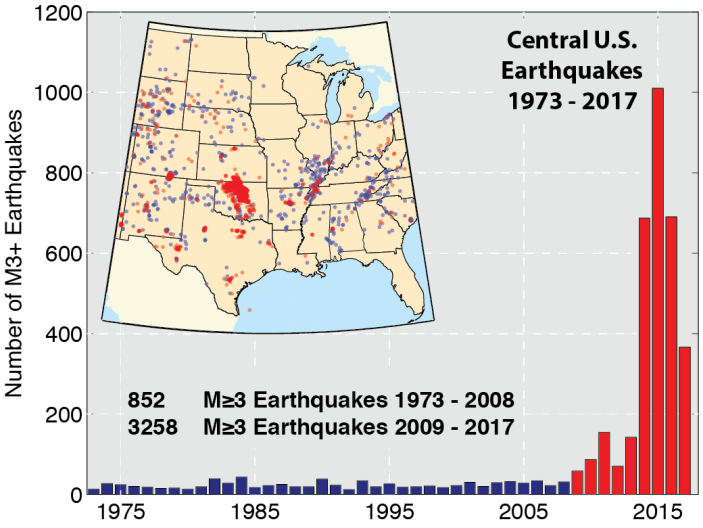
Induced Seismicity from Oil and Gas Operations

Earthquakes caused by wastewater disposal and hydraulic fracturing

Manmade Earthquakes

Any activity that significantly changes the pressure on or fluid content of rocks has the potential to trigger earthquakes. This includes geothermal energy production, water storage in large reservoirs, groundwater extraction, underground injection of water for enhanced oil recovery, and large-scale underground disposal of waste liquids.[1] The fact that underground fluid injection can trigger damaging earthquakes has been understood since the 1960s, but historically such earthquakes have been very rare.[2] The sharp rise in noticeable earthquakes in the central United States from 2008 to 2015 was caused by massive increases in the underground disposal of produced water from the oil and gas industry.[3] Since mid-2015, declining rates of produced water disposal have led to fewer earthquakes in the central United States.

Hydraulic fracturing has caused some small earthquakes, but these are comparatively unusual: in a 2016 study of Canadian wells, 0.3% of hydraulically fractured wells were linked to earthquakes of at least magnitude 3.[4]



The sharp rise in small but noticeable earthquakes in the central United States, caused largely by huge increases in the underground disposal of produced water from oil and gas production. M = magnitude (see blue box). Image credit: U.S. Geological Survey[5]

Earthquakes Caused by Wastewater Disposal

In the central United States, particularly in central Oklahoma and south-central Kansas, the oil and gas boom in the early 2000s vastly increased the amount of produced water in need of disposal. Across the region, as more water was injected in deep disposal wells, earthquake activity increased:

- In Oklahoma, wastewater disposal rates tripled from 1 million barrels per day in 2010 to almost 3 million in 2014. Before 2008, Oklahoma had only a few earthquakes larger than magnitude 3 (M>3) per year; in 2014 the state had 579; and in 2015 there were 903 M>3 earthquakes in Oklahoma. These earthquakes clustered in areas with many large-volume disposal wells, strengthening the link between underground water disposal and induced earthquakes.[3] In 2015, underground water disposal began to decline, and in 2016 the number of M>3 earthquakes decreased to 623. This decline in underground disposal of produced water reflects both reduced production (due to lower oil prices) and state regulations.[3]

Induced Seismicity: Fast Facts and Figures

- 2.5 billion gallons of water are produced every day in the U.S. from about 900,000 oil and gas wells.[6] That's 7.5 gallons per U.S. resident per day.
- Roughly 90% of all produced water is injected[6] into roughly 150,000 wells: 40,000 are used only for wastewater disposal and the rest inject water for enhanced oil recovery.[7]
- Earthquakes caused by underground wastewater disposal have been most common and powerful in Oklahoma.[8]
- In Oklahoma, earthquake activity peaked in early 2015, with roughly three M>3 earthquakes every day.[9] From early 2015 to early 2017, earthquake activity decreased to less than one M>3 earthquake per day as less wastewater was injected underground.[3]

Damage caused by the magnitude 5.7 earthquake near Prague, Oklahoma, November 6, 2011. Unreinforced stone and brick buildings (especially chimneys) are some of the most vulnerable structures in any earthquake. Image credit: Brian Sherrod, USGS[10]

- In south-central Kansas, deep wastewater disposal volumes increased roughly tenfold from 2011 to 2014. In Harper and Sumner counties, which historically do not experience M>3 earthquakes in most years, over 100 M>3 earthquakes were recorded in 2015.[11] From 2015, decreasing injection volumes were followed by a decrease in earthquakes, and in 2016 there were fewer than 20 M>3 earthquakes in all of Kansas.[12] In 2017, Kansas saw slightly more earthquakes, but overall earthquake activity remained low.
- Texas went from having roughly two M>3 earthquakes per year before 2008 to around 12 per year from 2011 to 2016.[13]

Other areas that have seen noticeable earthquakes induced by wastewater disposal (in much lower numbers than Oklahoma) include Colorado, New Mexico, Arkansas, Ohio, and Wyoming.

Earthquakes Caused by Hydraulic Fracturing

Hydraulic fracturing does not generally cause earthquakes large enough to be felt (M>3), but there have been some exceptions:

- A study in Canada linked roughly 0.3% of hydraulically fractured wells to M>3 earthquakes.[4] Although most of these earthquakes occur close to and at the same time as hydraulic fracturing operations, a small percentage of induced earthquakes may occur months later.[14]
- In Ohio, both Poland Township (2014) and Harrison County (2015) have experienced M3 earthquakes caused by hydraulic fracturing.[3,15]
- In Oklahoma, some small (mostly ≤ M3) earthquakes have been linked to hydraulic fracturing in a small proportion of hydraulically fractured wells.[3]

Earthquake Risk Management and Mitigation by States

State regulators focus on identifying the precise location and magnitude of an earthquake and then determining its cause. If earthquakes are linked to wastewater injection, regulators can instruct operators to cease or limit injection rates and water volumes in nearby wells.[16,17] Many regulators also require that new injection wells avoid areas near known active faults. In Oklahoma, these techniques have effectively reduced the number of felt earthquakes.[3] Similar procedures have been applied to hydraulic fracturing operations in some states (e.g., Ohio): if earthquakes are detected, operations must be modified or suspended.[3]

Produced Water

Most oil- and gas-bearing rocks also contain water. When this is extracted along with oil and gas, it is called "produced water". For more on produced water reuse and disposal, see "Using Produced Water" in this series.

Earthquake Magnitude

Earthquake magnitude (M) describes the amount of energy released by an earthquake. For every two units of magnitude, the energy release is roughly 1000 times larger. M3 and larger can often be felt, and M5 can cause moderate damage. The largest earthquakes are all naturally occurring and can reach M9 or greater. Underground wastewater disposal has been linked to earthquakes as large as M5.8 in Oklahoma.[18]

References & More Resources

For a complete listing of references, see the "References" section of the full publication, *Petroleum and the Environment*, or visit the online version at: www.americangeosciences.org/critical-issues/petroleum-environment