Swiss Re

The link between hydrofracking, wastewater injection and earthquakes: key issues for re/insurers

Introduction

The scale of increased earthquake activity in Oklahoma over recent years is unparalleled. Since 2008 the number of magnitude 3.0 earthquakes per year has grown from roughly 2 per year to an average of nearly 3 per day. This now makes Oklahoma the most seismically active of the lower forty-eight states. It's highly likely that this dramatic rise in earthquake occurrence is largely a consequence of human actions. Along with the increase in seismicity, Oklahoma has seen a growth in its oil and natural gas operations since 2008, specifically hydraulic fracturing (often referred to as "hydrofracking" or "fracking") and the disposal of wastewater via deep well injection. Both hydrofracking and deep well injection involve pumping high-pressure fluids into the ground. A consensus of scientific opinion now links these practices to observed increases in seismic activity. Earthquakes where the cause can be linked to human actions are termed "induced earthquakes", and present an emerging risk of which the insurance industry is taking note.

While they've been most abundant in Oklahoma, induced earthquakes have been on the rise in many parts of the United States (Figure 1), and beyond. The worldwide growth of the hydrofracking industry has brought several emerging risks to the attention of the insurance industry (see Swiss Re's *SONAR: new emerging risk insights* report, 2015). Induced earthquakes add another dimension. Not only is there an increased risk of a damaging natural catastrophe, but there's also a risk of liability for that damage. A large induced earthquake will lead to complexity and confusion in determining how to compensate damaged parties. A large proportion of property not insured against earthquake damage in the affected regions may compound the problem. Furthermore, some insurers and reinsurers have a potential for loss accumulation through property and casualty lines of business that may not have been considered previously.

In this paper, we summarize the relevant scientific background of why the hydrofracking industry boom has led to increased earthquake activity, especially in Oklahoma. We explain current understanding of how earthquakes are induced and some difficulties of establishing causality for a specific earthquake, after it has occurred. To quantify the current risk landscape, we present results from our in-house earthquake loss model after updating earthquake frequencies to a level observed in recent years. We further consider other key issues for insurers and reinsurers, such as liability precedents, the low penetration of earthquake insurance, and the potential influence of oil industry regulation. Throughout this paper, we focus on Oklahoma where the issue is most acute. However, induced earthquakes are also on the rise in Kansas, Texas, Western Canada and elsewhere. Our final suggestions as to how our industry can better respond to this emerging risk are relevant far beyond the boundaries of Oklahoma.

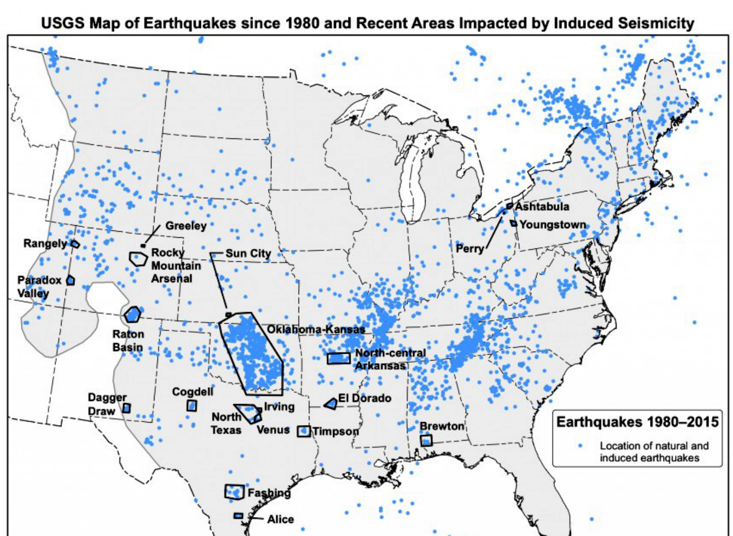


Figure 1: United States Geologic Survey map of earthquake activity (magnitude 2.5 and larger) in the central and eastern US since 1980. The 21 regions of suspected induced seismicity are highlighted.[1]

Hydrofracking and wastewater injection

Whereas the increased seismic activity in the central part of the US is a new phenomenon, the process of hydrofracking isn't. The method, conceived in the mid-20th century,[2] has been in use for decades. The practice began by using vertical wells. However, in recent years the industry has also applied the technique to horizontal and directional wells which has allowed for improved production. Hydrofracking deploys a high-pressure, water-based solution to create a network of fractures deep within the rock formation. The increase in fluid pathways allows well operators to extract more oil or gas from the rock. Depending on the local geology and practices of the well operator, the injected fluid contains varying levels of chemicals that are used to improve efficiency of the well.[3] A "propping agent", usually sand, is also injected to preserve the newly created conduits so oil and gas can flow upward.

During the course of normal well operations, the production of a vast quantity of wastewater (millions of gallons per well) is unavoidable. Some of this wastewater is "produced water", ie saltwater previously trapped within the rock along with the oil or gas. The rest of the wastewater is "frac flow-back", the water-based fluid injected during the hydrofracking process. The ratio of these two wastewater types varies by the region of production, but in Oklahoma, most of the wastewater is produced water.[4]

Wastewater is not suitable for human consumption or agricultural use and can often be extremely hazardous. The common practice in Oklahoma is to dispose of it by injection into a deep well that extends far below the aquifers used for drinking water. In some cases, the fluid is used for enhanced oil recovery where it is injected into an older oil or gas reservoir to squeeze out the last remaining reserves. The rate of wastewater injection varies substantially from well to well, but can be astonishingly high – up to 1 million barrels a month.[5] Oklahoma disposed of over 6 billion barrels of wastewater from 2009–2014.[6]

Inducing earthquakes

Hydrofracking itself creates very small magnitude earthquakes during the process of fracturing the rock. These earthquakes are so small that they're generally not felt at the surface. In some cases, however, the process has been linked to stimulating larger earthquakes. This is especially true in Western Canada, where 62% of the 258 magnitude 3.0+ earthquakes recorded from 1985-2015 have been associated with hydrofracking wells.[7]

The vast majority of the earthquakes associated with hydrofracking are actually related to wastewater injection. This is because wastewater injection involves pumping large volumes of fluid at high pressure in a less targeted manner than the hydrofracking process. Injecting fluid deep into the ground changes the balance of tectonic stresses within the rock. This can push pre-existing faults closer to the point of failure and cause an earthquake.

Research has shown that some locations may be more prone to induced earthquakes than others. In mid-2015, there were roughly 35,000 wastewater disposal wells active in the US, with an additional 80,000 injection wells being used for enhanced oil recovery.[8] However, only a small fraction have been associated with felt earthquakes. There is still debate over whether the factors influencing a disposal well can be linked to an increase in earthquake activity. It's clear that geological and geophysical factors such as rock types, pre-existing fault planes, and pre-existing levels of seismic hazard will all play a role. However, so far no one can reliably predict when and where induced earthquakes will occur.

At present, there's no definitive method to distinguish between a naturally occurring earthquake and one induced by human actions. Although induced earthquakes tend to be shallower, the properties of induced and natural earthquakes are otherwise relatively similar. When earthquakes have occurred near a disposal well, researchers have used statistical methods and time series analysis to determine a probability that they were induced. In many cases, we can be near-certain, but it is unlikely there will ever be 100% certainty. Even if an earthquake is judged to have been induced, it might be difficult to determine the well specifically responsible when there are several in the vicinity. Another problem is the lack of a clear distinction between directly induced earthquakes and earthquakes triggered by previously induced earthquakes. These are all important questions in the context of establishing liability for damages, and it's not clear how it may be addressed by a court in the future.

Historical precedents

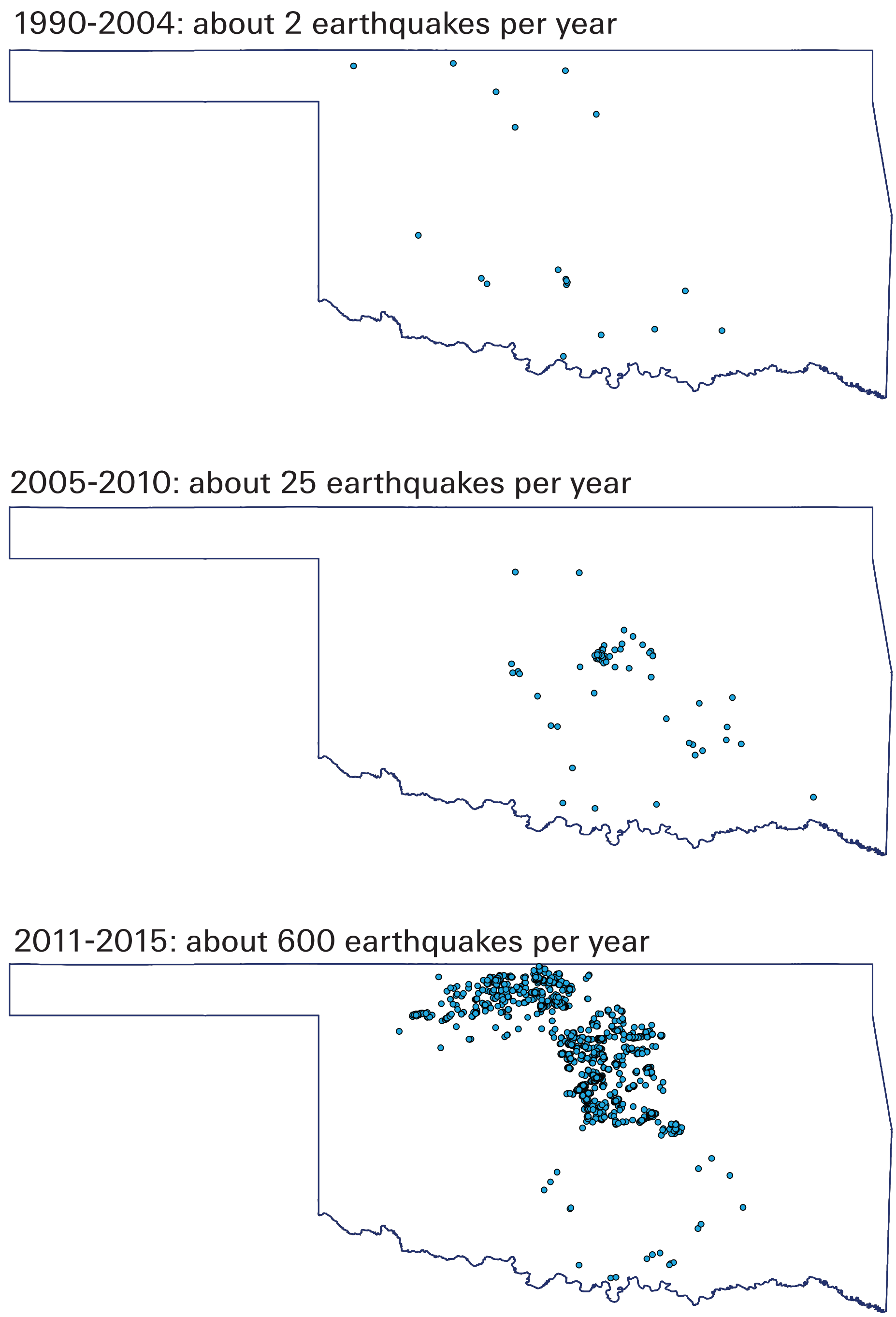
The largest earthquake linked by scientists to wastewater disposal is the 2011 magnitude 5.6 Prague, Oklahoma earthquake, which was also the largest earthquake ever recorded in the state.[9] More recently, in February 2016, a magnitude 5.1 earthquake occurred in northwest Oklahoma, and was the third largest in the state's history. The shaking from both of these events affected sparsely populated regions but caused notable damage to nearby buildings, knocking over chimneys and cracking building walls. Closer to Oklahoma City, around the town of Edmond, a pair of earthquakes during the 2016 New Year period with magnitude 4.3 and 4.2 interrupted power for 4,400 residents.

The issue of induced seismicity is global and not strictly limited to the hydrofracking industry. The potentially high cost of induced earthquakes is highlighted by examples in Switzerland and the Netherlands. Earthquakes were induced during development of geothermal operations near the Swiss cities of Basel and St. Gallen. In Basel, several earthquakes exceeded magnitude 3 and led to the cancellation of the project and insurance claims of about USD 6-8 million. In the Netherlands, hundreds of damaging earthquakes have been linked to production of the Groningen gas field. In 2015, courts ruled that energy companies should compensate residents for damage and declining property values. It has been reported that the producer has set aside USD 1.35 billion for this compensation.[10]

Oklahoma's seismic shift

The recent rise of induced earthquakes is most significant in the state of Oklahoma. In 2015 alone, the United States Geologic Survey (USGS) reported nearly 900 earthquakes of magnitude 3.0 or larger in the state. In contrast, the 35 years leading up to 2005 showed a steady rate of around 1 to 3 earthquakes per year (see Figure 2 and Figure 3). A consensus of academic opinion agrees that the overall rise in seismic activity in Oklahoma is connected to widespread wastewater injection. Although the state is littered with faults and a few naturally occurring earthquakes would be expected, an increase in earthquake activity like this can't be explained by our understanding of natural tectonic activity.

Figure 2: Blue shading highlights the location of seismic activity within the boundaries of Oklahoma during three different time periods. Prior to 2004, earthquakes were rare and sparsely distributed across the state. Recently, earthquake activity is concentrated in the center of the state and toward the Kansas border, concurrent with the expansion of wastewater disposal practices in the state.



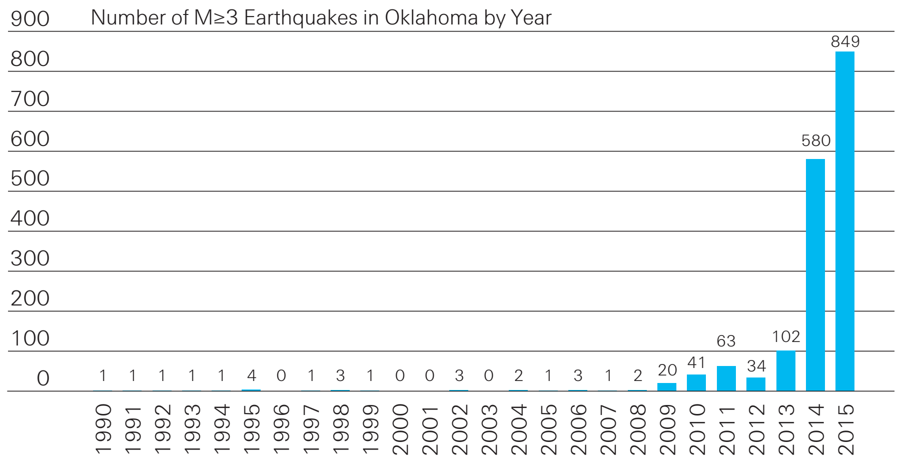


Figure 3: Number of magnitude 3.0 or larger earthquakes in Oklahoma since 1990 according to the USGS, as of June 1, 2016.

Many of the states that have recently increased injection of wastewater have also seen an increased number of induced earthquakes (Figure 1). However, it's not fully clear why the increase is so much more pronounced in Oklahoma. It appears that Oklahoma sees more induced earthquakes than other states due to the combination of high volumes of wastewater injection, a pre-existing level of seismic hazard, and its particular geological formations.[11]

An earthquake of moderate to large size (magnitude 5.5 or larger) in a highly populated location is now a worrisome but realistic scenario. Oklahoma's major population centers of Oklahoma City and Tulsa have experienced some shaking, but fortunately no large magnitude earthquakes. However, earthquake activity has increased in the vicinity of these cities (Figure 4). Another troubling scenario is a damaging earthquake near Cushing, Oklahoma. In this small town, many of the nation's oil pipelines meet and tens of millions of barrels of crude oil are stored. An earthquake with strong shaking in this area could damage pipelines and cause widespread leaking of oil into the surrounding environment. This scenario has led some to claim that induced earthquakes pose a national security threat.[12]

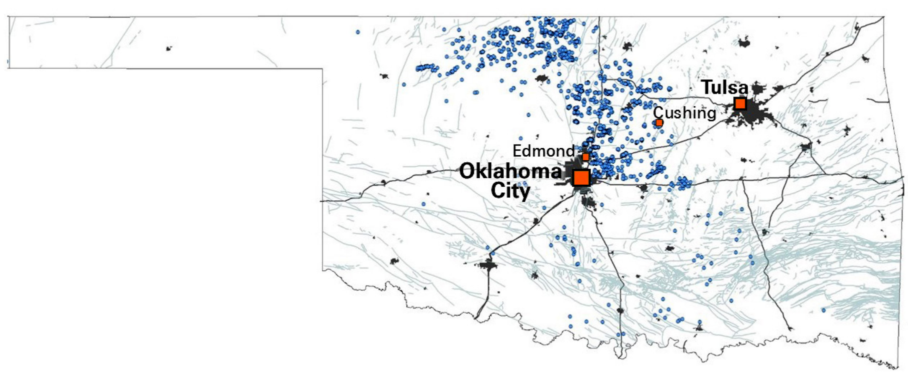
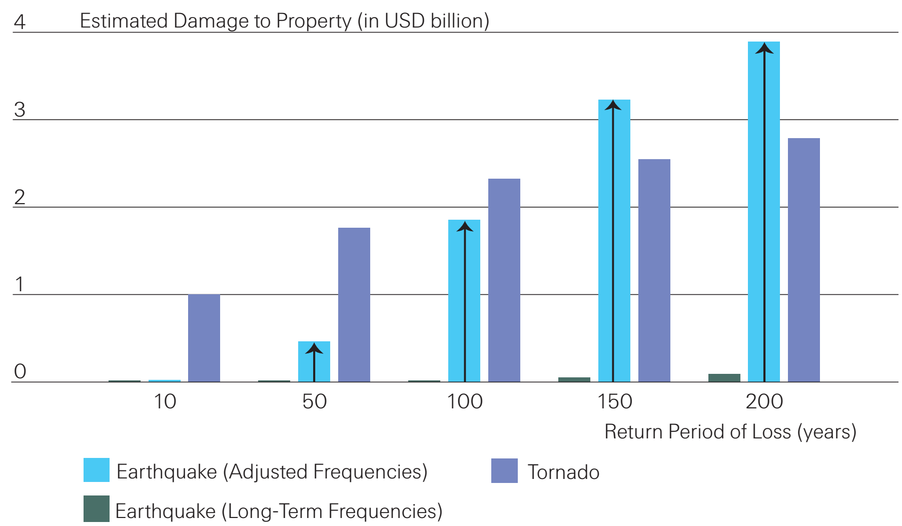


Figure 4: Faults (light green lines) are present in most regions of Oklahoma while the recent seismic activity (blue circles) is primarily concentrated in the north-central part of the state. Urban areas (orange squares) referenced in this paper are indicated along with major roadways (black lines).

Increased potential for loss

Since the increase in earthquake activity is a relatively new situation, most models used to estimate damage from earthquakes don't incorporate the associated increase in seismic hazard. Using a representative portfolio of residential and commercial values in Oklahoma (insured and uninsured), we estimate the impact of increased earthquake probability on expected loss from property damage. We increase the expected frequencies of earthquake occurrence in our in-house loss model from long-term historic rates to a rate observed in recent years. As a result, the expected frequency of a damaging (ie loss-causing) event increases nearly 15 times (Figure 5). Prior to 2009, a damaging earthquake in the state of Oklahoma was expected once in roughly 100 years. With the updated model reflecting the increased rate of activity, the expectation is now roughly 1 in 7 years. Furthermore, the chance of an earthquake causing significant damage (over USD 1 billion) is now a 50- to 75-year occurrence, while being a near-impossibility at the previous levels of seismic hazard. In these experiments, earthquake probabilities were increased only in the region of observed increases in seismicity rates (see map in Figure 4). If we increase the earthquake probabilities uniformly over the entire state, the losses are roughly 5% higher. In Figure 5, we compare the losses from earthquake shaking to those expected from a more common Oklahoma peril, namely tornado. While tornado remains the dominant peril for short return periods, earthquake losses become more costly for return periods over 100 years. In other words, financially preparing for the worst-case tornado scenario wouldn't leave adequate protection for a severe earthquake loss that is now much more likely. Specific portfolios with high exposure in Oklahoma could now see more risk due to earthquake than for tornado.

Figure 5: Estimated future economic damage for the state of Oklahoma at different return periods due to earthquakes and tornadoes. Green bars (barely visible) show earthquake risk at the seismic hazard levels of ten years ago, while blue bars results for today's seismic hazard. Tornado loss estimates (purple bars) are shown for comparison.



Earthquake insurance gaps

An important point regarding our analysis is that the losses estimated are largely uninsured. About 15% of property owners have some level of earthquake protection. This is up from roughly 2% in 2011 as a result of the Oklahoma Insurance Department encouraging homeowners to add earthquake cover to their homeowner policies.

Traditional earthquake insurance is designed to protect against a total loss, and usually comes with a high deductible of 10% or more. So far, earthquakes in Oklahoma haven't been damaging enough to cause much loss above the level of a typical deductible. Hence, insurers have little experience with settling earthquake claims in the region.

High deductibles and frequent events could be problematic for many policyholders. Since deductibles are typically applied to each individual event, small to medium repeated events can build up sizeable uncovered damages over time. The cost to repair these damages can be a large financial burden to many homeowners and businesses.

There are common exclusions written into insurance policies that may leave policyholders responsible for even more shaking-related losses. Masonry damage is a typical exclusion, as is a "man-made ground motion". According to the Oklahoma Insurance Department, the insurance industry paid only 8 of 100 earthquake-related claims in 2014. This low settlement rate could highlight a disconnect between the coverage that policyholders believe they have, and the actual coverage they are buying. In October 2015, Oklahoma's Insurance Commissioner asked insurers to clarify their policies as to whether they would cover induced earthquakes in their existing policies. In a survey of Oklahoma insurers, 70% of respondents reportedly clarified that their earthquake policies cover hydrofracking-related earthquakes.

The combination of high deductibles, common policy exclusions and a low overall take-up rate leads to a potentially large uninsured loss in the event of a big earthquake. This raises the questions of whether damaged parties would pursue litigation, and whether it would be possible to hold one party liable for causing an earthquake. The answers to these questions aren't currently clear in Oklahoma.

The liability landscape

In 2015, Oklahoma's Supreme Court unanimously ruled that citizens can sue oil and gas companies for damages in state courts following an induced earthquake.[13] The suit arose in relation to injuries and damages sustained in the 2011 magnitude 5.6 earthquake near Prague. The court rejected industry influences to have such lawsuits decided by a state regulatory agency, specifically the Oklahoma Corporation Commission (OCC). While the court ruled in favor of the citizen, it did not take a position on the underlying argument of whether wastewater disposal wells caused the earthquake responsible for the injuries and damage.

A separate ongoing lawsuit is seeking class action status for people in 9 counties who claim their homes were damaged by earthquakes.[14] If class action status is granted, it would make it more attractive to litigate against oil and gas companies operating in the region after future earthquakes.

It may be extremely difficult to to hold an operator liable for inducing an earthquake as a result of an individual disposal well, especially given the high density of disposal wells in Oklahoma. It remains to be seen how many, if any, companies will be held accountable for seismic activity in the region. Oil and gas industry advocates have suggested that if well operators are held liable for damages related to the seismicity, the latter could shut down production operations in the region. Such statements weigh heavily on the citizens and lawmakers of Oklahoma, where the oil and gas industry provides jobs and helps support the state's economy, especially in rural areas.

The questions of whether and by how much induced earthquakes could expose the insurance industry to losses via liability coverage isn't clear. There are precedents for insurance payouts related to induced earthquake damages in Switzerland. Two induced earthquake scenarios may be useful to consider for risk managers in the insurance industry: an earthquake beneath a heavily populated area like Oklahoma City or Tulsa that leads to a class-action lawsuit, or an environmental disaster following an earthquake beneath Cushing's oil and gas storage tanks and pipes. It's unlikely that most well operators carry enough insured limit, if any, for these scenarios. Here, there's an opportunity for insurers and reinsurers to take a lead role in encouraging risk averse behavior among the operators they insure. For example, underwriters could consider the seismic monitoring capabilities of an operator and location of its wells to improve risk selection and portfolio management.

Regulating to mitigate future induced earthquakes

Regulations relating to induced earthquakes vary from state to state. The Oil and Gas Conservation Division of the Oklahoma Corporation Commission has attempted to mitigate seismic hazard by suggesting measures for well operators following the detection of a small induced earthquake. Following a pair of closely located earthquakes of a certain magnitude, the OCC outlines an "area of interest" centered on the earthquake epicenter. Within these regions, well operators are asked to cease or limit their injection practices. More broadly, Oklahoma regulators have been asking disposal well operators to voluntarily reduce the wastewater volume and injection pressure in the Arbuckle formation.

Limiting injection volumes is widely thought to be helpful as there appears to be a strong link between high-volume (or high-rate) injection wells and those that produce earthquakes. However, these measures can't fully eliminate the risk of additional earthquakes, since a cascading chain of triggered earthquakes may have already started. Furthermore, the cutbacks are currently voluntary in Oklahoma. Industry response has implied that overall cutbacks in wastewater injection could only be achieved by reducing oil and gas production in Oklahoma. While most companies participate in the suggested reductions following a detected earthquake, the pressure to continue wastewater injection operations may increase from an economic point of view as the price of oil and gas continues to remain low. Changing regulations, and how the oil and gas industry respond, remain the biggest contributor to uncertainty of how the risk will change in the future.

Conclusions

The increase in seismic activity in regions of wastewater disposal has reached an unprecedented level in many regions of the central US. Although this paper highlights the seismicity increase in Oklahoma, many other states experience spikes in seismicity including Colorado, Kansas, Ohio, Texas, as well as Canadian provinces and other locations across the globe. This emerging risk is one that we can't afford to ignore.

Property and business owners in Oklahoma and other affected regions should insure themselves against future earthquake damage. Despite the relatively high deductibles, earthquake insurance can provide a safety net for the extreme levels of damage possible in a shaking event. The probability of a large event causing widespread damage is now too high to neglect. When incorporated into the Swiss Re model for earthquake hazard, the probability of a USD 100 million-loss event increases approximately 30 times.

Insurers and reinsurers must take steps to assess their own risk and preparedness for a damaging earthquake, as we have at Swiss Re. Prices and risk models developed more than a few years ago are no longer relevant given the levels of hazard we observe today. Accumulation of loss from property and liability lines of business haven't been a consideration for earthquake scenarios in the past. Such accumulation is now a realistic possibility and the industry should incorporate this into risk management practices. On the liability side, careful underwriting could identify drilling or disposal operations with less stringent risk management practices. This can be a tool for managing exposure within an existing book of business.

There are also opportunities for the insurance industry to take a proactive approach in creating a more meaningful product for such a unique type of earthquake risk. Two options might be: 1) a product that incorporates an aggregate cover for those suffering multiple small losses or 2) a decreased deductible and decreased limit of cover option for those more concerned about smaller levels of damage.

Endnotes:

1 Petersen, M.D., Mueller, C.S., Moschetti, M.P., Hoover, S.M., Llenos, A.L., Ellsworth, W.L., Michael, A.J., Rubinstein, J.L., McGarr, A.F., and Rukstales, K.S., 2016, 2016 One-year seismic hazard forecast for the Central and Eastern United States from induced and natural earthquakes: U.S. Geological Survey Open-File Report 2016–1035, 52 p., http://dx.doi.org/10.3133/ofr20161035.

2 http://www.geosociety.org/criticalissues/hydraulicFracturing/history.asp [accessed August 2016]

3 https://fracfocus.org/chemical-use/what-chemicals-are-used [accessed August 2016]

4 Walsh, F. R. and M. Zoback (2015), Oklahoma's recent earthquakes and saltwater disposal, Science Advances, v. 1, n. 5, pg.1-9, doi: 10.1126/sciadv.1500195.

5 Rubinstein, J. L. and A. B. Mahani (2015), Myths and Facts on Wastewater Injection, Hydraulic Fracturing, Enhanced Oil Recovery, and Induced Seismicity, Seismological Research Letters, v. 86, n.4, pg. 1060-1067, doi: 10.1785/0220150067.

6 See Table 2 of Murray KE (2015) Class II Saltwater Disposal for 2009–2014 at the Annual-, State-, and County- Scales by Geologic Zones of Completion, Oklahoma. Oklahoma Geological Survey Open-File Report (OF5-2015). Norman, OK. pp. 18.

7 Atkinson, G. M. et al. (2016) Hydraulic Fracturing and Seismicity in the Western Canada Sedimentary Basin, Seismological Research Letters, doi:10.1785/0220150263

8 Rubinstein, J. L. and A. B. Mahani (2015), Myths and Facts on Wastewater Injection, Hydraulic Fracturing, Enhanced Oil Recovery, and Induced Seismicity, Seismological Research Letters, v. 86, n.4, pg. 1060-1067, doi: 10.1785/0220150067.

9 Keranen, K.M. et al. (2013) Potentially induced earthquakes in Oklahoma, USA: Links between wastewater injection and the 2011 Mw 5.7 earthquake sequence, Geology, v. 41, n. 6, pg. 699-702, doi:10.1130/G34045.1.

10 http://www.reuters.com/article/netherlands-gas-groningen-idUSL5N11818020150902 [accessed August 2016]

11 Walsh, F. R. and M. Zoback (2015), Oklahoma's recent earthquakes and saltwater disposal, Science Advances, v. 1, n. 5, pg.1-9, doi: 10.1126/sciadv.1500195.

12 http://www.bloomberg.com/news/articles/2015-10-23/oklahoma-earthquakes-are-a-national-security-threat [accessed August 2016]

13 2015 OK 53, 353 P.3d 529

14 Jennifer Lin Cooper v. New Dominion LLC, No. CJ-2015-0024 (District Ct., Lincoln Cty., Okla., Feb. 10, 2015)

Swiss Re America Holding Corporation
175 King Street
Armonk, NY 10504

Telephone +1 914 828 8000
Toll Free +1 877 SWISS RE
www.swissre.com

Title:
The link between hydrofracking, wastewater injection and earthquakes: key issues for re/insurers

Author:
Sarah Barrett

Contributing authors:
Iain Bailey
Michael Diggin

Graphic design and production:
Juan Pertuz
Media Production/Corporate Real Estate & Logistics

publications@swissre.com

Swiss Re publications can also be downloaded from www.swissre.com

8/16, en - USA