Wastewater injection spurred biggest earthquake yet, study finds

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A 2011 magnitude 5.7 quake near Prague, Okla., apparently triggered by wastewater injection, buckled U.S. Highway 62. Credit: (ohn Leeman

A new study in the journal *Geology* is the latest to tie a string of unusual

earthquakes, in this case, in central Oklahoma, to the injection of wastewater deep underground. Researchers now say that the magnitude 5.7 earthquake near Prague, Okla., on Nov. 6, 2011, may also be the largest ever linked to wastewater injection. Felt as far off as Milwaukee, more than 800 miles away, the quake—the biggest ever recorded in Oklahoma—destroyed 14 homes, buckled a federal highway and left two people injured. Small earthquakes continue to be recorded in the area. The study appeared today in the journal's early online edition.

The recent boom in U.S. energy production has produced massive amounts of wastewater. The water is used both in hydrofracking, which cracks open rocks to release natural gas, and in coaxing petroleum out of conventional oil wells. In both cases, the brine and chemical-laced water has to be disposed of, often by injecting it back underground elsewhere, where it has the potential to trigger earthquakes. The water linked to the Prague quakes was a byproduct of oil extraction at one set of oil wells, and was pumped into another set of depleted oil wells targeted for waste storage.

Scientists have linked a rising number of quakes in normally calm parts of Arkansas, Texas, Ohio and Colorado to below-ground injection. In the last four years, the number of quakes in the middle of the United States jumped 11-fold from the three decades prior, the authors of the *Geology* study estimate. Last year, a group at the U.S. Geological Survey also attributed a remarkable rise in small- to mid-size quakes in the region to humans. The risk is serious enough that the National Academy of Sciences, in a report last year called for further research to "understand, limit and respond" to induced seismic events. Despite these studies, wastewater injection continues near the Oklahoma earthquakes.

The magnitude 5.7 quake near Prague was preceded by a 5.0 shock and followed by thousands of aftershocks. What made the swarm unusual is that wastewater had been pumped into abandoned oil wells nearby for 17

years without incident. In the study, researchers hypothesize that as wastewater replenished compartments once filled with oil, the pressure to keep the fluid going down had to be ratcheted up. As pressure built up, a known fault—known to geologists as the Wilzetta fault—jumped. "When you overpressure the fault, you reduce the stress that's pinning the fault into place and that's when earthquakes happen," said study coauthor Heather Savage, a geophysicist at Columbia University's Lamont-Doherty Earth Observatory.

The amount of wastewater injected into the well was relatively small, yet it triggered a cascading series of tremors that led to the main shock, said study co-author Geoffrey Abers, also a seismologist at Lamont-Doherty. "There's something important about getting unexpectedly large earthquakes out of small systems that we have discovered here," he said. The observations mean that "the risk of humans inducing large earthquakes from even small injection activities is probably higher" than previously thought, he said.

Hours after the first magnitude 5.0 quake on Nov. 5, 2011, University of Oklahoma seismologist Katie Keranen rushed to install the first three of several dozen seismographs to record aftershocks. That night, on Nov. 6, the magnitude 5.7 main shock hit and Keranen watched as her house began to shake for what she said felt like 20 seconds. "It was clearly a significant event," said Keranen, the *Geology* study's lead author. "I gathered more equipment, more students, and headed to the field the next morning to deploy more stations."

University of Oklahoma seismologist Katie Keranen (left) and Oklahoma State University geophysicist Estella Atekwana install a seismometer following a series of earlier quakes. Credit: Shannon Dulin

Keranen's recordings of the magnitude 5.7 quake, and the aftershocks that followed, showed that the first Wilzetta fault rupture was no more than 650 feet from active injection wells and perhaps much closer, in the same sedimentary rocks, the study says. Further, wellhead records showed that after 13 years of pumping at zero to low pressure, injection pressure rose more than 10-fold from 2001 to 2006, the study says.

The Oklahoma Geological Survey has yet to issue an official account of the sequence, and wastewater injection at the site continues. In a statement responding to the paper, Survey seismologist Austin Holland said the study showed the earthquake sequence could have been

triggered by the injections. But, he said, "it is still the opinion of those at the Oklahoma Geological Survey that these earthquakes could be naturally occurring. There remain many open questions, and more scientific investigations are underway on this sequence of earthquakes and many others within the state of Oklahoma."

The risk of setting off earthquakes by injecting fluid underground has been known since at least the 1960s, when injection at the Rocky Mountain Arsenal near Denver was suspended after a quake estimated at magnitude 4.8 or greater struck nearby—the largest tied to wastewater disposal until the one near Prague, Okla. A series of similar incidents have emerged recently. University of Memphis seismologist Stephen Horton in a study last year linked a rise in earthquakes in north-central Arkansas to nearby injection wells. University of Texas, Austin, seismologist Cliff Frohlich in a 2011 study tied earthquake swarms at the Dallas-Fort Worth Airport to a brine disposal well a third of a mile away. In Ohio, Lamont-Doherty seismologists Won-Young Kim and John Armbruster traced a series of 2011 earthquakes near Youngstown to a nearby disposal well. That well has since been shut down, and Ohio has tightened its waste-injection rules.

Wastewater injection is not the only way that people can touch off quakes. Evidence suggests that geothermal drilling, impoundment of water behind dams, enhanced oil recovery, solution salt mining and rock quarrying also can trigger seismic events. (Hydrofracking itself is not implicated in significant earthquakes; the amount of water used is usually not enough to produce substantial shaking.) The largest known earthquakes attributed to humans may be the two magnitude 7.0 events that shook the Gazli gas fields of Soviet Uzbekistan in 1976, followed by a third magnitude 7.0 quake eight years later. In a 1985 study in the Bulletin of the Seismological Society of America, Lamont-Doherty researchers David Simpson and William Leith hypothesized that the quakes were human-induced but noted that a lack of information

prevented them from linking the events to gas production or other triggers. In 2009, a geothermal energy project in Basel, Switzerland, was canceled after development activities apparently led to a series of quakes of up to magnitude 3.4 that caused some $8 million in damage to surrounding properties.

In many of the wastewater injection cases documented so far, earthquakes followed within days or months of fluid injection starting. In contrast, the Oklahoma swarm happened years after injection began, similar to swarms at the Cogdell oil field in West Texas and the Fort St. John area of British Columbia.

The Wilzetta fault system remains under stress, the study's authors say, yet regulators continue to allow injection into nearby wells. Ideally, injection should be kept away from known faults and companies should be required to provide detailed records of how much fluid they are pumping underground and at what pressure, said Keranen. The study authors also recommend sub-surface monitoring of fluid pressure for earthquake warning signs. Further research is needed but at a minimum, "there should be careful monitoring in regions where you have injection wells and protocols for stopping pumping even when small earthquakes are detected," said Abers. In a recent op-ed in the Albany (N.Y.) Times Union, Abers argued that New York should consider the risk of induced earthquakes from fluid injection in weighing whether to allow hydraulic fracturing to extract the state's shale gas reserves.

Provided by Columbia University