accompany the students, assist them with any necessary maintenance to the data loggers, and convert the data into an Excel spreadsheet after returning from the cave. MCICSL staff then visit TK Stone Middle School to teach the students how to use Excel for data management, graphing the data, and visually analyzing the data (Figure 2). Later the students analyze the data, draw conclusions from their results, and present their findings to classmates, students at other schools, community members, and professional audiences.

Results

Data analysis is ongoing, and all results are considered preliminary. However, the students' research has resulted in some surprising findings. Echo River (in cave) remains a relatively constant 13.5 to 14.5°C year-round, while the water temperature in River Styx (in cave) varies greatly. The students have recorded temperatures in River Styx as low as 3.6°C and as high as 20°C. These are much greater temperature extremes than resource managers and scientists would have predicted. The River Styx also appears to go into its stable reverse flow pattern more frequently than previously suspected.

Conclusions

Everyone involved with this project believes it is highly beneficial from both scientific and educa-

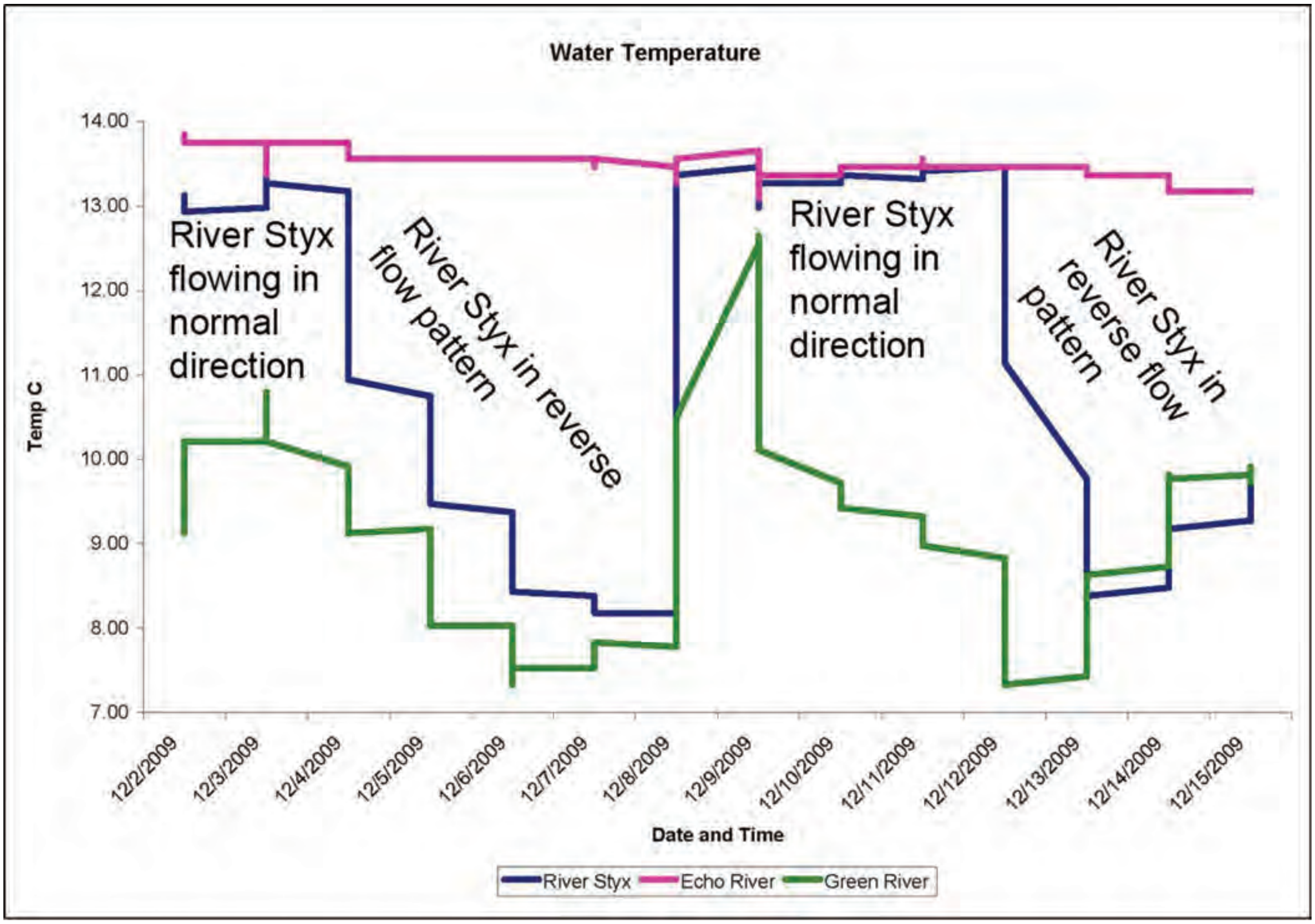

Figure 2. Graph of River Styx (in cave; blue line), Echo River (in cave; pink line), and Green River (surface; green line) water temperatures during a two week period in December 2009. Annotations are provided on the graph to show how the students visually interpret the data by comparing the River Styx water temperature to that of the Green River and Echo River.

tional viewpoints. Scientifically, the project is important because the changes in water temperature associated with the River Styx's reverse flow pattern could impact geological, archeological, and biological resources found within the surrounding cave passages. Also, as precipitation patterns are altered due to climate change, the frequency and duration of the reverse flow patterns will likely change. The students' data provide resource managers and scientists a baseline against which future changes can be compared.

Educationally, the project is important because the students involved don't just learn about science, they become scientists. Through this project, they learn to think and act like researchers. They learn that in real research, things don't always work out as planned. Through their research the students learn valuable critical thinking, technology, public speaking, and leadership skills.

We look forward to continuing this project; however, no project is without its challenges. Below is a discussion of some of the challenges we have run into, lessons we have learned along the way, and suggestions we would make to others considering starting a research project that includes students.

Challenges

Limited time. The students can only come to the park a few times a year, and only for a few hours at a time. We have to work around school schedules, testing dates, snow days, etc. They also have limited time for data analysis in their classrooms. Of course, we always want more time and think about how much more we could do if we only had it. However, much can be done in a limited amount of time so the lack of more time shouldn't be used as an excuse for not doing a project.

Fieldwork logistics. The students are conducting real scientific research and collecting real data, and thus have to deal with the challenges that come with fieldwork. This can be a new experience for them. Each spring, the students have hiked two miles into the cave to find that Echo River was flooded, and they were not going to be able to download the data. Instead, MCICSL staff would have to come back later and gather the data for the students. Major floods have washed away data loggers and summer droughts have left the data loggers hanging in midair instead of in the water. It can be tempting to try and "fix things" for the students, but learning that fieldwork is not always easy, that it comes with unique challenges, and that scientists have to learn how to deal with those challenges, are important lessons. It also ensures that the project remains a real research project, instead of becoming more of a controlled science experience.

Lack of funding. Initially, Ms. Weber obtained a grant from Dow Corning to purchase five data loggers. Mammoth Cave National Park loaned the project five additional data loggers, so that each site could have a pair of data loggers. We are currently seeking additional funding to replace some of the original data loggers, and potentially expand the project.

Lessons learned

Always allow extra time. Everything takes more time than expected. As we walk to our field sites, we encourage the students to observe their surroundings and ask questions. The students love the fact that we will stop and talk about the things in which they are interested, and they always have lots of questions. It is common for us to take over two hours to hike two miles, and then make the return trip in 45 minutes. It is evident that the students remember what we talked about, because students that come later in the year eagerly ask about things that earlier groups of students saw on their trips. This shows us that the extra time we spend with the students is time well invested.

Expect a lot from the students; they'll live up to your expectations. We give the students ownership of the research project, and involve them in all steps of the scientific process. If they arrive at Mammoth Cave in "field trip mode," we simply remind them that they are there as scientists and researchers, not students, and there is an immediate change in behavior and attitude. When they return to the classroom, they become the leaders as they share their experiences and research with the rest of the seventh grade science students. In addition to the science, math, and leadership skills that they gain through this project, the students also gain technology and public speaking skills through virtual presentations to students at other schools, and through attending and presenting at professional conferences.

Maintaining good communication is important. This point is true for any project, but becomes even more important for conducting research with students. It is important to make sure that park and school administration knows what the students are doing, what they are finding, and even the "just cool, fun stuff" associated with the project. Also, since MCICSL staff are at Mammoth Cave more often than the students, MCICSL staff pass information along to the teachers (and thus to the students) about interesting observations made when the students aren't able to be there to make the observations themselves. The teachers have also set up an online discussion site for the students. Using a Moodle interface (similar to the Blackboard interface used by many universities), the students are able to read comments and discussions from previous students, discuss the research and other interesting things they encountered during the field work, and share pictures. The teachers have also posted related articles and videos for the students to read and watch.

Drop the jargon, sometimes. We are working primarily with gifted students who often enjoy learning new vocabulary. However, like anyone else, they can become bored if we use too many technical terms or use them too often. We try to create a balance between challenging them with technical terminology (like "hydrology") and using less technical words or phrases that convey the same meaning (like "how the water flows"). Sometimes even substituting words like "mysteries" or "puzzles" for words like "scientific investigations" and "research" can make the project more appealing and "fun-sounding" for the students. This lesson is probably more important for students who may not be as interested in new vocabulary words.

Have fun! Probably the most important lesson of all is to simply have fun! If you are having fun, then the students will too. Allowing the students to discover that they can have fun while learning and conducting research is probably the most important lesson they can learn.