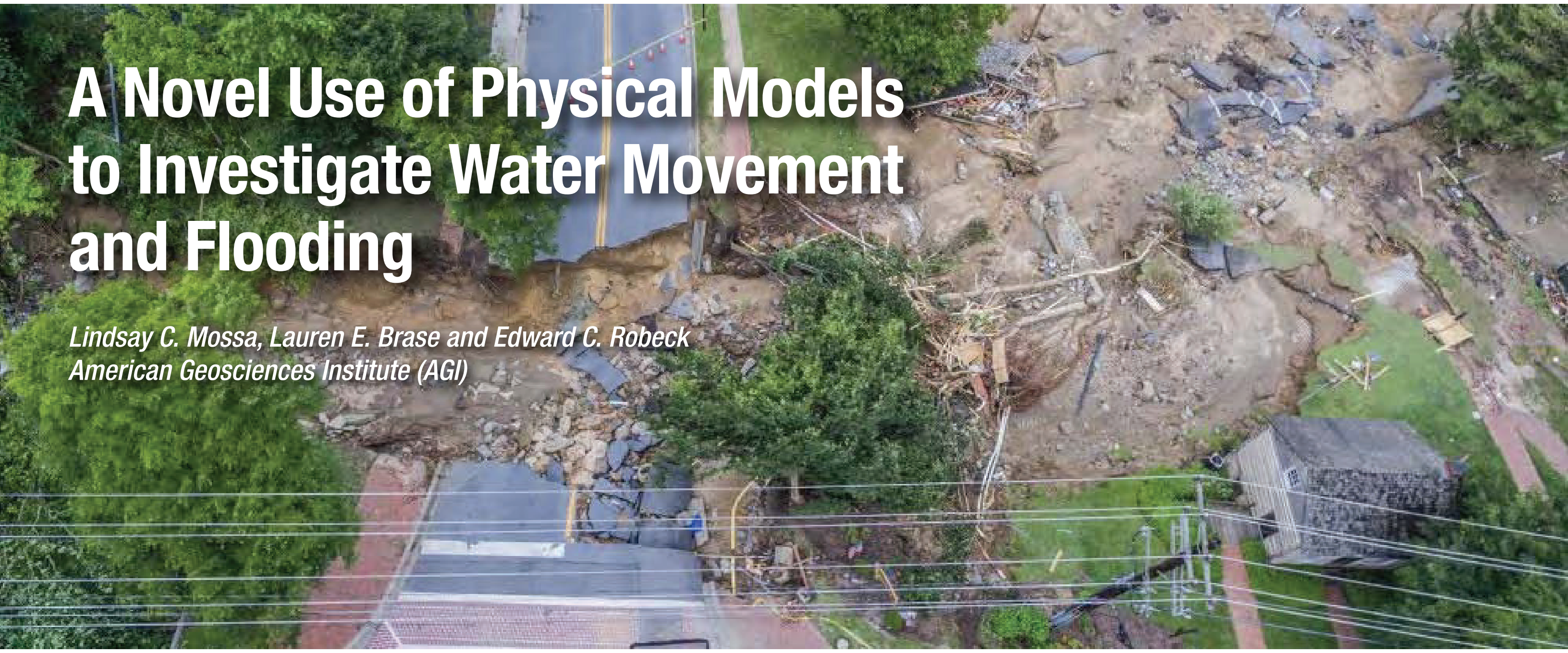

A Novel Use of Physical Models to Investigate Water Movement and Flooding

Lindsay C. Mossa, Lauren E. Brase and Edward C. Robeck
American Geosciences Institute (AGI)

An aerial view of Ellicott Mills Drive at Main Street in Ellicott City, MD on May 28, showing where flash floods carved out a chunk of the road.

Photo courtesy Howard County government.

Abstract

Research shows the effectiveness of elementary school students using models to understand complex phenomena, such as flooding and other natural hazards. Models were used in a five-day lesson sequence for fourth graders to help students to make predictions and observations of factors that affect river height and how these factors can contribute to flooding. Students first used an aquifer model to observe that water can move to a river as groundwater or surface water flow. They then used a novel stream table model to test the effect of land cover types on water movement to a river. The models helped students make sense of water concepts related to flooding and encouraged students to analyze real-world data and consider water movement in their community. These models are an engaging approach to learning about water movement and flooding, which can also be adapted to study other river-related phenomena.

Introduction

The use of models is a well-established teaching approach that can be made more consistent with scientific practice if the models are designed to make predictions, manipulate variables, and guide explanations of phenomena (Ke et al., 2021). Including models in instruction, even when modeling is not an explicit part of the performance expectation being addressed, strengthens students' opportunities to develop their abilities with science and engineering practices. Models can help students recognize the complexities of phenomena that affect people in important ways, such as natural hazards, so the challenges of addressing them can be made clear.

Floods are the most common natural hazard in the United States and worldwide, and they have become more common over the past two decades (CRED & UNDRR, 2020). Almost one in four people in the world are exposed to high flood risks (Rentschler et al., 2022), and floods impact sustainable development in many communities (UNDRR, 2022). Precipitation flowing across impervious surfaces in urbanized areas is one factor contributing to the increased incidence and severity of flooding (Feng et al., 2021). The availability of data associated with these effects—specifically rainfall, river height, and land cover—makes floods an excellent topic for earth science lessons and provides opportunities to develop students' skills and understanding around scientific practices related to modeling.

Through an NSF-funded research project undertaken by the American Geosciences Institute (AGI) and the Education Development Center's Oceans of Data Institute (https://www.edc.org/oceans-data-institute) a five-day curriculum for fourth graders was developed that incorporates multiple uses of models and data to explore water movement. A historic "1000-year" flash flood that occurred in May 2018 in Ellicott City, Maryland, was chosen as the anchoring phenomenon for the curriculum. While flooding in Ellicott City is common, there has been an increase in the severity of floods in part due to a significant increase in the amount of impervious surfaces within and around the city (Russ et al., 2020). The lesson sequence was initiated with a video of the flood, setting the stage for discussions of the causes for this phenomenon and the investigations that followed.

Table 1. NGSS dimensions addressed in the five-day lesson sequence.

Dimensions	Classroom Connections
Science and Engineering Practice	
Developing and Using Models	
• Develop and/or use models to describe and/or predict phenomena.	Students test the effect of a pervious surface on water movement to a river.
• Identify limitations of models.	Students discuss how their model differs from the real world and how that can affect the data they collect.
• Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.	Students test the effects of an impervious surface on water movement to a river and compare the results to that of the "natural" pervious surface.
Argument from Evidence	
• Construct and/or support an argument with evidence, data, and/or a model.	Students compare data collected from pervious and impervious land covers to describe differences in real-world data, specifically the change in height of two rivers which were similarly surrounded by different land covers.
Disciplinary Core Idea (DCI)	
ESS3.B: Natural Hazards	
• A variety of hazards result from natural processes (e.g., earthquakes, tsunamis, volcanic eruptions). Humans cannot eliminate the hazards but can take steps to reduce their impacts.	Students investigate natural and human made factors that affect water movement and flooding.
Crosscutting Concept	
Cause and Effect	
• Cause and effect relationships are routinely identified, tested, and used to explain change.	Students test and describe the relationship between rain events and a rise in river height.

In the full lesson sequence students also consider strategies that can be used to mitigate the severity of flooding see Table 1 for NGSS (NGSS, 2013) connections to these specific uses of models). The link to the full curriculum, "Using Data to Study Rivers and Flash Flooding," instructions for setting up the models, links to NGSS, and related assessments, can be found at https://awesomeaquifer.com/training-videos.

Figures 1a and b. Awesome Aquifer Kit Setup. The Awesome Aquifer kits (a) are clear containers in which students build a model riverbank (the hill) and riverbed to (b) allow for the prediction and observation of water movement. Students poured water over the riverbank and, in a class discussion, described water movement through the gravel and to the riverbed. Blue water was used to improve the visibility of the water.

Photo Credit: a) L. Brase, AGI, b) L. Mossa, AGI

Using a Model to Understand How Water Can Move

In their most basic use, models help students conceptualize phenomena they cannot directly observe, such as groundwater flow (Baumfalk et al., 2018; Zangori et al., 2017). In the first lesson of the five-day sequence, we used a physical model—the Awesome Aquifer Kit (https://awesomeaquifer.com/) to model groundwater flow from a riverbank to a riverbed. First, to activate prior knowledge we asked students about how rainfall affects rivers. In some cases, responses included ideas that were misconceptions to address, such as that rain must fall directly into a river to affect its height. After making a model riverbank and riverbed, students poured water on top of the bank and made observations of where the water traveled. (See Figures 1a and b.)

Discussions revealed students' observations:

Student 1: We pushed the rock so it was like a riverbed. And then we dribbled water on top of it.

Instructor: Yes, and where did that water end up?

Student 2: The bottom. Through the cracks and into the bottom.

Instructor: But then what do we call that bottom? What was that modeling?

Student 3: The river!

Student 4: The bed.

Instructor: Thank you. Somebody tell me one thing you observed in our model.

Student 2: The water went through the rocks and then it slowly came out from the bottom.

Instructor: [students using "agree" hand movement] I'm seeing a lot of agreement... Any challenges?...

Student 5: When we poured it, it went to different pathways from the cracks.

The term *groundwater flow* was introduced to describe the movement of water to the riverbed through the gravel. Students were asked whether they also saw water travel over the surface of the gravel, and the term *surface water flow* was introduced. Students quickly concluded that groundwater flow was the predominant movement type in this model.

Using a Model to Explore Variables that Impact Water Movement

After students explored that water could move as groundwater or surface water, they investigated how land cover could impact the method of water transport. A novel use of stream tables was developed to enable modeling of the effects of pervious and impervious surfaces on water movement to a river. The stream tables were set up with a cloth that represented land cover types in the top third and a river channel carved into the sand on the bottom two-thirds. The land cover materials chosen mimicked both the perviousness and the colors of actual surfaces–green cloth for grass and

Figure 2a (left). A student group testing a (a) pervious surface on the stream table. The student at the top of the images is the "rain maker," adding water using a modified 2L rain bottle on pervious surface uphill of the river. Other student roles include: the "water watcher," who observes where the water is going and verbalizes how water is moving through the model; the "river watcher," who verbalizes when the sawdust (located midstream) moves to indicate the river has started flowing and the timer should be stopped and the "time-keeper," who times the trial from when the "rain" starts until the river starts flowing. **Safety Note:** Since students were working with water, each group had a towel to clean up any spills. Students were instructed not to touch the wet sand or sawdust for safety reasons. Photo Credit: L. Mossa, AGI

Figure 2b (right) . A student group testing an impervious surface on the stream table. Photo Credit: L. Mossa, AGI other pervious landscapes, and grey vinyl for impervious pavement and buildings (Figures 2a and b). Working in groups, students were assigned a number (1-4) representing a specific role, so a variety of observations could be made. Roles were switched for each trial so students had different experiences and to maintain interest across trials. A pre-made "rain bottle" was used by students to pour water on the model. Students timed the interval from when the rain began until water flowed in the model river. This allowed comparisons of the time it took for water to move in different conditions.

Students ran two trials of the pervious surface model and created a class data table (Figure 3), which facilitated a discussion of variations in time and sometimes missing data (e.g., one group cleared the stop-watch before recording their time).

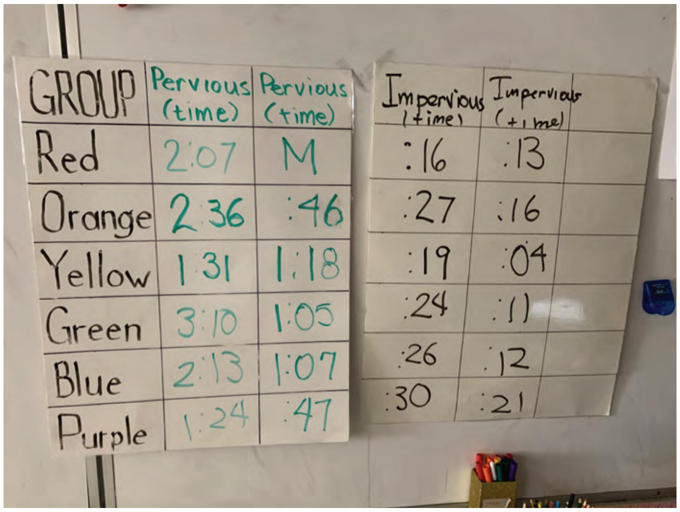

Figure 3. Student-collected data from the stream tables. Two trials were done for each surface, which led to a discussion of reasons for differences in times between trails, most notably, antecedent conditions. Discussions about differences between the two land covers centered around the lag between a rain event and river flow when water moves as groundwater flow. Photo Credit: E. Robeck, AGI

The students were provided a diagram that depicted the stream table setting (i.e., natural or urban) and they drew on the diagram to record their observations of water movement. A discussion of student observations revealed that a majority of the water moved to the river as groundwater flow when the pervious surface (green cloth) was on the stream table:

Instructor: What can you say about the relationship between the rain starting and the river flow starting?

...Student 1: When the rain started, it took seven minutes for the actual river to start.

Instructor: That's right. It took a long time for the river to start.

Student 2: It took eight minutes at first.

Instructor: Yes, we have a lot of different times... The stream tables are the same, the sand is the same. Why would there be different times?

Student 3: Some people had different strategies...Moving the rain bottle fast or slow. Or around or straight.

The stream table procedure was repeated using the grey vinyl to simulate an impervious surface.

Through their observations students concluded most of the water traveled to the river in the form of surface water flow, which was based on students' observations of rapid water movement over the grey vinyl which was consistent across the groups' data.

Instructor: How about on an impervious surface? ...How did the water get to the river?

Student 1: Like it slid off the impervious surface and down into the river.

Students' eagerness to share their data and observations revealed their enthusiasm for using the stream tables. As students shared their observations, we also discussed aspects of the stream table model that did not accurately represent real-world features, including:

- Rivers are not surrounded by 100% pervious or impervious surface, but rather, a mix of the two;
- The materials surrounding and within a riverbed vary;
- Rivers differ in shape and size;
- The slope of the land may vary;
- There are several variables that differ between rainfall events (e.g., amount, duration, and location).

As the bullet points above indicate, students' discussions provided many ideas in addition to land cover that impact water movement and that could be explored on the stream tables.

The lessons also involved students learning how to analyze real-world data, and through observations of this data as it was represented on graphs, they recognized that some rain events lasted longer than others and/or had higher peaks, indicating greater intensity. To explore these variables, the rain bottles could be altered (e.g., using more holes), as could the location where the model rain falls (e.g., not always uphill from the river). Another student noted that one of the stream tables was propped up higher than others, causing a difference in the angle of the river, which led to a discussion of how slope might affect water movement. Additionally, other substrate materials like aquarium gravel or a soil-sand mixture could be used to explore impacts on water movement.

The final lesson of the sequence focuses on surface water flow mitigation strategies, which mainly involve replacing impervious surfaces with pervious surfaces like infiltration basins or pervious pavement. The grey vinyl could be altered by students to test these strategies (e.g., by adding holes), which would also contribute to the "developing models" component of the SEP used in these lessons.

Using Models to Facilitate Discussions Around Data

Using hands-on models allowed students to collect and analyze data and relate their findings to professionally collected real-world data (e.g., from USGS river gauges) as they developed their understanding of flooding. The data also prompted fruitful discussions that addressed specific aspects of their experiences. For example, when comparing their times for the pervious surface, they noted that the second trial was faster than the first, which led to a discussion of antecedent conditions (e.g., how soil moisture can affect water movement). They also readily recognized evidence that water movement over the impervious surface was always faster than with the pervious surface, which gets to the fundamental issue of how human activity affects the frequency of floods.

A series of questions was used to get students to connect their data and observations from the models to the real-world data being used to understand flooding. Aspects of the data that students were able to observe in the model included:

- Rainfall can result in an increase in river height,
- There is a lag between a rainfall event starting and the river height rising,
- A longer lag occurs when a river is surrounded by pervious surfaces than when a river is surrounded by impervious surfaces.

Students compared the stream tables with other kinds of models and information sources, like images and maps. Aerial satellite images of the rivers and the surrounding areas allowed students to visually assess the relative amounts of pervious versus impervious surfaces. The students' observations were reinforced by the use of pie charts created using GIS data to show the relative quantities of groundcover in the actual landscapes. Together, the images and charts allowed a comparison of the conditions around the rivers being considered, demonstrating the benefit of using multiple information sources to enhance understanding beyond the models and making connections to the real world.

Conclusions

The models within these lessons provided an engaging, student-centered platform to initiate discussions of phenomena, data, and their communities. Students were able to use these models to make observations and predictions, and then offer explanations of the phenomena, which they justified with evidence. Students recognized that there were additional variables affecting the phenomena being explored, and that they could design tests about each of these variables. Overall, our use of physical models strengthened students' understanding of the dynamics and complexities of the phenomenon of flooding, and the role of science and engineering practices in understanding events that affect people around the world.

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About the Authors

Lindsay C. Mossa is an Education Specialist at the American Geosciences Institute (AGI). She has fifteen years of high school science teaching experience in New York and Maryland schools. She has written curriculum for middle and high school courses using the *Next Generation Science Standards* for life, physical, and earth sciences. She has also delivered numerous professional development sessions for teachers, covering topics such as pedagogy, science content, and technology use in the classroom. She can be contacted at lmossa@americangeosciences.org.

Lauren E. Brase is an Education Specialist at the American Geosciences Institute (AGI). She has designed a range of curriculum materials including hydrology units for fourth graders, paleontology activities for eighth-graders, astronomy and chemistry courses for high schoolers, and labs and field trips for undergraduate geology courses. Lauren taught high school science for five years and was a teaching assistant while earning her master's degree in Earth, environmental, and planetary sciences. She can be contacted at lbrase@americangeosciences.org.

Edward C. Robeck is the Director of Education & Outreach at the American Geosciences Institute (AGI). He has extensive formal background in curriculum design, holding graduate degrees in Curriculum & Instruction from the University of Nebraska—Lincoln (master's) and from the University of British Columbia (PhD). He has been a teacher in formal and informal settings, worked in commercial publishing, and conducted educational research. He can be contacted at ecrobeck@americangeosciences.org.