ISSUE 2 | Winter 2016/17

MISSION: water

Who's Minding the Planet?

Corvette Catastrophe
Studying Car-Swallowing Sinkholes

Ecologists without Borders
Waterkeepers at the Roof of the World

Sustainable Development
Coastal Terraforming in Lusail City, Qatar

LIFE AFTER HORIZON
...rts on the Gulf Coast

In this Issue

Welcome to the 2nd edition of MISSION: Water, a magazine featuring the organizations and researchers tackling the world's most challenging water issues. I'd like to give a special thanks to all the participants in our inaugural edition who helped make the magazine's launch such a success – and another thank you to the contributors telling their story in this issue.

I'm excited to see MISSION: Water feature stories from around the globe, with topics ranging from climate change in the arctic to grassroots monitoring coalitions in the Himalayas. This edition also puts a spotlight on the work of environmental professionals confronting the lingering effects from some of the world's worst environmental disasters, including the Deepwater Horizon spill and the Gold King Mine incident in Colorado.

We hope you enjoy the magazine, and let us know if you're interested in joining us for the next issue!

Timothy A. Grooms

Timothy A. Grooms
Director of Marketing - Xylem Analytics, NA

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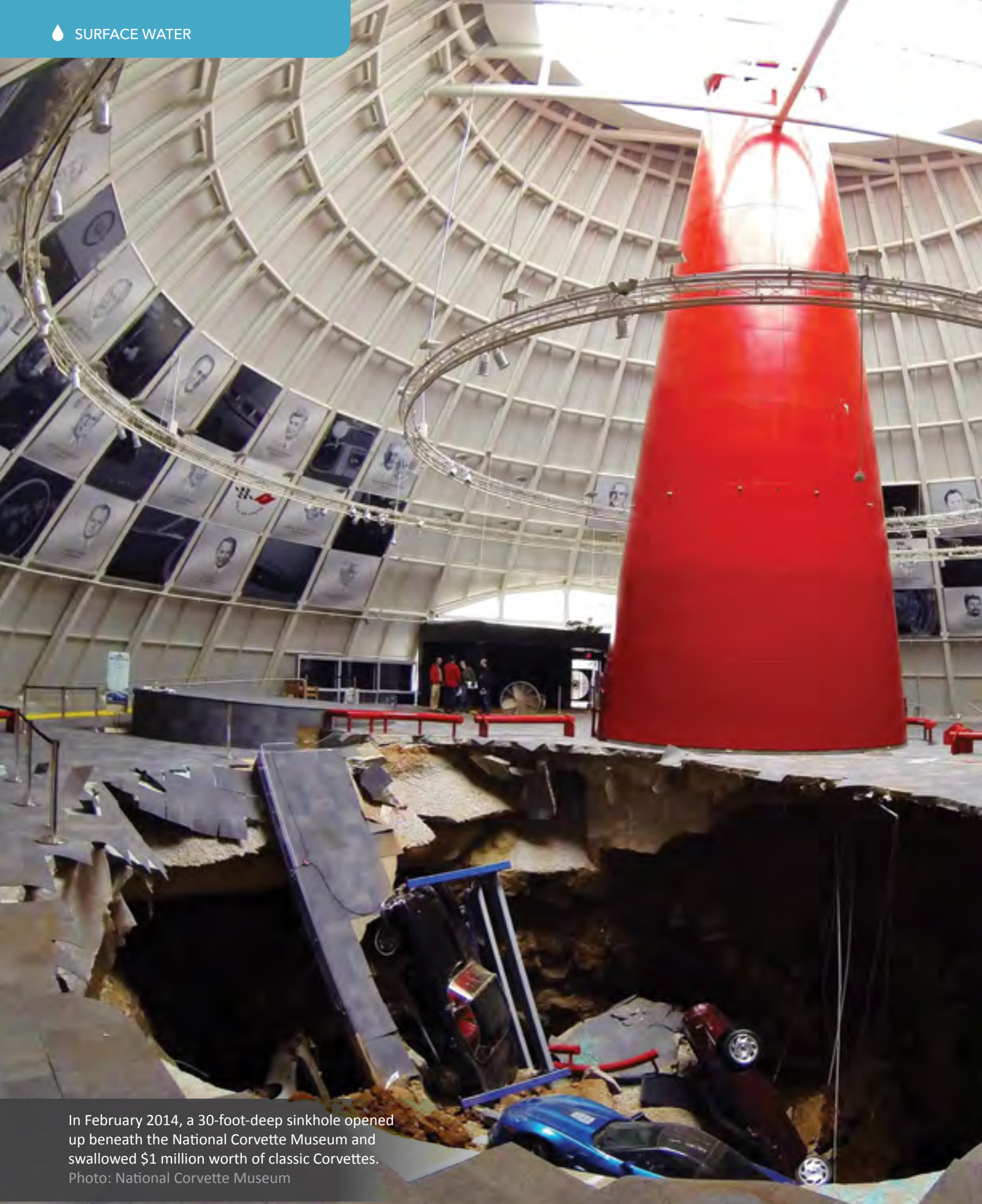


In February 2014, a 30-foot-deep sinkhole opened up beneath the National Corvette Museum and swallowed $1 million worth of classic Corvettes.
Photo: National Corvette Museum

CORVETTE CATASTROPHE

A car-eating sinkhole opens a window into Kentucky's subterranean caves

STEVE WERBLOW

At 5:38 a.m. the morning of February 12, 2014, security cameras registered a strange movement at the National Corvette Museum in Bowling Green, Kentucky. The grainy footage shows a half-dozen candy-colored sports cars appear to settle just slightly in the play between spotlight and shadow. Then, under a muscular, orange T-top, a panel of floor tiles drops away. And another.

For 30 long seconds, the car hangs on by its tail light before more floor disappears and the car, along with the white one parked in the next spot, disappear into the earth. The footage is silent, but you can almost hear the sound of a crash and breaking glass in your imagination.

By 5:39 a.m., eight classic 'Vettes, worth a total of about $1 million, were swallowed by a collapsing cave that left a yawning hole, 12 by 18 meters across and 9 meters deep, in the center of the museum's atrium.

In geologic terms, it was just one more sinkhole among hundreds in south central Kentucky's Warren County. The region sits atop karst, an eroded limestone formation riddled with ever-expanding caves and channels. But instead of becoming just another farm pond, weedy pit or temporary road hazard, the National Corvette Museum sinkhole became global news—and a prime opportunity to learn and teach about the karst geography that Bowling Green is built upon.

Common Geology

Most people don't think much about karst landscapes, though 25 percent of the world's population lives on top of them. In fact, karst covers about 12 percent of the earth's ice-free land surface. But as much as the story of karst is written in stone, the heart of the subject is water.

Karst aquifers provide 20 to 25 percent of mankind's drinking water. Because groundwater is connected directly to the surface by sinkholes, caves and fissures in the rock and flows quickly through subterranean rivers and tunnels, karst aquifers are extremely vulnerable to pollution. And water—slightly acidic and capable of dissolving limestone—continues to carve new tunnels and enlarge existing caves that make karst formations look like Emmenthaler cheese or bubble-riddled pizza crust.

The unique and fragile nature of karst geography generally comes to light when new sinkholes form in populated areas, opening the earth in a scene straight from the Bible and giving people on the surface a window into the porous world below.

"Most of them are slow-forming subsidence sinkholes that take thousands of years to form," notes Jason Polk, associate professor of geosciences at Western Kentucky University in Bowling Green and a global authority on sinkholes. "There's not too much to worry about as far as cars or people. We don't have many reports of big, catastrophic sinkholes like the Corvette Museum.

"At the National Corvette Museum, after the sinkhole occurred, we could see that there was just a few feet of distance between concrete and the roof of the cave," Polk adds. "The ceiling had migrated upward over hundreds of years, thousands of years. Little by little, water continues to move. Storms can undermine the system because rain continues to erode away the ceiling. The weight of the water as it's sitting there, making the clayey soils and overlying rock heavier, can be an issue."

Heavy rains and deep freezes in February 2014 created the perfect conditions to break the cave ceiling lying just a few feet beneath the museum's car collection, Polk explains. The weathered rock was stretched to its limit, spanning a cavern more than 12 meters wide. The massive weight of water-laden soil and rock, frozen in place, stressed it further. Then a thaw created a pulse of meltwater, possibly eroding away the last millimeters of structure that held up the roof. That's when the first Corvettes started dropping 9 meters to the floor of the cave, along with 160 truckloads of limestone, soil and debris. "It was a perfect storm," Polk says.

"It was a perfect storm."

Above: Drone footage of the sinkhole.
Below: The heartbreaking aftermath.
Photos: National Corvette Museum

A geologist uses an EXO sonde to monitor changes in water quality in a sinkhole adjacent to the Corvette Museum.
Photo: Dr. Jason Polk

Sinkhole Study

The day of the collapse, Jason Polk and a team of his graduate students and colleagues found themselves in the museum's Skydome, peering into the sinkhole. A WKU engineering student piloted a drone into the hole, using a camera on board to help spot buried Corvettes and look for signs of an underground river that could have caused the collapse.

Meanwhile, Polk and his team went to an old sinkhole on the museum's property—used as a retention pond for drainage from the building and parking lot—to look for more insight into conditions that could explain the collapse and perhaps warn of further problems.

Their key tool was an EXO multiparameter water quality sonde from YSI, a Xylem brand. Logging measurements of water turbidity (TSS, or total suspended solids), specific conductance, pH, temperature and level every 10 minutes, the monitoring sonde was Polk's eyes and ears as he searched for indications that the old pond and the new sinkhole could be connected. He and his team also monitored whether runoff from the museum was making its way to the pond or undermining other areas of the lot or buildings.

While crews at the museum were drilling foundation structures and filling the sinkhole, turbidity and level were the key parameters on Polk's mind. A spike in turbidity could indicate that sediment-enriched drilling water was flowing from the museum sinkhole into the pond, or that other water was somehow making the trip. That would have been fascinating. It would have also raised a huge red flag, indicating that a blowout or further collapse could be imminent.

Throughout the rainy spring, level and water quality readings in the pond showed that gutter and parking lot runoff indeed drained straight into the retention pond, but no other sources of water seemed to be flowing into the depression. That was good news.

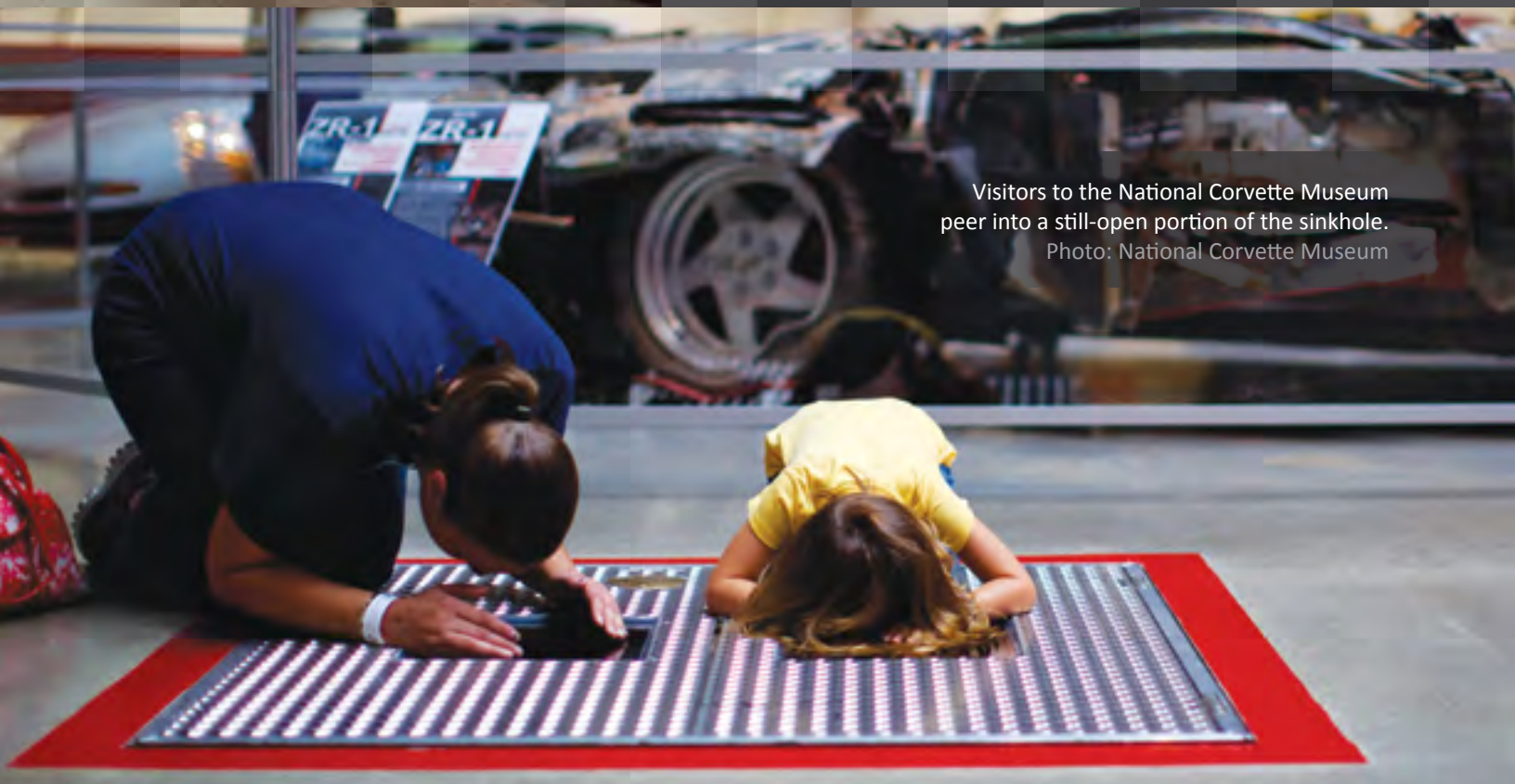
Photo: National Corvette Museum

Better Than Ever

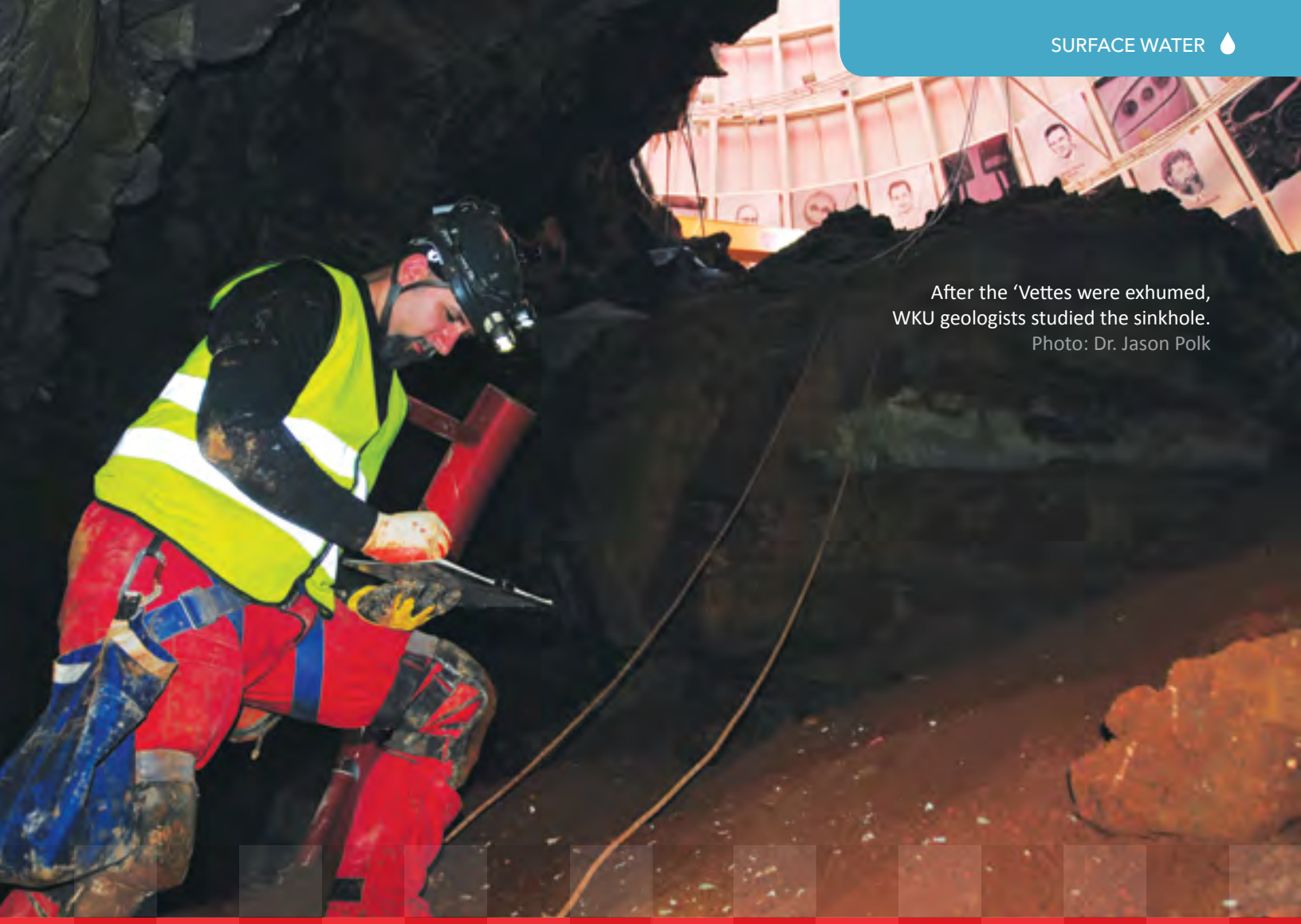
When the excavation was complete and the site deemed safe, Polk—an accomplished caver—and some of his colleagues went into the sinkhole. It was surprisingly dry, without the underground river most geologists expected to see. It was also surprisingly extensive, part of a cave system that was more than 60 meters long, 12 meters wide and as deep as 27 meters beneath the surface. Mapping the cave gave Polk a chance to ground-truth the observations he and his team made with the EXO sonde at ground level.

"It gave us very different investigative techniques from beginning to end," he notes.

The National Corvette Museum spent about $5 million digging out the Corvettes, restoring some (with the help of General Motors), filling the sinkhole and rebuilding the Skydome floor. Katie Frassinelli, marketing and communications manager for the museum, says the repair project utilized 3,977 tons of crushed limestone fill, and a grid system of concrete beams connecting 72 micropiles to underpin the new floor. Those micropiles are high-strength steel rods drilled deep into the bedrock beneath the cave, each capable of holding up 150,000 pounds. The deepest micropile reaches 25 stories beneath the museum.



Visitors to the National Corvette Museum peer into a still-open portion of the sinkhole.
Photo: National Corvette Museum



After the 'Vettes were exhumed, WKU geologists studied the sinkhole.
Photo: Dr. Jason Polk

Educational Opportunity

As crews excavated the sinkhole in the National Corvette Museum, rescued buried sports cars and filled in the massive cave, visitors flocked to the museum to see not only the car collection, but the sinkhole itself.

"When it first happened, it was so unbelievable people just came to see the sinkhole," says Katie Frassinelli, the museum's marketing and communications director. "It was in our best interest to show people what had happened. People started peering through the PlexiGlass window, watching them dig those cars out.

"We had a 67-percent increase in tourism the year it happened, and kept growing from there," she adds.

With annual visitor numbers approaching 250,000 in 2014 and 2015, the National Corvette Museum has turned the sinkhole disaster into a teaching moment. A new Corvette Cave-In exhibit, inaugurated on the second anniversary of the appearance of the sinkhole, includes interactive displays, exhibits of the restored cars as well as the remaining wrecks extracted from the debris, and detailed information on karst geography and sinkholes. Visitors can peer into a manhole cover to the bottom of an unfilled portion of the sinkhole. There's even a sculpted area that gives guests a sense of what it's like to be at the bottom of a sinkhole.

Frassinelli admits that the events of February 12, 2014 gave her "a little bit of a panic attack." But the museum survived, and is thriving. General Motors volunteered to restore two of the most valuable cars, including the one-millionth Corvette to roll off the assembly line. And Bowling Green remains a great place to live and work, she says. In fact, Bowling Green residents talk about sinkholes like Los Angelenos describe earthquakes or Miami residents discuss hurricanes.

"Sinkholes are really common here," Frassinelli tells visitors. "What is uncommon with us is that it was in a building, and Corvettes fell into it. This is a safe place to work and live and drive."

Extensive System

Water quality monitoring at the museum site is complete, but Polk and his team rely heavily on continuous, long-term monitoring sondes to study the water running through the karst formation beneath Bowling Green. (He also studies Florida karst formations and aquifers in Central America and elsewhere.)

Polk uses his cellular telemetry systems to report on key testing sites in near-real time. Rapid changes in level and temperature can indicate the presence of floodwater mixing with karst groundwater. Shifts in specific conductance and turbidity can signal a wash of pollutants from the surface. Monitoring data are posted to a website and mobile app for easy access by scientists, city officials and the public as part of the Under Bowling Green educational initiative.

Through the **underBGKY.org** website, the Under Bowling Green team educates residents about the connections among houses and roads on the surface, caves and sinkholes, and groundwater. Text and illustrations emphasize the proper treatment of caves and sinkholes to minimize pollution.

The scientists and policymakers behind Under Bowling Green are also using the EXO2 data to glean a better understanding of the dynamics of stormwater, pollution and flooding in the system, which is constantly subject to change as new caves collapse or old sinkholes clog up.

“As water makes its way underground, [the karst] is like a bathtub,” Polk explains. “The holes the water goes into eventually become holding chambers. There are many spring outlets, most of which eventually feed into the Barren River, the hydrologic border of the city. There are over 2,000 injection wells in the city, draining down the surface water and filling up the karst just as fast. They could plug with sediment, or they could collapse some more, or an injection well could flood.

“Every time we build, every time we change the hydrology, every time we pave over a surface, these are all potential risks,” he emphasizes.

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The rescue of the Corvettes brought attention to the mysteries of karst formations beneath Bowling Green. Photo: National Corvette Museum

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[Figure 2]
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YSI.com

Integrated Systems & Services
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WaterLOG
sales@waterlog.com
WaterLOG.com

SonTek
inquiry@sontek.com
SonTek.com

Aanderaa Data Instruments AS
aanderaa.info@xyleminc.com
Aanderaa.com

Hypack
hypack@hypack.com
Hypack.com

Questions or comments?
MissionWater@Xyleminc.com

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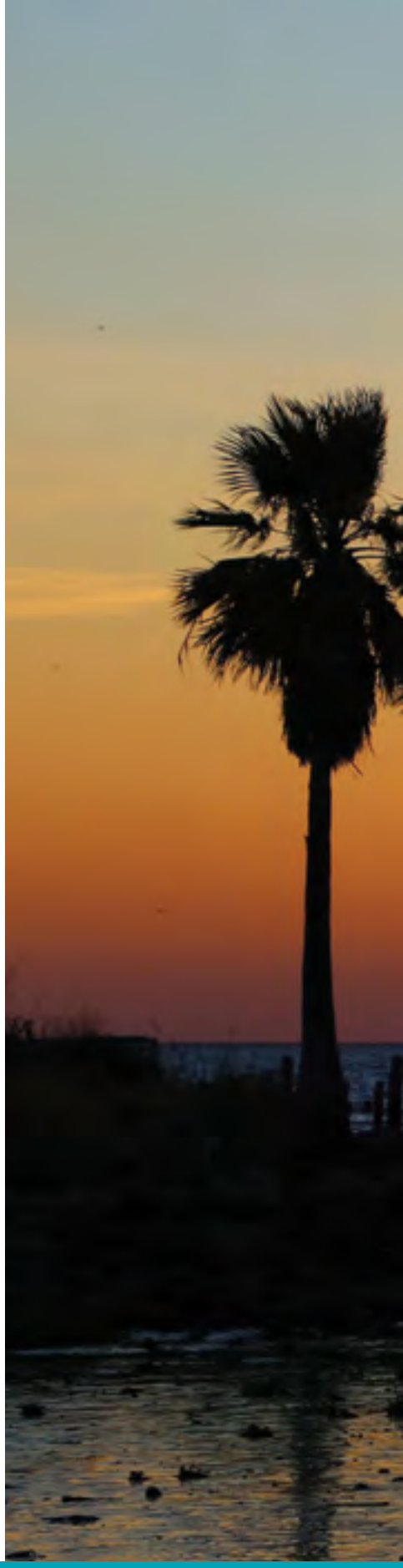

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