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The Shale Revolution and Earthquakes

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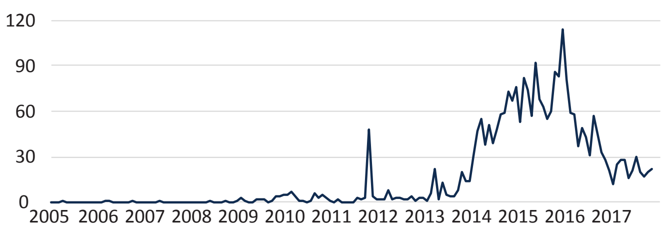
In some states, particularly Oklahoma, oil and gas activities have led to a sharp rise in human-caused earthquakes, also known as “induced seismicity.” In Oklahoma, the number of quakes registering 3.0 or greater in magnitude (the threshold where quakes are typically felt at the surface) grew dramatically through 2016. While most are too small to cause damage, several quakes of magnitude 5.0 or greater have damaged homes, businesses, and other infrastructure, though no major injuries or fatalities have been reported. This brief provides an overview of the key causes of these quakes, along with how new technologies and policies can reduce the risks.

Figure 1. Monthly Count of OK Earthquakes, ≥3.0M



Data source: US Geological Survey

Earthquakes Caused by Fracturing or Depletion

While many news headlines have described induced seismicity as being caused by “fracking,” there are a relatively small number of cases where hydraulic fracturing has directly caused earthquakes. Researchers have identified a small number of minor quakes in Ohio, Oklahoma, Texas, and the United Kingdom where hydraulic fracturing appears to be the primary cause. However, quakes in Canada linked directly to hydraulic fracturing have registered as high as 4.6 in magnitude.

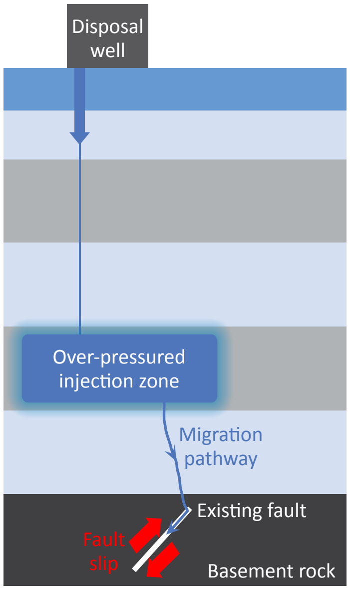
Disturbances in some cases may also be caused by oil or gas depletion. One well-documented case occurred in Long Beach, California, where parts of the city sank by more than 20 feet due to the reduced underground pressures caused by oil extraction (the problem was halted when operators began pumping water into the underground formations to maintain pressure). Many earthquakes in the Netherlands have also been linked to depletion of natural gas.

Earthquakes Caused by Wastewater Disposal

The vast majority of growth in human-caused earthquakes associated with oil and gas development in the United States has been linked to the disposal of oil and gas wastewater. Every oil and gas well produces at least some wastewater—regardless of whether it is hydraulically fractured—in some cases generating 20 or more barrels of water for every barrel of oil. The water that is comingled with oil and gas deep underground is called “produced water,” while water used for hydraulic fracturing that returns to the surface is known as “flowback.” In most regions, produced water volumes are

RFF’s Alan Krupnick and Isabel Echarte published *Induced Seismicity Impacts of Unconventional Oil and Gas Development* (www.rff.org/seismicityimpacts), which reviews the seismicity literature as part of a broader assessment of the impacts of fracking. Studies are generally retrospective, establishing a relationship between seismicity and oil and gas activities. Recently, some work has moved to assess the probability of future seismic events, but almost none assess the above-ground impacts of induced seismicity.

* This is one of a series of issue briefs based on *The Fracking Debate: The Risks, Benefits, and Uncertainties of the Shale Revolution* (Columbia University Press, 2017) by Daniel Raimi. Raimi is a senior research associate at Resources for the Future.



larger than flowback volumes, though both must be managed carefully due to the contaminants they contain.

Oil and gas wastewater is often injected deep underground into disposal wells, sited in locations where geological conditions prevent the contaminated water from migrating upward and damaging usable aquifers. In some locations, including in Oklahoma, the large volumes of wastewater pumped into some of these underground formations have substantially increased underground pressures, and water has migrated downward from its intended destination. In some cases, this water has encountered natural pathways that allow it to flow to existing faults in deeper rock formations known as "basement rock." Under the right geological conditions, the addition of this new fluid will alter subterranean pressures enough to allow a fault to slip, causing an earthquake. This has been the primary cause of the Oklahoma earthquakes, along with quakes in Arkansas, Kansas, Ohio, and Texas. Notably, most injection wells do not cause earthquakes, and there has been little or no increase in shale states such as Colorado, North Dakota, and Pennsylvania (though very little wastewater injection occurs in Pennsylvania).

Strategies to Prevent and Reduce Earthquakes

Companies, regulators, and researchers have increasingly collaborated to identify the causes and reduce the prevalence of these quakes. In Oklahoma, after moving slowly for several years, stakeholders collaborated to identify injection zones where wastewater injections were most likely to induce quakes, and regulators restricted the volumes disposed of in those locations. As the figure on page 1 shows, these reductions have helped reduce the number of quakes in Oklahoma since their implementation in 2015, though lower production and associated wastewater levels have also played a role.

A number of states, including Oklahoma, Ohio, Pennsylvania, and Texas have deployed or enhanced seismic monitoring arrays, which are able to detect very small quakes. Because these small quakes are often precursors for larger, potentially damaging seismic events, regulators and operators can use real-time data from these arrays to halt or adjust underground activities, substantially reducing the risks. These technologies have enabled states to deploy "stoplight" systems, where operators receive "go," "caution," or "stop" indicators for wastewater disposal and fracturing based on real-time seismic data.

Additionally, researchers have partnered with regulators in some states to develop better maps of underground fault networks, which could help operators and regulators better understand areas of concern.

The Value of Proactive Policy

Many of the measures described above represent proactive steps taken by regulators to anticipate and prepare for problems before they occur. However, policy responses in the early 2010s moved relatively slowly in some states, particularly in Oklahoma. The rapid growth in earthquakes that ensued led to widespread popular media coverage which, in many cases, mischaracterized the cause of the seismic events, helping cement in the public imagination the notion that "fracking" causes earthquakes.

The relatively slow response also means that quakes are likely to continue in Oklahoma, perhaps for years. Even with reductions in the volumes of wastewater injection, the underground pressures that have built up over time will disperse slowly. In another case of induced seismicity, where waste material from chemical weapons manufacturing was disposed of deep underground in Colorado in the 1960s, quakes lasted for several years even after injections were completely halted.

Looking forward, the combination of better mapping of fault networks, deployment of seismic arrays, careful monitoring by regulators and operators, and "stoplight" systems can reduce—though likely not eliminate—the risk of earthquakes associated with hydraulic fracturing and wastewater disposal.