GOING Underground

A field investigation and lab activity on karst topography and water systems

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Students learn science best with activities that mirror the way scientists work (Donovan and Bransford 2005; NRC 1996). This article describes how geologists investigate groundwater flow systems in areas of karst topography—geologic formations shaped by dissolving bedrock—and provides a way for students to replicate this research. Students also use electric current to model water currents and map unseen flow routes.

Groundwater: An important resource

The water cycle is commonly discussed in life science, Earth science, and environmental studies. Unfortunately, within the water cycle, the process of water infiltration and underground flow is often given scant attention (Ben-zvi-Assarf and Orion 2005).

From 25 to 30% of all freshwater is stored underground as groundwater (Alley, Reilly, and Franke 1999; USGS 2011); its volume greatly exceeds the amount of water in surface streams, rivers, and lakes. Studying groundwater movement helps us understand an area's geology and identify important environmental concerns such as water supply sources at risk from polluters. For students, investigating the behavior of local underground streams—particularly those involving karst topography—can help promote meaningful learning.

The work of scientists

Acquiring informed observations

Scientists need background information to examine a scientific phenomenon. Otherwise, they can't distinguish what observations are relevant, tangential, or unconnected. For example, knowledge of karst systems, which are found in almost all 50 states (Figure 1), helps scientists know where to look for the telltale geologic features:

- swallow holes or sinks (any place where water goes underground),
- sinkholes (closed depressions in soil or bedrock that are formed by the erosion and transport of Earth material from below the land surface and drain to the subsurface),
- sinking streams (a stream that disappears underground),
- springs (where water emerges from the subsurface), and
- caves (formed where water has dissolved bedrock).

FIGURE 1

Karst regions in the continental United States.

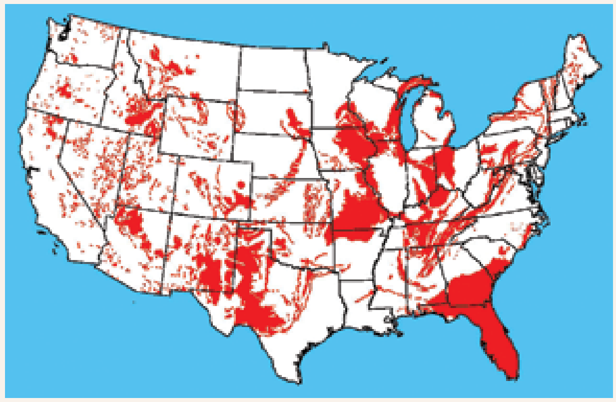


IMAGE COURTESY OF THE NATIONAL ATLAS OF THE UNITED STATES, UNITED STATES GEOLOGICAL SURVEY

In karst, networks of underground conduits largely replace the typical patterns of drainage from surface streams found elsewhere. Circulating groundwater enlarges fractures in the bedrock, slowly dissolving limestone and other carbonates and forming networks that can be extensive and highly complex. Large conduits, known as *caves,* represent only a small portion of the total network (Alley, Reilly, and Franke 1999; AGI 2001).

Asking testable questions and hypothesizing

To examine a specific karst system of interest, scientists often start with topographic and geologic maps depicting sinkholes, springs, or structural features (e.g., faults) that guide groundwater flow. They plan for extensive fieldwork, since many karst features aren't shown on maps. During this initial process, testable questions emerge such as

- What is the most likely direction for groundwater flow?
- Which sinkholes and springs are connected?
- Which of these sinkholes and springs are geographically close but internally disconnected, and how might this relate to bedrock structure?

After identifying where water sinks and sources are, scientists can develop tentative predictions of their underground connections. They can hypothesize that one or more sinks are somehow connected with one or more springs downstream. This leads to a series of tests to eliminate various possibilities.

Testing the hypothesis

In karst, much of the drainage is not directly observable, so scientists often trace groundwater flow routes using water-soluble organic dyes. These dyes can be detected even when diluted and are easy to handle, inexpensive, and nontoxic. Some of the most commonly used dyes are fluorescein, eosine, and sulphorhodamine B (SRB), which all have unique fluorescence signatures.

To test his or her hypothesis about the flow route, a scientist places charcoal-based dye receptors (dye-traps) at each possible destination (i.e., all springs and surface streams in the vicinity) (Figure 2). Then, he or she pours a small quantity of concentrated dye into the sinkhole or sinking stream. (**Safety note:** Indirectly vented chemical-splash goggles, gloves, and aprons are required when using these dyes.) Different dyes can be used to make simultaneous traces from different locations. If the site has no in-flowing water, the scientist adds about 1,000 liters of water from a hose or truck-mounted water tank. The dye-traps are then left in place for one or two weeks (Aley 2002).

CAUTION

About karst.

Karst topography can be found throughout the United States. Over time, the dissolution of soluble rock (e.g., limestone) produces complex underground drainage networks. Sinkholes, springs, and caves are common features.

Groundwater flow in karst aquifers—the saturated zone beneath the water table—generally follows subterranean pathways of converging conduits, much like the tributaries of surface streams. A karst conduit is an enclosed channel or tunnel of varying size and length that readily allows the flow of groundwater. Using electricity to model karst conduit flow is appropriate because both electricity and water tend to follow routes of least resistance (see "In the laboratory," p. 55).

FIGURE 2

Charcoal-based dye-trap.

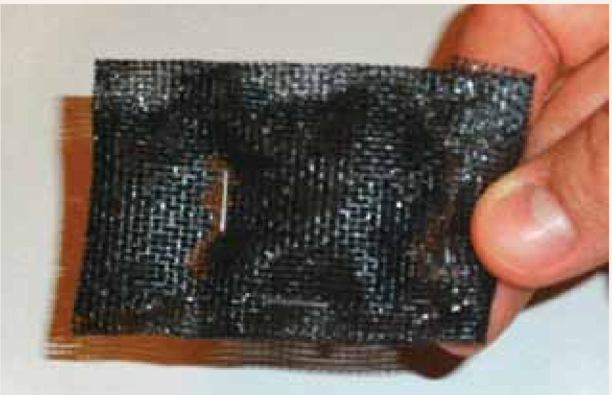


PHOTO COURTESY OF J. DRUEN

Analyzing the data

To confirm or reject the hypothesis that two points within an underground water system are connected, scientists must obtain evidence that the dye is discharged from a particular spring. In the lab, dye is extracted from the dye-traps with a solvent. The solvent is poured into a test tube and placed within a spectrofluorophotometer, which directs a burst of intense light at the test tube. If dye is present, the sample emits light (or fluoresces) at a unique wavelength.

Dye may sometimes be lost if it doesn't appear at any of the sites monitored by receptors. The field study may have missed a spring, or the study area boundaries may have been too limited. Even then, the results are still valuable and can be used to plan future tracing studies.

Considering sources of error

Karst conduit systems can be complex, and it's not easy to predict exactly where the dye will go. Conduit networks often have crossing channels at various levels that can produce different results before and after heavy rainfall. A perfect example is a project that one of us coordinated (O'Dell and Druen 2010). The first test, using multiple dyes in the karst valley of Tarkiln Creek in Kentucky, indicated two separate flow routes to two springs and thus two different conduit systems (Figure 3, p. 56). Later, after verification that all residual dye had cleared from the system, the test was repeated with the same dyes. The second test showed dye from a single injection point in both springs, which contradicted the first test and suggested that the springs were, in fact, connected.

In the end, it turned out that the second test had been made during a time of high flow, and that water had emerged from one conduit system halfway up the valley, crossed to the other side, and gone down a sinkhole into the other system—making a connection on the surface. So, the first test was validated after all since it turned out that the springs were *not* connected by an underground conduit.

Student projects

In the field

SCILINKS THE WORLD'S A CLICK AWAY
Keywords: The water cycle
at *www.scilinks.org*
Enter code: TST121101

The logistics of bringing students into the field to conduct a real dye-trace experiment can be challenging, but the learning experience is well worth the effort. (**Safety note:** Indirectly vented chemical-splash goggles, aprons, and gloves are required when handling dyes.) A number of considerations are important for planning and executing such an experiment. The teacher's goal is to carry out a successful trace: Even though a negative result provides useful information, students will be more stimulated by a positive one.

CAUTION

Since the trace requires detailed knowledge of the methodology, the terrain, and all possible sink points and discharge points (e.g., springs), it's best to recruit outside expertise. Seek out professionals at a state geological survey or water agency, the Earth science department of a regional university, or in local geological engineering firms. Such professionals are often willing to volunteer time and supplies and can usually suggest a suitable testing site.

The field learning experience can be carried out in three phases:

1. a planning session in the classroom, based on information provided by the expert and geologic and topographic maps;
2. a field visit to inject the dye(s) into one or more sink points; and
3. a lab visit to see where the analysis takes place.

If there is no karst terrain near the school, students can use library resources or the internet to learn about and report on this topic. A local geologist can still be an important resource as a guest speaker or to suggest reliable geology websites. Other karst resources and lessons for teachers are available from the United States Geological Survey, the National Parks Service, the Karst Waters Institute, and the National Speleological Society (see "On the web").

In the laboratory

In addition to possible field studies, students can also model karst water systems in the lab. Here, they discover unseen conduits using an activity that incorporates electric flow. This activity can introduce a field investigation or be used afterward as reinforcement and review. The materials needed include

- 20 pieces of 8.5 × 11 in. black poster board
- a hole puncher or utility knife
- aluminum foil
- insulating tape (e.g., electrical tape)
- two size-D batteries
- two battery holders

FIGURE 3

Tracing flow systems.

Under low-flow conditions, three different nontoxic dyes (eosine, fluorescein, and sulforhodamine-B [SRB]) were injected into sinkholes. These dyes later emerged at lower springs in the valley. The arrows represent interpretations of the probable underground flow pathways. The results of this dye-tracing experiment suggest the existence of two separate but parallel groundwater flow systems.

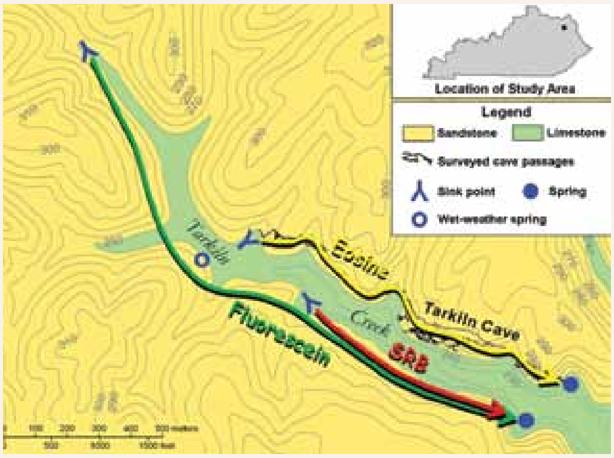
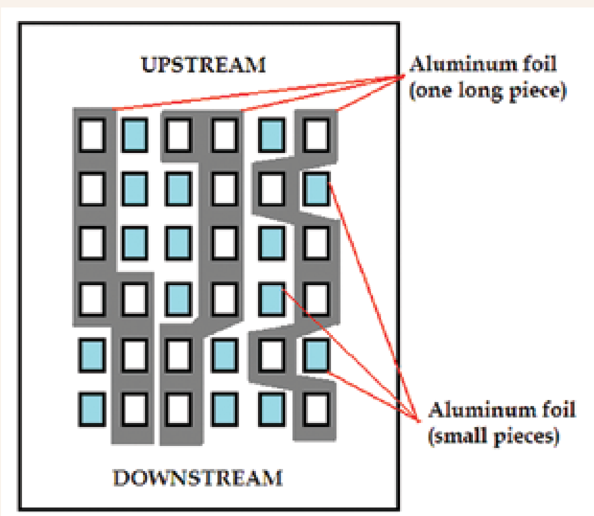


FIGURE 4

Sample poster board.

This graphic shows the back of the poster board with 36 holes. "Conduits" will have one or more long pieces of aluminum foil (shown in gray but hidden from student view) connecting several holes; holes that are not part of the conduits are covered in small, individual pieces of foil (shown in blue).



- two insulated copper wires
- two alligator-clip wires
- one small lightbulb
- a bulb holder
- safety glasses or indirectly vented chemical-splash goggles

To begin, prepare several pieces of black poster board by arranging 36 holes (about 1 cm in diameter) in six rows and six columns. Label the top of the poster board "upstream" and the bottom "downstream." Using one long, thin piece of aluminum foil and starting at any of the top holes, create one continuous connection between a few of the holes, ending in any of the bottom ones. This can be repeated for a second or third "conduit," but be sure they don't overlap.

Those holes that aren't connected should be covered with individual pieces of aluminum foil and insulated with electrical tape (Figure 4). Cover the back of the poster board with another piece of poster to hide the connections, and repeat until you have 10 poster board models, each with a unique connection pattern. After these are prepared, give students a worksheet that illustrates the poster model (see "On the web").

The next part of the activity uses electric current to represent water currents—and to detect unseen conduits. Connect the two size-D batteries and a lightbulb with wires, leaving the circuit open with two alligator-clip "probes" (Figure 5). (**Safety note:** Use caution when working with sharps such as wires; they can cut or scratch skin.) Place the lightbulb in the electric circuit before it's switched on; connecting batteries and wires without a lightbulb can produce a short circuit and get quite hot.

To implement the activity, divide students into groups, give them the poster boards, and ask them to use the alligator-clip probes to identify which aluminum foil spots are connected (making the lightbulb glow). Students color these points on their worksheets, representing an underground water channel, or conduit.

After all the connections have been identified, student groups report their findings. For example, students can compare and contrast their field experiences and the classroom activity. Similarities might include using two points to infer a connection, identifying the type of matter flows (electrons or water), and understanding that directly observing connections isn't possible. Differences might include estimating flow speed (fast with electricity, slower with water), stating how connections are detected (e.g., lightbulb, dye), and discussing scale. A sample rubric for assessing students' presentations is available online (see "On the web").

The benefits

This "hidden conduit" activity has clear advantages over karst conduit models built with sand, large aluminum foil pans, flexible tubing, or other materials. The prepared poster boards are light, portable, reusable, and less messy, and the activity takes only 10–15 minutes to complete. Most high school students can handle the analysis, comparison, and contrast involved in both the field experience and the poster board activity.

Apart from its relevance to karst systems, the activity can also be used as a "black box" activity that allows students to experience how scientists use indirect evidence to model systems that cannot be directly seen, such as the interior of atoms or Earth's core.

Try implementing the activity as open inquiry. Ask questions to help students think about the personal and environmental importance of studying groundwater in their community. Students can then discuss options for discovering underground water networks.

Conclusion

On our dynamic Earth, groundwater is an especially important and topical issue because it impacts the lives of many people. Hundreds of millions of people around the world, both urban and rural dwellers, depend on wells and springs for drinking water. Groundwater is equally important to global agriculture. Many people, particularly in the United States, eat fruits, vegetables, and grains that were irrigated by pumping water from groundwater aquifers.

The planet's groundwater resources are abundant but vulnerable. To protect this important resource from pollution sources (e.g., landfills, septic tanks, pesticides, fertilizers) and overuse (by extracting more water than nature can replenish), we must understand groundwater in the larger context of the water cycle and Earth systems.

FIGURE 5

Materials needed for "hidden conduit" activity.

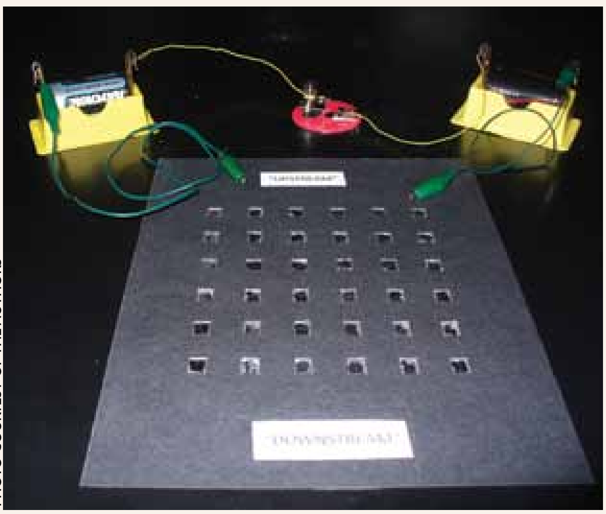


PHOTO COURTESY OF THE AUTHORS

Karst flow systems, which are relatively close to the surface, are particularly vulnerable to pollution, so scientists' work in tracing underground connections is often vital for protection of these aquifers.

The study of groundwater flow routes also provides an excellent opportunity to demonstrate real-life applications of the types of inquiries scientists conduct every day. High school science students should readily identify with the struggles and satisfaction of investigating these unseen water paths in both field and lab activities. ■

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On the web

Karst Waters Institute: *www.karstwaters.org/educationlinks/teachers.htm*

National Parks Service: *www.nature.nps.gov/geology/caves/program.htm*

National Speleological Society: *www.caves.org*

Rubric and printable version of the "hidden conduit" activity: *www.nsta.org/highschool/connections.aspx*

United States Geological Survey: *http://water.usgs.gov/ogw/karst/index*

References

Aley, T.A. 2002. *The Ozark Underground Laboratory's groundwater tracing handbook*. Protem, MO: Ozark Underground Laboratory.

Alley, W.M., T.E. Reilly, and O.L. Franke. 1999. Sustainability of ground-water resources. *U.S. Geological Survey Circular* 1186: 79.

American Geological Institute (AGI). 2001. *Living with karst: AGI environmental awareness series.* Alexandria, VA: AGI.

Ben-zvi-Assarf, B., and N. Orion. 2005. A study of junior high students' perceptions of the water cycle. *Journal of Geoscience Education* 53 (4): 366–373.

Donovan, M.S., and J.D. Bransford. 2005. *How students learn: Science in the classroom.* Washington, DC: National University Press.

National Research Council (NRC). 1996. *National science education standards.* Washington, DC: National Academies Press.

O'Dell, G.A., and J. Druen. 2010. Valley stress-release fracturing as a predictive model in conduit development: The karst hydrogeology of Tarkiln Creek, Elliott County, Kentucky. Presentation at the 96th Kentucky Academy of Science Annual Meeting, Bowling Green, KY, November 13.

United States Geological Survey (USGS). 2011. Where is Earth's water located? *http://ga.water.usgs.gov/edu/earthwherewater.html*