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Finding Fault: Induced Earthquake Liability and Regulation

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Overview

Man-made earthquakes have followed the hydraulic fracturing boom into the twenty-first century. In recent years, operators have hydraulically fractured more than 100,000 wells in the U.S. In tandem with the current increase in unconventional oil and gas production in the U.S., the number of earthquakes in the central and eastern parts of the country has increased dramatically: more than 300 earthquakes above a magnitude 3.0 occurred in the three years from 2010 to 2012, compared with an average rate of 21 events per year from 1967 to 2000.[1] Although hydraulic fracturing stimulation operations routinely produce earthquakes below magnitude 2, so-called "microearthquakes"[2] that are too small to be felt, these operations pose a very low risk of inducing larger, destructive earthquakes.[3] To date, earthquakes induced by hydraulic fracturing in Oklahoma,[4] Texas,[5] Canada,[6] and the United Kingdom,[7] though large enough to be felt at the surface, have not posed serious risk.[8]

On the other hand, disposal of hydraulic fracturing wastewater by injection into deep wells poses a greater risk because the practice can induce larger earthquakes by elevating fluid pressure and weakening preexisting faults.[9] Of the more than 30,000 wastewater disposal wells in the U.S., only a small fraction are associated with the risk of inducing seismicity, typically due to disposal of very large volumes of water or pressure perturbations of basement faults.[10] To date, hydraulic fracturing wastewater disposal has caused damaging earthquakes in Arkansas,[11] Ohio,[12] Oklahoma,[13] and Texas.[14] These earthquakes have been caused by commercial injection well disposal operators-entities that charge hydraulic fracturing operators a fee for disposing of their wastewater-and so-called "non-commercial" injection well disposal operators-oil and gas exploration and production companies that dispose of their own wastewater. Yet despite the risk of induced seismicity, underground injection of wastewater remains the safest, most cost-efficient method of disposal favored by industry and environmental regulators alike.[15]

Questions arise regarding the ideal framework for confronting the risk of induced seismicity from hydraulic fracturing wastewater disposal.[16] The hydraulic fracturing industry is developing a set of best practices to address the issue of induced seismicity, and many major operators already employ seismicity mitigation policies.[17] The Environmental Protection Agency's ("EPA") jurisdiction to regulate induced seismicity risk remains unclear[18] and the agency has not yet attempted to regulate this risk.[19] The EPA is nevertheless investigating the matter[20] and has adopted a series of questions for determining whether a particular seismic event was induced.[21]

Induced earthquakes have resulted in a variety of responses in the states where they have been experienced, from moratoria to regulation to litigation. Arkansas and Ohio have imposed moratoria on wastewater injection in areas where the practice has induced earthquakes. Ohio and Colorado have enacted regulations to prevent the risk of induced seismicity from wastewater disposal injection. Plaintiffs have sued injection well operators in Arkansas and Texas for damage allegedly caused by earthquakes.[22]

This Report will survey ways in which state regulation and various doctrines of common law liability[23] address the risk of induced seismicity in five jurisdictions: Arkansas, Colorado, Ohio, Oklahoma, and Texas. Ohio's regime merits special emphasis for having both the most robust regulatory scheme for preventing induced earthquakes and a well-developed and nuanced body of law regarding strict liability for concussion damage. In addition, this Report will discuss possible trends regarding the interplay of regulation and liability, and their effects. This Report does not seek to make conclusions about which regulatory framework or liability doctrine is best, but merely to point out the advantages and disadvantages of their various features.

In the States

Throughout the United States, the Underground Injection Control ("UIC") program regulates the construction, operation, permitting, and final plugging and abandonment of approximately 50,000 Class II wastewater disposal wells.[24] Passed in 1974,[25] the Safe Drinking Water Act ("SDWA") authorized the EPA to delegate primary enforcement responsibility ("primacy") over underground injection control to the states to ensure safe drinking water for the public by protecting underground sources of drinking water from contamination by injected fluids.[26] States receive primacy over regulating Class II wells in one of two ways. Pursuant to SDWA Section 1422, a state may gain primacy over any or all classes of wells by developing a state UIC program that is at least as stringent as the federal program and promulgates regulations meeting minimum requirements including inspection, monitoring, and recordkeeping requirements for operators. SDWA Section 1425 provides an alternative route for states to obtain primacy over Class II wells[27]: states with existing regulatory bodies overseeing oil and gas production may make an optional demonstration that their program is effective in protecting underground sources of drinking water pursuant to approval criteria outlined in EPA guidance.[28] Most oil and gas producing states[29] exercise primary enforcement authority for Class II wells. To date, twenty-three states[30] have obtained primacy over Class II wells pursuant to Section 1425.[31] If a state chooses not to assume program responsibility or if its UIC program plan is not approved, the EPA must implement the UIC program in that state. In eleven states[32] and the District of Columbia, the EPA implements the UIC Class II program.

In states that have assumed UIC program primacy, state-level injection well regulation regimes vary considerably. States with primacy can assign regulatory authority to different state agencies. Some states regulate injection wells through a single agency, such as an oil and gas commission, and other states divide the regulatory authority between several agencies, such as those with oversight over protecting the environment and public health. Primacy allows states to permit facilities, inspect wells, enforce against violations, and otherwise regulate underground injection activity within the state.[33] In addition, there are ten EPA UIC regions in the country that facilitate coordination between the EPA and the states, as well as among the states themselves, in each UIC region. As a result, there is often a high degree of similarity in permitting regulations among states in the same UIC region. Injection well regulations govern technical issues such as wellbore construction, allowable sources of injected fluid, and operational requirements such as maximum injection pressure and periodic testing. As part of the Class II well permitting process, reports on faults and geological features may be required for the purpose of evaluating whether the injected fluid will be contained and not contaminate underground sources of drinking water. In sum, there is a wide range of variability among jurisdictions regarding how induced seismicity may be addressed as part of the injection well regulatory regime.

EPA regulations[34] govern well permitting procedures in states in which the Class II Well UIC Program is either administered by the EPA or in which primacy was obtained pursuant to SDWA Section 1422. These EPA regulations only apply in a minority of states, since in most cases, state regulatory bodies derive primacy under SDWA Section 1425.[35] These EPA regulations include well permitting requirements for siting, casing, injection pressure, and reporting on surrounding geology of wells, as well as providing for permit revocation.[36] At present, these regulations provide limited avenues for deterring induced earthquakes.[37] The EPA regulations also include well casing and cementing requirements,[38] although casing and cementing methods are not believed to play any role in inducing earthquakes. The most important EPA regulations are those requiring disclosure of factors that induce seismicity: fluid injection pressure and the presence of nearby faults.[39] Although both fluid injection pressure and volume are believed to be independently and conjunctively responsible for induced seismicity, EPA regulations only address injection pressure, likely because only injection pressure is thought to affect the integrity of the well and, subsequently, contamination risk. There is some question, however, as to how jurisdiction to regulate the risks posed by induced seismicity could be derived under the SDWA and enforced under the UIC program.[40]

By contrast, state-level regulation rests on a strong legal foundation because it has been passed under state enabling statutes. It also uniquely accounts for various state-specific factors, including local geology, environmental concerns, and economic priorities. States[41] have varying requirements for Class II wells. Some states treat commercial disposal wells differently from non-commercial wells, whose operators generated the wastewater through their own hydraulic fracturing operations. States have responded to the risk of induced seismicity in a variety of ways. Seismicity risk reporting is becoming a requirement of the well permitting process in some states; in some areas, local and state-wide moratoriums on hydraulic fracturing have been imposed due to induced seismicity, and states are also considering legislation affecting the disposal of hydraulic fracturing wastewater which would have consequences for underground injection wells. This report will survey liability and regulation for induced seismicity in the five states that have experienced induced earthquakes related to hydraulic fracturing industry operations.[42]

A. Ohio

Ohio has 2,455 Class II wells,[43] over 240 of which are active wells capable of accepting hydraulic fracturing wastewater for disposal.[44] To date, operators have injected more than 202 million barrels of oilfield fluids underground.[45] More than half of hydraulic fracturing wastewater disposed of in Ohio each year comes from out of state, much of it from Pennsylvania, which lacks appropriate geology for disposal wells.[46] Before 2011, there were no documented instances of earthquakes induced by underground injection through Class II wells in the state, yet in 2011, injection of hydraulic fracturing wastewater induced a series of earthquakes near Youngstown, Ohio.[47]

1. Regulation

In 1983, Ohio assumed primacy[48] from the EPA for regulating Class II injection wells in the state. Since then, the Ohio Department of Natural Resources ("ODNR") has operated the program. The Department's response to the emerging risk of earthquakes induced by wastewater injection disposal provides an interesting case study.

Months after extensive inspection revealed no cause for concern, doubt arose that a properly permitted well, Northstar 1, might pose an induced seismicity risk.[49] Because ODNR regulators lacked sufficient seismic data, ODNR hired an outside research partner to monitor seismic activity in the area.[50] A few weeks later, residents nearby felt a small earthquake, and a few days later, Ohio regulators shut down the likely culprit-the Northstar 1 well-on the basis of the researchers' preliminary findings.[51] The next day, the area around Youngstown, Ohio experienced a 4.0 magnitude earthquake, and the governor imposed an emergency moratorium on additional wells in the area.[52]

On March 9, 2012, ODNR adopted new standards for Class II well injection permits.[53] On July 10, 2012, the governor of Ohio issued an executive order for the Ohio Division of Oil and Gas Resource

Management to incorporate these standards into strengthened injection well permitting and monitoring requirements by administrative rule.[54]

A key change is that now operators applying for a Class II well injection permit must provide regulators with geophysical logs regarding permeability zones and other available data germane to preventing the risk of induced earthquakes. Previously, operators were merely required to submit basic data regarding the siting of the well within the region's geological formations. The new regulations require that operators must submit a review of existing geologic data for known faulted areas so that wells will not be located in them and a plan for monitoring seismic activity.[55] In addition, the new regulations use a variety of mechanisms to ensure that well injection pressure is kept at a safe level[56]-a level which will likely not induce earthquakes.[57] In addition, operators must report the results of any mechanical integrity tests, mechanical failures, downhole failures, and corrective actions taken and their results. These reforms make Ohio's regulation of induced seismicity risk the most robust of any state.

Furthermore, Ohio's permit application requires operators to comply with surety and insurance requirements.[58] These requirements apply to both commercial and non-commercial injection wells, as Ohio regulations do not distinguish between injection well operators who profit from disposing of wastewater generated by hydraulic fracturing operators, and hydraulic fracturing operators who dispose of their own wastewater. There is no evidence as to whether surety and insurance requirements deter damage caused by injection well operators, or deter the practice of outsourcing liability for such damage to thinly capitalized entities. This can be problematic because the degree of financial assurance maintained by an injection well operator affects the degree to which those injured by an induced earthquake may potentially recover damages. For instance, the operator of the Northstar 1 well, D&L Energy, transferred ownership of the well permit to a subsidiary of which it was a principal. After the transfer, the subsidiary petitioned regulators for permission to inject greater volumes into the well, which ultimately caused the earthquake. Yet after their operations induced earthquakes, D&L Energy could not be held accountable for the damage caused-the company filed for bankruptcy sixteen months after the earthquakes.[59] At present, no regulations addressing induced earthquakes in Ohio appear poised to tackle the problem of injection well operators becoming judgment-proof.

However, there are a variety of potential regulations through which Ohio could discourage hydraulic fracturing operators from outsourcing wastewater disposal to injection well operators and in turn reduce the risk of induced seismicity. For instance, the surety and insurance requirements could be increased to such a degree that only hydraulic fracturing operators could pay them, driving out smaller wastewater disposal companies unlikely to be able to sufficiently compensate parties injured by an induced earthquake. In tandem with such a measure, Ohio could provide that the surety and bonding requirement for injection well operations would be waived for hydraulic fracturing operators capable of demonstrating a high level of financial assurance. Such a policy already exists for plugging and abandonment risk associated with offshore wells in the outer continental shelf.[60] Presumably, such a policy would deter operation of injection wells by operators incapable of maintaining a sufficient level of financial assurance and would incentivize hydraulic fracturing operators to operate their own wells and therefore be accountable for the risks associated with disposal of the wastewater they generate. Companies that undertake hydraulic fracturing operations generally have resources as well as experience and knowledge of geophysics far exceeding that required in the commercial wastewater injection disposal industry. Accordingly, incentivizing hydraulic fracturing operators to dispose of their own wastewater would shift these responsibilities to companies best technically able to reduce the likelihood of an induced earthquake, and would ensure that in the event of an earthquake, affected parties would be able to recover from the company that benefited financially from the production of the injected wastewater in the first place.

In the alternative, Ohio could discourage outsourcing of seismicity risk to injection well operators by imposing separate well permit requirements for commercial and non-commercial well operators, and imposing more stringent conditions on permit applications-such as extensive seismicity risk surveying and testing-from commercial well operators. For the distinction between commercial and non-commercial permitting requirements to have a significant impact on deterring risk outsourcing, however, an applicant for a non-commercial well permit would need to demonstrate that they conducted the hydraulic fracturing operations that generated the wastewater to be injected in order to qualify for the less stringent requirements. Although such regulations cannot be guaranteed to prevent entirely the risk of induced earthquakes, they could add another layer of deterrence to the already robust regulatory framework for induced seismicity risk in Ohio.

2. Liability

Regulation directly impacts the operation of hydraulic fracturing wastewater disposal wells, yet the conduct of operators is also affected by the shadow of liability cast by Ohio common law. Various doctrines under Ohio law impose liability for damage caused by concussion.[61] Developed primarily in the context of blasting cases, theories of concussion liability apply to damage caused by induced earthquakes as well. Ohio law imposes liability for concussion damage under a variety of strict liability theories, holding operators liable regardless of the care exercised in the conduct that caused the damage. Negligence law also holds operators liable for concussion damage in Ohio. Together, these two theories present injured parties with a means of securing redress for damage incurred as a result of shockwaves permeating from induced earthquakes, and presumably deter operators from inducing earthquakes.

Strict liability reflects the view that a party should not be made to bear an injury that he played no part in causing, regardless of whether the party responsible for the harm exercised an adequate level of care. Such a standard of liability presents a stronger deterrent to operators than does the standard of negligence. Under Ohio law, strict liability for concussion damage may be imposed as a trespass; the doctrine of *Rylands v. Fletcher*; an ultrahazardous activity under the First Restatement of Torts; or an abnormally dangerous activity under the Second Restatement of Torts. Each of these doctrines has advantages and limitations in its applicability to induced earthquake concussion damage.

The old common-law doctrine of trespass makes operators strictly liable for property damage caused by concussion or vibration under Ohio law.[62] Such claims have generally arisen in cases involving damage caused by blasting, quarrying, or sonic booms from aircraft. Under the doctrine of trespass by concussion, Ohio courts have awarded damages and injunctive relief.[63] Injunctive relief appears to be a problematic remedy for induced earthquakes. Regulators, and not courts, presumably have greater institutional competence to impose a moratorium on wastewater injection, and in Ohio, regulators have executed this responsibility quite competently. Accordingly, damages awards under a trespass theory appear to be the most appropriate strict liability remedy for induced earthquakes because concussion shocks trespass upon the land, thereby causing damage to person or property.

The doctrine of *Rylands v. Fletcher* holds a party liable for failing to retain on his property something that causes damage to the property of another, including concussion damage. Precedent in Ohio has relied upon *Rylands v. Fletcher* to apply strict liability in awarding damages for injury to property caused directly and foreseeably by concussion.[64] In the context of an earthquake induced by underground wastewater injection, it would not need to be demonstrated that the wastewater itself came onto an underground portion of the land, but merely that the concussion from the earthquake reached the injured party's property. As with trespass, because Ohio courts have applied *Rylands v. Fletcher* purely on a finding that damage was caused by concussion, as is inevitably the case with earthquakes, the doctrine is also well suited to address induced earthquake liability.

In addition, Ohio courts have utilized the similar but distinct doctrines of ultrahazardous activities[65] and abnormally dangerous activities[66] to establish strict liability for concussion damage. However, there are barriers to applying these doctrines to earthquakes induced by wastewater injection. Unlike blasting, wastewater injection is neither abnormally dangerous nor ultrahazardous. Likewise, induced seismicity is not inherently dangerous or ultrahazardous in Ohio, as low seismicity levels associated with hydraulic fracturing operations and unfelt earthquakes typically cause no damage. Another limitation is that under Ohio law, a past landowner cannot be held strictly liable for ultrahazardous activities after ownership passes to another.[67] Applying such a theory of strict liability could, therefore, excuse an operator responsible for inducing an earthquake in instances where operation changed hands over time, since while cumulative injection can cause induced earthquakes, a time frame for causation can be difficult to establish. For these reasons, theories of ultrahazardous or abnormally dangerous activities are problematic and less apropos to a finding of strict liability than are trespass and the doctrine of *Rylands v. Fletcher*.

Under Ohio law, liability for concussion damage may also be established under a negligence theory.[68] Unlike strict liability, negligence forces the plaintiff to bear an injury without recourse if the operator responsible for such injury has acted pursuant to a standard of due care. Accordingly, although negligence may not be as equitable to parties suffering concussion damage from an induced earthquake, if Ohio courts are unwilling to apply strict liability to address a new phenomenon, negligence may nevertheless provide some potential recovery for affected parties.

In sum, Ohio's induced seismicity regulations and concussion damage law provide various avenues through which to address the risk of induced earthquakes. Ohio's robust regulatory framework should make induced earthquakes far less common by avoiding problematic injection locations and well pressures and volumes. Surety requirements help to ensure that wastewater disposal operators will not be entirely judgment-proof, although the lack of more stringent regulations for commercial injection well operators may do little to incentivize hydraulic fracturing operators to internalize the seismicity risk associated with wastewater injection instead of outsourcing it. In addition, concussion law in Ohio provides a plethora of theories for holding injection well operators liable for induced seismicity damage under strict liability or negligence. Ohio's well-developed body of concussion law and its detailed regulations for preventing induced earthquakes demonstrate the array of various options available to courts and regulators in other jurisdictions as well.

B. Colorado

There are over 885 active Class II wells in Colorado, including over 297 wastewater injection wells, which collectively inject approximately 355,000 barrels of wastewater per day.[69] To date, none of these wells has been implicated in induced earthquakes, nor have oil and gas operations induced earthquakes in the state before 2011. However, Colorado's history is not devoid of induced earthquakes: wastewater injected by the military at the Rocky Mountain Arsenal induced a series of very damaging earthquakes in the 1960s and 1970s.[70] Yet only recently has Colorado expanded Class II well permit regulations specifically to target the risk of induced earthquakes.

1. Regulation

Since Colorado received primacy over Class II injection wells in 1984, the Colorado Oil and Gas Conservation Commission ("COGCC") has permitted and monitored these wells.[71] As part of the permit approval process, regulators have historically fixed a maximum fluid injection volume and a maximum injection pressure. The maximum allowable surface injection pressure is determined by a calculation based on either a default fracture pressure gradient[72] or a higher injection zone fracture gradient, if one is found to exist through step rate injection testing conducted by the operator. For wells requiring injection under pressure,[73] COGCC sets maximum injection pressures below the fracture gradient uniquely defined for each injection well in order to minimize the potential for injection's inducing seismicity. These regulations have not changed significantly as COGCC regulations have evolved to address induced seismicity risk.

On August 23, 2011, injection of wastewater produced from coalbed methane operations in the Raton Basin induced a magnitude 5.3 earthquake[74] near Trinidad, Colorado. In response, the COGCC expanded the UIC permit review process in September 2011[75] to include a seismicity review by the Colorado Geological Service ("CGS"). Relying on CGS geologic maps, the U.S. Geological Survey ("USGS") earthquake database, and area-specific knowledge, CGS, in conjunction with the Colorado Division of Water Resources,[76] now provides an opinion on seismic potential for pending wells under these new regulations.[77] Since January 19, 2012, if historic seismicity has been identified in the vicinity of a proposed well, COGCC requires an operator to define the seismicity potential and the proximity to faults through geologic and geophysical data before approving the permit. The regulations also provide for communication between regulators and the permit holder after operations have begun, and immediate notification if seismicity that could be problematic appears. Since these regulations have been imposed, Colorado has experienced no subsequent induced earthquakes.

COGCC regulations[78] also impose financial assurance requirements for Class II well operators. These rules may ensure that injection well operators will not be entirely judgment-proof in the event of an induced earthquake, although they are likely insufficient to fully compensate for damage that would be caused by an induced earthquake, as the financial assurance requirements were intended to guard against more garden-variety forms of environmental damage, such as water contamination. In addition to the financial assurance regulations, the permit rules also implicate accountability for induced earthquakes by allowing an operator to inject at a higher surface injection pressure if testing is conducted beforehand to demonstrate its safety. Such regulation may create a mild competitive advantage for more sophisticated operators over those incapable of conducting the testing. In sum, unlike Ohio, Colorado appears to mildly incentivize sophisticated operators to conduct injection well operations over less sophisticated players; presumably, this may result in safer operations. However, as in Ohio, the law does not fully ensure that parties affected by an earthquake will be able to recover from an injection well operator capable of compensating their claims.

2. Liability

Colorado courts impose strict liability for concussion damage.[79] Colorado courts have also upheld damages awards stemming from concussion based on a negligence theory.[80] In concussion liability cases, the appropriate remedy is damages, not injunctive relief.[81] In addition, under Colorado law, an operator cannot evade liability for concussion damage by engaging an independent contractor to perform work of an inherently dangerous nature unless proper precautions are taken.[82] Because wastewater injection involves the inherent danger of inducing an earthquake in many parts of Colorado due to the state's susceptible geology, particularly in the Rocky Mountains, it is especially important that producers of unconventional oil and gas be unable to evade liability by outsourcing wastewater injection to independent disposal companies. Accordingly, because Colorado concussion regulation provides for strict liability, damages only, and proscribes outsourcing liability, it is particularly well suited to deterring induced earthquakes caused by wastewater injection.

C. Oklahoma

Oklahoma has over 10,500 active disposal injection wells.[83] In January 2011, small earthquakes of magnitude 2.9 and lower were induced by hydraulic fracturing activities,[84] and in November 2011, wastewater disposal injection induced a magnitude 5.7 earthquake-the largest ever recorded in the state-destroying fourteen homes and injuring two people.[85]

1. Regulation

Oklahoma has primacy for the underground injection control program for Class II wells in the state, which is administered by the Oklahoma Corporation Commission.[86] Oklahoma has no Class II permit regulations relating to induced seismicity risk, although the Oklahoma Geological Survey is examining the possibility of induced seismicity from hydraulic fracturing.[87]

Oklahoma imposes a variety of permitting requirements for Class II wells. Operators must publish notice of proposed injection well projects in local newspapers as part of the permit application. In at least one instance, this requirement has led to protest by area residents concerned about contamination of underground water sources and environmental damage.[88] The operator subsequently withdrew its permit application after residents contested it before an administrative law judge of the Oklahoma Corporation Commission, the body responsible for issuing such permits.[89] To date, however, residents in Oklahoma (nor apparently in other states) have not yet contested injection well permit applications on the basis of induced earthquake risk.

In addition, Oklahoma regulates commercial and non-commercial Class II disposal wells differently, requiring more information in an application for a commercial Class II disposal well permit than for a non-commercial permit. Although such a distinction carries the potential to enable the Corporation Commission to discourage outsourcing the disposal of wastewater to commercial wastewater injection well operators, these commercial operators continue to exist in the state.[90]

2. Liability

Oklahoma courts have applied strict liability and rejected negligence in cases involving concussion damage, but the law is not fully developed in this area and at least one case holds open the question of which standard should apply.[91] Accordingly, in the absence of both a clear standard of strict liability and regulation, little law appears to deter operators from inducing earthquakes in Oklahoma.

D. Texas

In 1982, Texas became the first state to assume primacy for regulating Class II wells. Texas contains over 52,000 Class II wells, more than any other state. Each month, 290 million barrels of hydraulic fracturing wastewater are disposed of in Texas.[92] Texas has experienced earthquakes induced by extraction of oil and produced water during hydraulic fracturing in South Texas overlying the Eagle Ford Shale, as well as swarms of many small earthquakes in short succession due to wastewater injection in North Texas in areas overlying the Barnett Shale.[93]

1. Regulation

New regulations promulgated by the Texas Railroad Commission to prevent induced seismicity risks came into effect on November 17, 2014: the new rules require applicants for a permit to operate an oil and gas disposal well to provide U.S. Geologic Survey data regarding seismic events in the area surrounding the well, and the Commission may also require monitoring of wells and reporting of additional information, including seismic activity logs, geologic cross-sections, pressure front boundary calculations, and structure maps.[94] If a disposal well is determined, after notice and opportunity for a hearing, to be a cause of problematic seismic activity, the Commission may set injection pressure and rate limits, ban injection temporarily, or revoke the disposal well permit.[95] In addition, the Railroad Commission hired a seismologist to enable the agency "to further examine any possible correlation between seismic events and oil and gas activity."[96]

2. Liability

Texas has expressly rejected strict liability for concussion damage, and instead requires that such claims be evaluated under a negligence standard.[97] The fact that Texas common law only mildly deters operators from inducing earthquakes through the diminished threat of liability under a mere negligence standard may account for the fact that Texas has experienced more induced earthquakes than any other state.

E. Arkansas

In February 2011, an earthquake swarm including a magnitude 4.7 earthquake struck central Arkansas near the towns of Guy and Greenbrier.[98] Wastewater injection is believed to have caused the earthquakes. A class action lawsuit against the operators of the wells settled and two initial defendants went bankrupt.[99]

1. Regulation

In Arkansas, the Arkansas Oil and Gas Commission ("AOGC") has primacy for administering the Class II underground injection control program. After earthquakes rocked parts of central Arkansas, the AOGC instituted a permanent moratorium on hydraulic fracturing in the affected area. The boundaries of the moratorium area were developed after collaboration between regulators and industry players to identify faults to be avoided by injection activities. Arkansas also has a variety of regulations affecting well permitting, operations, and financial assurance requirements.

Arkansas has detailed regulations affecting the permitting and operating requirements for Class II injection wells, including regulations setting maximum injection pressure[100] using a calculation method similar to that employed in Colorado. Although the state has fairly well-developed rules for regulating Class II wells, no regulations are specifically aimed at induced seismicity risks, save for the moratorium.[101] Nevertheless, the AOGC retains authority to determine appropriate zones for injection disposal in order to protect drinking water sources and to ensure conservation of oil and gas resources in the state.[102] This rule would suggest that AOGC lacks jurisdiction to regulate induced earthquake risk prophylactically unless water contamination or hydrocarbon waste is an issue.

Arkansas distinguishes between commercial and non-commercial wells, and has the most specific and useful definition of any of the states surveyed for what constitutes a commercial well.[103] However, more stringent regulations are not imposed on commercial well operators, save for a nominally stricter regulation requiring notice before a well is established. As in Oklahoma, both commercial and non-commercial operators must issue a notice in a newspaper in the county of the well as part of the permit process; in the case of commercial disposal wells in Arkansas, notice must also be mailed to the county judge. In addition, although Arkansas imposes a financial assurance requirement for injection well operators, the requirement does not have heightened requirements for commercial well disposal operators, nor does the existing level of financial assurance appear to be sufficient for ensuring that operators who induce earthquakes will not be judgment-proof. Indeed, shortly after the Guy-Greenbrier earthquakes, commercial injection well operators believed responsible for the quakes went out of business. Nevertheless, the AOGC Director retains the authority to propose additional requirements for any new disposal wells, and exercise of that authority to ensure that only hydraulic fracturing operators with a high degree of financial assurance are able to operate injection disposal wells might help prevent future earthquakes.[104]

2. Liability

Although there is not much authority on the issue, Arkansas law seems to impose liability for concussion damage only under a negligence standard, and not under strict liability.[105] In the litigation against well operators implicated in the Guy-Greenbrier earthquakes, plaintiffs alleged a variety of liability theories, including trespass, nuisance, and negligence before settling.[106] In the absence of deterrence from a strict liability rule and regulation regarding induced earthquake risk, the threat of a moratorium functions as the law's primary deterrent of further induced earthquakes.

Trends

A. Regulation

1. Themes and Policy Concerns

Recent earthquake events indicate that the damage induced by industrial activities can be substantial. In the context of achieving deterrence and compensation, the risk that an operator will become insolvent or will be insufficiently capitalized is real. Bonding and insurance requirements, geophysical reporting and monitoring requirements which present high barriers to entry, and judicial veil-piercing all may prove effective safeguards against this risk. More stringent requirements for commercial injection well operators as opposed to operators responsible for their own injection activity may also help accomplish this goal. Bonding waivers for operators able to demonstrate sufficient financial assets and revenues, such as those associated with offshore drilling leases, may incentivize companies to disclose what entity is benefiting from the injection activity.

2. Effects

Various aspects of regulation impact induced earthquake risk associated with wastewater injection and hydraulic fracturing operations to different effect. Both Arkansas and Ohio imposed moratoria. This appears to be an effective deterrent, as subsequent operations have not induced earthquakes in either state. Colorado, Ohio, and Texas preventatively regulate seismicity risk, yet additional earthquakes have only ceased in Colorado and Ohio since regulations were imposed. By contrast, although Oklahoma and Texas are the only two states that have experienced earthquakes induced both by wastewater disposal injection and hydraulic fracturing, anti-earthquake regulations were only recently enacted in Texas and remain lacking in Oklahoma. The fact that operators continue to induce earthquakes suggests that the degree of regulation, coupled with the absence of responsive moratoria, may embolden some operators to ignore the risk of induced seismicity in these states. Exactly why some states have chosen to regulate induced earthquake risk more rigorously than others, despite the fact that all of these states have experienced earthquakes of similar magnitudes, remains unclear, although the explanation may be political. In Oklahoma and Texas, oil and gas industry comprises a substantial portion of the economy, which may in part account for inertia against regulation. Accordingly, the existence or absence of seismicity-specific state regulation after induced earthquakes are observed appears to have an impact on the continuing prevalence of induced earthquakes.

Another interesting issue is the effect of distinctions between commercial and non-commercial disposal wells, in different state's regulatory regimes, since commercial operators tend to have fewer resources to compensate for earthquake damage whereas non-commercial operators disposing of their own waste tend to have greater financial assurance. Only two states treat commercial and non-commercial wells differently: Arkansas and Oklahoma. Yet the potential this presents for imposing requirements on commercial wells so stringent as to discourage hydraulic fracturing operators from outsourcing wastewater disposal has not been fulfilled. Wastewater disposal wells continue to be operated in these states-among others-by small operators who lack resources for comprehensive geophysical site-characterization studies that could mitigate the risk of an induced earthquake. In sum, although differential regulations for commercial and non-commercial disposal well operators have the potential to affect the prevalence of induced earthquakes, this potential has not yet been realized.

B. Liability

1. Options

In responding to novel risks posed by new industrial activities, different liability frameworks can promote different values[107] and involve different administration costs.[108] Imposing strict liability[109] for a particular risk incentivizes the operator of the industrial activity to better understand and avoid the risk. Furthermore, a strict liability backstop protects the public fully from partially-understood harms, giving regulation breathing room to develop deliberately by anesthetizing public opposition. On the other hand, after regulations and standard practices develop within an industry to reduce risk from the industrial activity, a negligence rule encourages adoption of those standards.[110]

2. Deterrence

Liability for induced earthquake damage, just like liability for concussion damage caused by blasting explosions, can take many forms. In all the jurisdictions surveyed, negligence claims for concussion damage are allowed to proceed, but plaintiffs may recover under a strict liability theory only in Ohio and Colorado. It is difficult to ascertain whether concussion liability theories have much impact on the thinking of operators whose activities carry the risk of inducing earthquakes. It would seem unlikely that concussion liability, which has remained a fairly dormant area of the law for the last half century, would have substantially affected the conduct of operators before or after the link between wastewater injection and earthquakes was established over the last few years. Yet although regulation may be presumed to have a greater direct effect on potentially earthquake-inducing operations than liability, the importance of the common law in this area should not be overlooked. There may be a correlative relationship, if not a causative one, between strict liability regimes and deterrence of earthquakes. For instance, of the jurisdictions surveyed, Ohio and Colorado are the only two jurisdictions with strict liability for concussion damage and also the only two to have adopted strong regulatory frameworks specifically targeting the risk of induced earthquakes. Oklahoma and Texas have neither strict liability for concussion damage nor robust regulation to prevent induced earthquakes, and the two states have not only experienced damaging earthquakes, but have experienced successive swarms of earthquakes, suggesting that operators feel no need to mitigate these risks. Earthquakes in Texas have continued, even after a lawsuit was filed to recover for earthquake damage in Johnson City, perhaps indicating that the mere filing of a lawsuit, without more, possesses little deterrence value. And yet, what role liability theories and regulation may have on deterrence is muddled in Arkansas, a jurisdiction which, like Ohio and Colorado, has experienced no further earthquakes after the initial swarms: in Arkansas regulators imposed a moratorium, but no regulation; a lawsuit to recover for earthquake damage settled; and though not entirely clear, Arkansas law may favor negligence for concussion damage. Accordingly, although existing concussion law may not have much of an effect in the jurisdictions surveyed on the conduct of injection well operators and the companies who generate the wastewater they dispose of, the judicial creation of a liability rule for induced earthquake damage would likely have a powerful deterrent effect in the future. It remains to be seen whether, if any cases are ultimately resolved on the merits, the courts will apply strict liability, which imposes liability on the lowest-cost-avoider and the party responsible for causing the injury, or negligence, which incentivizes operators to abide by industry best practices. As of yet, it is uncertain which is the ideal liability framework, and the role that state regulation will play in such a determination.

Development of a liability framework or additional state regulation may provide stability beneficial to the public and industry alike by ensuring accountability for damage caused by induced earthquakes while minimizing the risk of reactionary regulation. Exactly what the ideal framework would look like is unclear, but existing regimes such as those discussed above should provide valuable guidance in moving forward.

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* The author earned her J.D. from Columbia Law School and practices law in Houston, Texas. She is especially indebted to Waldo D. Gullickson, geophysicist, and Professors Michael A. Heller and Susan L. Sakmar for their guidance.

[1]. William Ellsworth, Jessica Robertson & Christopher Hook, *Man-Made Earthquakes Update*, U.S. Geological Survey (Jan. 17, 2014, 1:00 PM), http://www.usgs.gov/blogs/features/usgs_top_story/man-made-earthquakes/ [http://perma.cc/8BVZ-43BS].

[2]. William L. Ellsworth, *Injection-Induced Earthquakes*, Science 1225942-3 (July 12, 2013), *available at* http://www.sciencemag.org/content/341/6142/1225942.full.pdf [http://perma.cc/AC9F-PMNG].

[3]. *Id*.

[4]. Austin A. Holland, *Earthquakes Triggered by Hydraulic Fracturing in South-Central Oklahoma*, 103 Bull. Seismological Soc'y Am. 1784 (2013). Holland notes that hydraulic fracturing operations in the Eola-Robberson oil field induced 116 earthquakes up to 2.9 magnitude from January 17, 2011 to January 23, 2011. Earthquakes in close proximity to the well began within twenty-four hours of hydraulic fracturing operations and ceased during two-day period when operations were suspended.

[5]. Extraction of large volumes of oil and associated water were responsible for earthquakes in the Eagle Ford shale in South Texas. The two largest, at a magnitude 4.8 near Fashing on October 20, 2011 and a magnitude 3.9 near Alice on April 25, 2010, caused shaking at the surface, although no injuries or severe damage were reported. Cliff Frohlich & Michael Brunt, *Two-Year Survey of Earthquakes and Injection/Production Wells in the Eagle Ford Shale, Texas, Prior to the M_w 4.8 20 October 2011 Earthquake*, 379 Earth & Planetary Sci. Letters 56 (2013); Cliff Frohlich, Jennifer Glidewell & Michael Brunt, *Location and Felt Reports for the 25 April 2010 M_{bLg} 3.9 Earthquake near Alice, Texas: Was It Induced by Petroleum Production?*, 102 Bull. Seismological Soc'y Am. 457 (2012).

[6]. Of the hydraulic fracturing-induced seismic events between April 2009 and December 2011 in the Horn River Basin in British Columbia, only one earthquake was felt at the surface and none caused property damage, injury, or a risk to the environment. *Investigation of Observed Seismicity in the Horn River Basin*, B.C. Oil & Gas Comm'n, Aug. 2012, http://www.bcogc.ca/node/8046/download?documentID=1270&type=.pdf [http://perma.cc/RHL8-FQ8A].

[7]. Hydraulic fracturing operations caused a number of earthquakes near Blackpool, England

between April and May 2011, the largest having a 2.3 magnitude. Christopher A. Green, Peter Styles & Brian J. Baptie, *Preese Hall Shale Gas Fracturing: Review & Recommendations for Induced Seismic Mitigation*, Dep't of Energy & Climate Change (2012), https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/15745/5075-preese-hall-shale-gas-fracturing-review.pdf [http://perma.cc/3ZC9-URJX].

[8]. The largest has only been a magnitude 3.6. Ellsworth, *supra* note 3.

[9]. *Id*.

[10]. *Id*.

[11]. Steve Horton, *Disposal of Hydrofracking Waste Fluid by Injection into Subsurface Aquifers Triggers Earthquake Swarm in Central Arkansas with Potential for Damaging Earthquake*, 83 Seismological Res. Letters 250 (2012).

[12]. In 2011, hydraulic fracturing wastewater disposal injection wells induced earthquakes ranging from magnitude 2.1 to 4.0 near Youngstown, Ohio. *Preliminary Report on the Northstar 1 Class II Injection Wells and the Seismic Events in the Youngstown, Ohio, Area*, Ohio Dep't of Natural Res., Mar. 2012 [hereinafter *Ohio Preliminary Report*], http://media.cleveland.com/business_impact/other/UICReport.pdf [http://perma.cc/8L36-XKXN]; Robert J. Skoumal, Michael R. Brudzinski & Brian S. Currie, *Earthquakes Induced by Hydraulic Fracturing in Poland Township, Ohio*, 105 Bull. Seismological Soc'y Am. 1785 (2015).

[13]. Katie M. Keranen, Heather M. Savage, Geoffrey A. Abers & Elizabeth S. Cochran, *Potentially Induced Earthquakes in Oklahoma, USA: Links Between Wastewater Injection and the 2011* M_w *5.7 Earthquake Sequence*, Geology (2013). On November 5, 2011, a magnitude 5.7 earthquake near Prague, Oklahoma caused by wastewater injection disposal was the largest recorded earthquake in state history. A study found an initial rupture plane within 200 meters of active injection wells and that decades-long lags between the commencement of fluid injection and the onset of induced earthquakes are possible.

[14]. Cliff Frohlich, *Two-Year Survey Comparing Earthquake Activity and Injection-Well Locations in the Barnett Shale, Texas*, 109 Procs. Nat'l Acad. Sci. 13934 (2012) (identifying earthquakes near Dallas-Forth Worth and Cleburne, Texas reported by the media in 2008 and 2009 caused by injection wells); Ashley Howe Justinic, Brian Stump, Chris Hayward & Cliff Frohlich, *Analysis of the Cleburne, Texas, Earthquake Sequence from June 2009 to June 2010*, 103 Bull. Seismological Soc'y Am. 3083 (2013) (identifying a magnitude 2.8 earthquake in Cleburne, Texas on June 9, 2009 and other earthquakes in the area caused by injection wells); Terrence Henry, *As Texas Towns Shake, Regulators Sit Still*, State Impact (Dec. 6, 2013, 6:00 AM), http://stateimpact.npr.org/texas/2013/12/06/as-north-texas-shakes-railroad-commission-sits-still/ [http://perma.cc/K37T-9W6W] (identifying a magnitude 3.6 earthquake in Azle, Texas, near Fort Worth, on November 30, 2013 linked to hydraulic fracturing wastewater disposal); Brian Clark Howard, *Are Oil and Gas Industries Behind the Rare Texas Earthquakes*, Nat'l Geographic News, Jan. 7, 2015, http://news.nationalgeographic.com/news/2015/01/150107-texas-earthquakes-cause-injection-wells-

fracking-science/ [http://perma.cc/6XQV-5B7T] (linking January 2015 earthquakes ranging from 1.6 to 3.6 in the Fort Worth Basin to wastewater injection well disposal).

[15]. Drew T. Bell & Lynn Kerr McKay, *Marcellus Shale: Implications of Ohio DNR's Report Regarding the Youngstown Tremors*, King & Spalding Energy Newsletter, Apr. 2012, http://www.kslaw.com/library/newsletters/EnergyNewsletter/2012/April/article9.html [http://perma.cc/Y244-HYYZ]. Other methods of fracturing fluid wastewater disposal include spilling the fluid onto the ground, releasing it into a body of water, and trucking it to a waste treatment facility, all of which are problematic for various reasons. Rebecca Hammer & Jeanne VanBriesen, *In Fracking's Wake: New Rules Are Needed to Protect Our Health and Environment from Contaminated Wastewater*, Natural Res. Def. Council, 2012, http://www.nrdc.org/energy/files/Fracking-Wastewater-FullReport.pdf [http://perma.cc/42M5-RQ5B]. The practice of disposing of wastewater by injecting it deep underground is not new. Unlike many instances of brine re-injection associated with traditional oil and gas operations, however, the wastewater generated by hydraulic fracturing activities cannot be returned to the formations in which the hydraulic fracturing is conducted because this would interrupt the production of hydrocarbons from the formation. Furthermore, the quantities of water left over from hydraulic fracturing activities greatly exceed the amounts of brine typically generated by traditional oil and gas operations. Accordingly, the increase in hydraulic fracturing is resulting in a surge of wastewater injection disposal in wells across the country, although recent technological developments may mitigate this trend of increased wastewater disposal injection activity since it is now possible to recycle as much as seventy-five percent of fluid in a single well. Concern over liability for earthquakes induced by wastewater injection may motivate operators to prefer recycling wastewater in hydraulic fracturing operations.

[16]. Although beyond the scope of this report, induced seismicity risks associated with carbon sequestration and enhanced geothermal systems raise similar concerns, though they are subject to different regulatory frameworks, particularly at the federal level.

[17]. On July 16, 2013, the Oklahoma Geological Survey convened a workshop aimed at developing recommended best practices to address induced earthquake risk. Tayvis Dunnahoe, *Understanding the Science Behind Induced Seismicity*, Unconventional Oil & Gas Report, Oct. 1, 2013, http://www.ogj.com/articles/uogr/print/volume-1/issue-3/understanding-the-science-behind-induced-seismicity.html [http://perma.cc/Q5GU-FL6X]. ExxonMobil already has a protocol. *See* Veil, *infra* note 19, at 29. The Department of Energy recommends using the stoplight method to mitigate induced seismicity risk in enhanced geothermal systems. Ernie Majer, James Nelson, et al., *Protocol for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems*, DOE/EE-0662, U.S. Dep't of Energy, Jan. 2012, at 21, https://www1.eere.energy.gov/geothermal/pdfs/geothermal_seismicity_protocol_012012.pdf [http://perma.cc/67QJ-73SK]. One facet of these best practices is community communication, and an example of a community-based induced seismicity damage claims resolution process is that operated by the Anderson Springs Community Alliance. *See generally* Anderson Springs Cmty. Alliance, http://www.anderson.springs.org [http://perma.cc/RJ9S-5QPX]. In addition, a Canadian commission investigated the connection between induced seismicity and hydraulic fracturing activities, and issued some basic recommendations of best practices. Brenden Hunter, Dean J. Watt & David Both, *Commission Finds Fracking Caused Seismic Events*, Fasken Martineau DuMoulin LLP, Sept. 5, 2012,

http://www.lexology.com/library/detail.aspx?g=fd07906b-3e60-4b4d-9da9-0d7dd22ed37f [http://perma.cc/7BK5-YYFG].

[18]. The SDWA gave the EPA authority over underground injection solely for the purpose of protecting the safety of sources of drinking water. Accordingly, whether the SDWA gives authority to regulate underground injection practices that induce seismicity hinges on whether induced seismicity threatens the safety of underground sources of drinking water, an issue that courts and policymakers have yet to address. *See* John Veil, *A White Paper Summarizing a Special Session on Induced Seismicity*, Groundwater Protection Council 33, Feb. 2013, http://www.gwpc.org/sites/default/files/white%20paper%20-%20final_0.pdf [http://perma.cc/ZZ5W-KWVV]; Mary Tiemann & Adam Vann, *Hydraulic Fracturing and Safe Drinking Water Act Regulatory Issues*, Congressional Research Service, Jan. 10, 2013, at 7, http://www.fas.org/sgp/crs/misc/R41760.pdf [http://perma.cc/YG9L-7QAC].

[19]. EPA is, however, in conversation with state regulators and in some EPA Underground Injection Control ("U

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