Will fracking put too much fizz in your water?

Leaky gas wells loom large in debate over drilling's impact on water quality

By **Erik Stokstad**

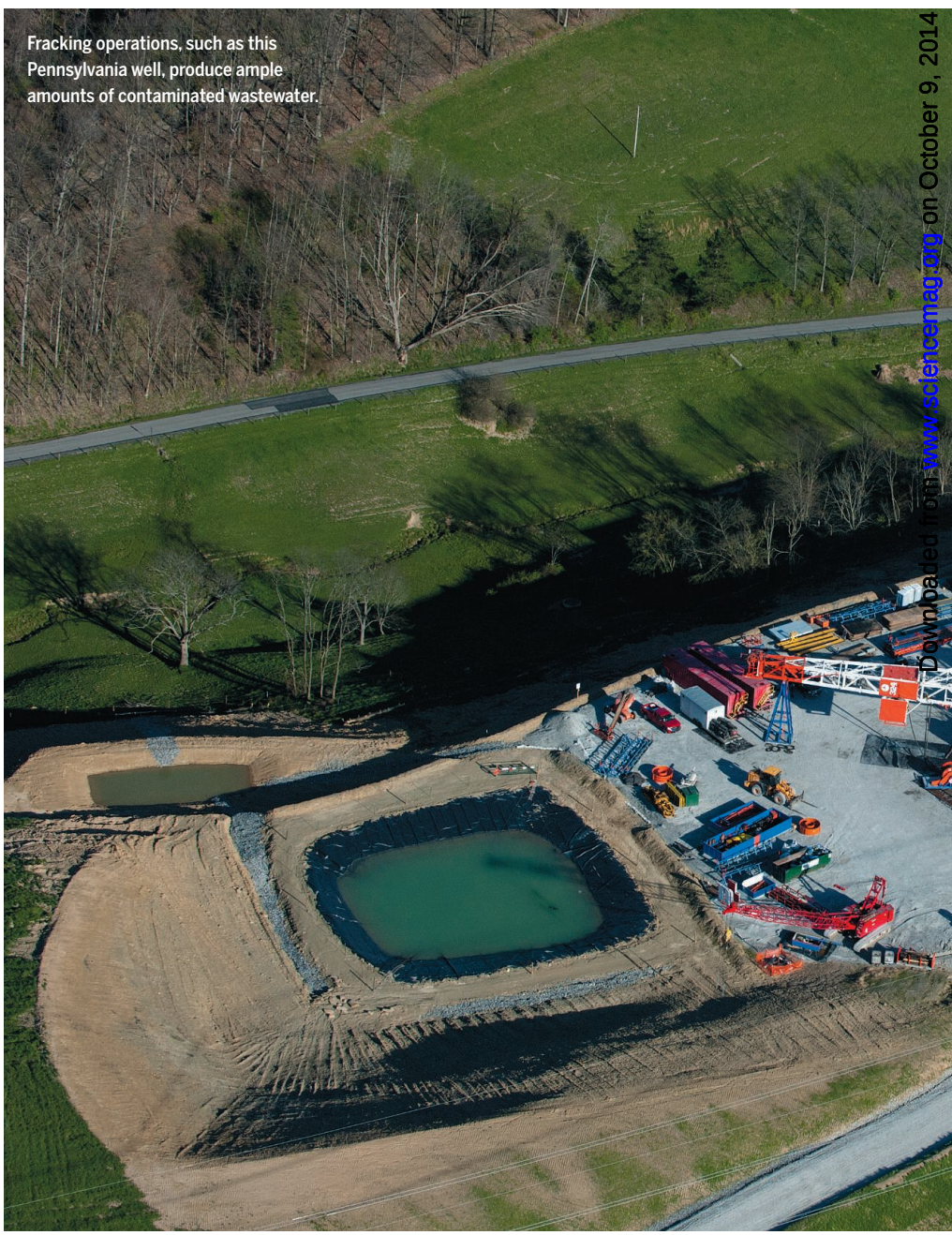
On New Year's Day 2009, the well in Norma Fiorentino's backyard exploded. An electric pump ignited methane that had seeped into her water well, and the blast was powerful enough to tear apart a concrete pad. That was just the beginning of the fireworks. Nineteen families in rural Dimock Township, Pennsylvania, blamed well contamination on stray methane leaking from nearby boreholes. They had been rapidly drilled by Cabot Oil & Gas Corp., which was searching for natural gas in the deep Marcellus Shale. After a lawsuit and government investigations, Cabot agreed to provide the families with cash settlements and water purification systems, but insisted that the methane had come from natural sources, not its gas wells.

The Dimock controversy, featured in the popular movie *Gasland*, shone a spotlight on the potential risks associated with the U.S. shale gas boom. Around the world, media have highlighted dramatic ruptures of pipelines, waste spills, well blowouts, and tanker truck crashes. The problems helped persuade officials in nearby New York state to declare a moratorium on fracking—the hydraulic fracturing that cracks rocks and coaxes natural gas from the Marcellus and other shale formations (see p. 1464). France, Bulgaria, and other countries have also banned fracking.

Perhaps the biggest fear is the potential to pollute drinking water. Although the new wave of high-volume fracking typically targets geological formations that are more than a kilometer down—far deeper than most drinking water wells and aquifers—many communities worry that they could become the next Dimock, their water tainted with methane or chemicals. Fracking opponents point to widespread complaints of contamination near gas wells. But industry advocates claim that there has never been a documented case of fracking harming drinking water.

Who's right? A growing corps of researchers is trying to find out. Some are testing water wells, while others comb through state environmental records. One team is trying to take advantage of an unusual natural experiment, documenting water quality along the border between frack-free New York and frack-heavy Pennsylvania. Meanwhile, gas companies are funding their own vast surveys of predrilling water quality—if only to defend themselves against postdrilling lawsuits. And many eyes are on the Environmental Protection Agency (EPA), which later this year is expected to release a much anticipated national study of fracking's effect on water.

Big money is at stake. If fracking is shown to be a major threat to water quality, companies could face potentially expensive regulation and lawsuits that could keep them from tapping shale formations holding natural gas worth billions of dollars. If not, the finding could hasten the end of moratoriums in New York and elsewhere. The research "will impact what counties, states, and countries will do, whether they give incentives to drill or put bans in place," says Robert Jackson, a hydrogeologist at Stanford University in Palo Alto, California.



Fracking operations, such as this Pennsylvania well, produce ample amounts of contaminated wastewater.

WATER IS AN ESSENTIAL INGREDIENT in fracking. Once a company has drilled a deep horizontal borehole, workers pump in an average of 15 million liters of pressurized water to break open the shale—10 to 100 times more water than in a conventional, vertical gas well. About 20% of this fluid, which is mixed with sand and chemicals to keep the fractures open, then flows back out of the well. With it comes so-called produced water, the mildly radioactive brine that permeates the shale itself.

Improperly managed, flowback waste can cause serious pollution. In Pennsylvania, Marcellus well operators now recycle most of the flowback to frack new wells. (In other regions, they dispose of the fluid by pumping it deep underground.) But until 2011, some trucked the fluids to municipal sewage treatment plants, which weren't equipped to deal with them. Worse, onsite storage ponds failed and rogue contractors dumped the dregs into streams. Such problems are not unique to fracking; conventional oil and gas wells create waste, too, although in smaller amounts. But once the pace of Marcellus fracking slows, some analysts fear, companies may be faced with an excess and nowhere to put it. "We see this potential train wreck on the horizon," says Mark Brownstein of the Environmental Defense Fund in New York City.

PHOTO: MARTHA RIEL

One irony of the fracking controversy is that the fracturing itself doesn't worry scientists. Because it typically takes place at great depths, any larger cracks are quickly squeezed shut by the weight of the overlying rock. So experts have assumed that gas or fluids are unlikely to escape. A 2004 study by EPA, for example, concluded that fracking posed little threat to underground supplies of drinking water; the finding helped persuade Congress in 2005 to exempt the practice from regulation under the federal Safe Drinking Water Act.

More recent studies are also finding scant evidence that contaminants are migrating up through fractures created by fracking. In Pennsylvania, scientists at the Department of Energy (DOE) have spent 9 months monitoring tracers injected into six commercial wells drilled into the Marcellus Shale. So far, there is no sign that gas or fracking fluids are moving toward the surface, reported DOE's Richard Hammack and colleagues this past August at the Society of Petroleum Engineers Eastern Regional Meeting. (A lingering concern, however, is the presence of countless abandoned oil and gas wells, some dating back a century, which could also provide a conduit for gas or fluids.)

The greater risk—for all wells—is that fluids or gas will escape through a faulty casing into shallow aquifers. To prevent leaks, crews pump cement into the 2-centimeter space between the pipe and the surrounding rock. But if the cement has gaps, contaminants can bubble up. Rarely, the steel pipe fractures or its threaded joints leak.

Poor cementing is a well-known hazard in conventional wells. In one tragic incident in 2004, gas escaped from a conventional well in Jefferson County, Pennsylvania, collected in a home basement, and exploded, killing a couple and their grandson. But before the media attention to the fracking surge, few people heard of the disaster. "It barely got a mention in the newspaper," says Fred Baldassare of ECHELON Applied Geoscience Consulting in Murrysville, Pennsylvania.

Now, researchers are examining how often Pennsylvania's fracking wells encounter similar problems by analyzing a well inspection database assembled by the state's Department of Environmental Protection (DEP). One effort, led by Susan Brantley of Pennsylvania State University (Penn State), University Park, concluded that inspectors found well construction problems at 3.4%, or 219, of the 6466 wells examined between 2008 and 2013; 16 were cited for leaking methane into ground water, her team reported in a review in *Science* (17 May 2013, p. 826), updated this month in the *International Journal of Coal Geology*. "From what we can see," she says, "the frequency of big problems is pretty low."

That estimate is probably too low, says engineer Anthony Ingraffea of Cornell University, who has also been analyzing the DEP records. He and colleagues pored over some 75,000 records for 41,000 gas wells inspected between 2000 and 2012. Using statistical techniques to make up for variations in how thoroughly inspectors scrutinize wells and document their visits, they estimate that at least 6% of Pennsylvania's more than 7000 fracking wells have compromised casings, compared with 1% of conventional wells. The findings are in review at the *Proceedings of the National Academy of Sciences* (*PNAS*), but the team is already trying to figure out why fracking wells have the much higher rate of problems. The numbers also suggest that more than 45% of wells fracked in northeast Pennsylvania since 2009 will end up leaking.

And worse is yet to come, he fears. The number of wells is still climbing, despite a recent slowdown. Drillers may be just 8% of the way toward exhausting the Marcellus Shale, he notes, although estimates of the amount of recoverable gas vary. "The cumulative impact will be unbelievable," Ingraffea predicts.

Although methane itself isn't toxic, the gas can stir up metals and minerals, particularly in old water wells. The key question for most people is whether any of the leaking methane is reaching their drinking water.

In a heavily drilled part of northeastern Pennsylvania, one study suggests that the answer is yes. A team led by Stanford's Jackson, then at Duke University in Durham, North Carolina, measured concentrations of methane at 141 drinking water wells in six counties, an area that includes Dimock. Wells within 1 kilometer of a natural gas well had methane concentrations that were six times greater than those of more distant water sources, they reported in *PNAS* in July 2013. And the chemical signature of the gas (determined by isotopic studies) closely resembled that of gas from the Marcellus Shale. The problem, they believe, was defective casings in fracking wells.

Sherry Vargason can ignite her kitchen faucet.

Industry experts agree that the errant gas leaked from faulty well casings. But they doubt that the source was the Marcellus. Instead, they think it came from younger, shallower geological formations not touched by fracking. About 80% of water wells in the region have some level of this methane, they note, which may be leaking into water wells through natural fractures. This possibility is suggested by several studies, including work in the May/June 2013 issue of *Groundwater* by geochemist Lisa Molofsky and colleagues at Cabot and at GSI Environmental Inc. in Houston, Texas. After analyzing methane data from 1701 water wells in northeastern Pennsylvania, Molofsky's team concluded that higher concentrations were linked to water wells located in val-

Searching for life in the deep shale

By **Elizabeth Pennisi**

For energy developers, the geological formation known as the Marcellus Shale represents a rich new source of natural gas. For environmental engineer Paula Mouser and geochemist Shikha Sharma, it represents a potentially rich source of new microbes.

Following up on some tantalizing but unconfirmed clues, the pair is looking for life in the deep, hot layers of rock—and considering how the gas boom might affect long-isolated ecosystems. Drilling companies care, too, because deep-dwelling microbes could corrode equipment, clog pipes, and even contaminate the gas. Microbes can "really affect the bottom line," says Mouser, who works at Ohio State University, Columbus.

"Next to nothing is known about the biodiversity of shale deposits," says Simon Malcomber of the National Science Foundation (NSF) in Washington, D.C., which is funding the work. Indeed, it's hard to imagine a more inhospitable environment than the Marcellus and similar gas-bearing formations (see map, p. 1467). The beds typically sit a kilometer or more down, where pressures are 500 times greater than those found at the surface, and temperatures exceed 70°C. One study in the 1990s, however, was able to culture microbes from shallower deposits of shale, but it came before genomic technologies made a more comprehensive look possible.

In 2012, Sharma—who works at West Virginia University in Morgantown—began to think deeper shale also hosted microbes. She was analyzing carbon isotopes in water from various kinds of wells and aquifers, looking for clues that would distinguish water coming from different underground sources. While studying a fracking well in Pennsylvania's Marcellus Shale, Sharma noticed that the water flowing out of the well "had a very different signature" than what had been injected. The data suggested that the returning fluid had

PHOTO: MARK THIESSEN

Some landowners complain about leaks from pipes carrying wastewater from fracking sites.

leys, where abundant natural fractures allow gas to escape from shallow sources. In addition, Molofsky and others suspect that the study by Jackson's team may have been biased, because it focused on an atypical contamination incident.

Industry experts also argue that leak risks are going down as drilling companies better understand the complexities of local geology and fracking well design. They are using cements enhanced with latex and other additives to plug natural fractures in the rock, for instance. And they routinely run geophysical tests during drilling to check for problems. It's the kind of practical experience that can't be gained in a research lab or during a drilling moratorium, ECHELON's Baldassare notes. Ingraffea and others, however, remain dubious that leaks will decline.

RESOLVING WHETHER FRACKING is a serious threat to water quality will take time. EPA's ambitious nationwide study, which Congress requested in 2009, has been slowed by political controversies over its scope. It's also a technical and logistical challenge, involving far-flung field studies. Another major obstacle is the lack of predrilling data about water quality in many areas. Although gas companies have tested tens of thousands of water wells above active and potential fracking zones, they haven't widely shared the data. "The lack of baseline information is a really serious issue," says Kate Sinding of the Natural Resources Defense Council in New York City.

Some clarity could come from an unusual situation found along the New York–Pennsylvania border. New York hasn't yet allowed fracking in its part of the Marcellus Shale, so researchers are parachuting into the border zone to quickly document water quality before a single new well is drilled. Laura Lautz of Syracuse University in New York, for example, is analyzing samples from more than 200 homeowner wells chosen at random in southern New York.

A coarser but cheaper approach to assembling predrilling baselines could come from researchers at the U.S. Geological Survey (USGS) and partner institutions. Rather than sample scores of individual wells, they are measuring methane in streams, which collect ground and surface water from a large area. Preliminary work in Utah, North Carolina, and Pennsylvania suggests that the methane persists long enough in some types of streams to provide meaningful measurements, USGS hydrologist Victor Heilweil and colleagues reported in the July/August 2013 issue of *Groundwater*. If perfected, the approach "gives a better chance of seeing the big picture," Heilweil says.

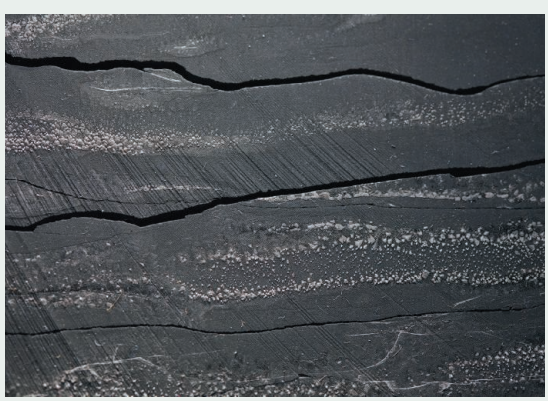
This approach could also allow concerned citizens to monitor the effects of drilling. Local groups, for example, could collect water samples, add chemicals to kill microbes that would otherwise consume any methane, and send the samples to a lab for analysis. Such monitoring methods need to mature, however, and researchers say it's also crucial to have more detailed and complete databases of drilling violations. Until then, the debate over fracking's impact on water quality is likely to endure. And for communities already experiencing drilling, says Penn State's Brantley, the shale gas boom is like "a giant experiment being run in our backyard." ■

mixed with deep water that either today or in the past was filled with microbes that produce methane, known as methanogens.

At about the same time, a team led by Mouser was finding similar hints in a study that screened flowback water from another Marcellus fracking well for microbial DNA. The early flowback contained a variety of salt-tolerant microbes that were not present in the injected water, the team reported online on 6 May in *Environmental Science & Technology*.

Mouser and Sharma suspect microbes are thriving in the brine that fills the shale's pores—and they are hoping their new NSF-funded study will prove it. This year, they plan to work with fracking companies to collect pristine shale samples from new boreholes, before injected surface water contacts the rock. They will get a full sense of what's down there by sequencing the microbial DNA. Then they will try to grow laboratory samples of any deep-living microbes they discover.

The information ultimately could help energy companies improve their methods, the researchers say. Drillers already add biocides to fracking fluids to protect against corrosion caused by bacteria, Mouser notes, but the chemicals might not be effective against deep-dwelling microbes. At the same time, certain fracking additives may actually promote the growth of some microbes, helping gum up wells. And if sulfide-producing microbes establish themselves, their waste products can contaminate the gas, lowering its value. ■



A chunk of Marcellus Shale, where fracking could affect microbes.

PHOTOS: (TOP TO BOTTOM) SCOTT GOLDSMITH; MARK THIESSEN