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Replenishing sapped groundwater could trigger small earthquakes

A boom in aquifer injection projects could unlock long-quiet faults

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Seismic stations in Virginia can sense tremors that may be triggered by recharging the Potomac Aquifer. RYAN POLLYEA

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Near the Atlantic Ocean, along the banks of the James River, 10 stainless steel pipes penetrate hundreds of meters into the silts and sands beneath southeastern Virginia. Next year, the Hampton Roads Sanitation District (HRSD) will begin to inject about 60 million liters of treated wastewater through the pipes each day, as part of a project to refill the giant but shrinking Potomac Aquifer, which stores water underground in the pore spaces of compacted layers of sand. When completed, the $2.8 billion project will be the largest of its kind in the Mid-Atlantic region.

Similar projects are planned or underway elsewhere in the country, all aiming to keep water flowing to households, businesses, and farms that have overpumped aquifers for decades. But the projects could come with an unwanted side effect: earthquakes. “Anytime fluids are injected deep underground and in large volumes, injection-induced seismicity is a concern,” says Ryan Pollyea, a geoscientist at the Virginia Polytechnic Institute and State University (Virginia Tech) who leads a research project related to the Virginia injection project, the Sustainable Water Initiative for Tomorrow.

Aquifers supply about half of the United States’s freshwater. Overpumping has drawn down these reserves, leading to sinking of the overlying land and, in places where oceans are nearby, saltwater intrusions. In southeastern Virginia—an area already vulnerable to rising sea levels—water levels in the Potomac Aquifer have dropped more than 30 meters in some places, says HRSD hydrogeologist Dan Holloway.

Water managers in California’s Orange County began to experiment with recharging aquifers nearly a century ago, says Adam Hutchinson, recharge planning manager for the Orange County Water District. Initially, they simply let water seep into the ground naturally, from giant holding ponds. But such surface water recharge is slow, and works best in places with large tracts of undeveloped land and loose, permeable soils. (The Potomac Aquifer, in contrast, is capped by a thick clay “lid” that inhibits natural recharge.)

So in the 1970s, Orange County sped up the process by taking water purified to drinking standards at sewage treatment plants and injecting it directly into the depleted aquifers. Hutchinson says the projects helped restore pressure in the aquifer, keeping saltwater intrusions from the Pacific Ocean at bay, while allowing Orange County farmers and residents to maintain their water-hungry ways. The country took notice: Water managers from Texas to Florida began to implement their own injection projects.

But Earth’s bedrock is full of faults, weak zones where slabs of crust grind past one another and generate earthquakes. Many sit dormant in the “basement” rocks below aquifers. When injected water seeps into these rocks, it raises the pore pressure—taking some of the load off the rocks. This decreases the stresses that normally keep faults clamped shut, leading to slip—and earthquakes.

“[When] the crust is in a very critical state, it requires a very small modification in the stress system to trigger some earthquakes,” says Nicola D’Agostino, a geodesist at Italy’s National Institute of Geophysics and Volcanology. Such earthquakes can take months or even years to show up, and they can appear tens of kilometers beyond the injection site. Even if injection stops, years of tremors may already be baked in. “It is not a simple switch on, switch off problem,” says Pier Luigi Bragato, a seismologist at Italy’s National Institute of Oceanography and Applied Geophysics.

No earthquakes tied to aquifers have yet been reported, but human-induced seismicity has unfolded countless times

in the oil and gas industry, which injects wastewater from fracking operations into deep rock layers that are disconnected from aquifers. In Oklahoma and Texas, these "astronomical volumes" can trigger daily quakes, says Katie Smye, a geologist at the Bureau of Economic Geology at the University of Texas at Austin. Although most are too small to feel, a 2011 magnitude 5.7 quake in Oklahoma destroyed homes and buckled a highway, and a magnitude 5.4 quake in Texas caused the evacuation of a hospital building in 2022.

In 2019, HRSD approached Pollyea, who previously studied seismicity tied to oil and gas, to look at the earthquake threat from its plans. He and his team set up five seismic stations around the planned injection sites to establish a baseline of the region's background rumblings. They also built a geological model of the aquifer and other subsurface layers, applying estimates of the rocks' properties and the orientation of known faults. The model also factors in the speed of injection, which determines whether fluid pressure is forced deeper into fault-ridden rocks.

The SWIFT Research Center in Suffolk, Virginia, has been testing injecting treated wastewater into the Potomac Aquifer since 2018, with no reported seismic effects. PETER MEANS FOR THE VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Using the model, Pollyea and his team tested proposed injection rates as high as nearly 10 million liters per day per well—some 50% greater than planned. The highest injection rate resulted in a pore pressure less than one-sixth of the pressure in a car tire, but still enough to cause seismicity, they reported in a paper in June. Last month, they reported more reassuring news for the Virginia project: A relatively impermeable layer of clay in the Potomac Aquifer should slow the seepage of water into basement rocks, potentially limiting earthquakes.

Demand for aquifer recharge may grow in regions such as California and Virginia because of thirsty data centers, which need vast amounts of water to cool the computers that power artificial intelligence, says Lorrie Council, underground injection control policy director at the nonprofit Ground Water Protection Council. "That stresses the whole water supply," she says. "I think we're going to see more [injection projects] in the future in places you wouldn't necessarily expect." She is already discussing aquifer injection projects in historically water-rich states such as Washington, Oregon, and Ohio.

That's all the more reason to ensure that earthquakes don't derail otherwise promising aquifer injection projects, D'Agostino says. Given Virginia's relatively quiet crust, dangerous quakes that cause severe damage are unlikely. But

"imagine, suddenly, you get earthquakes in places where they were very rare before," he says. Even if small, people are sure to notice—and infrastructure might not be designed to withstand it. And multiple small earthquakes increase the probability of a larger one, adds John Ogunleye, a geoscience graduate student in Pollyea's lab at Virginia Tech.

As these projects come online, it's important to keep in mind that "we do not control how the earth responds to our forcing," D'Agostino says. "As soon as we start interfering with the crust, we should be careful."

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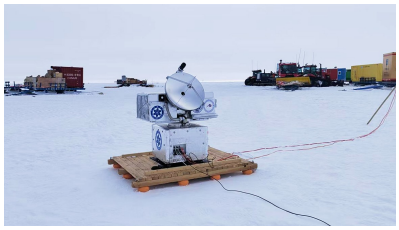

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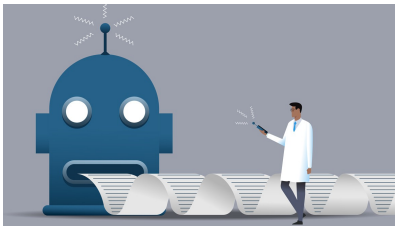

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