Finding Fault: Induced Earthquake Liability and Regulation

By Emery Gullickson Richards*

* 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.

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

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 &

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]

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

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

(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.

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

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 ("UIC") regions may be pressuring them to develop stringent regulations under threat of an EPA UIC audit and revocation of primacy to administer the Class II program in the state. *See* Bent & Elliott, *infra* note 49.

20. EPA investigated the issue decades before the hydraulic fracturing boom. *See* Craig Nicholson & Robert L. Wesson, *Earthquake Hazard Associated with Deep Well*

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.

Injection—A Report to the U.S. Environmental Protection Agency, 1951 U.S.G.S. Bulletin (1990), http://pubs.usgs.gov/bul/1951/report.pdf [http://perma.cc/MXX5-R2TH].

21. EPA adopted from the research of Zoback, et al., a series of questions to evaluate the likelihood of induced seismicity: (1) are these events the first known earthquakes of this character in the region, (2) is there a clear correlation between injection and seismicity, (3) are epicenters within five kilometers of wells, (4) do some earthquakes occur at or near injection depths, (5) if not, are there known geologic structures that may channel flow to sites of earthquakes, (6) are changes in fluid pressure at well bottoms sufficient to induce seismicity, and (7) are changes in fluid pressure at the hypocenter location sufficient to encourage seismicity? *Ohio Preliminary Report*, *supra* note 13, at 5.

22. Sean McLernon, *Fracking Earthquake Claims Bank on Uncertain Science*, LAW360, Aug. 26, 2013, http://www.law360.com/articles/467693/fracking-earthquake-claims-bank-on-uncertain-science [http://perma.cc/FRV7-JBDY]; *North Texas Earthquakes Prompt Hydraulic Fracturing Class Action Lawsuit*, BIGCLASSACTION.COM (Aug. 2, 2013), http://www.bigclassaction.com/lawsuit/North-Texas-Earthquakes-Hydraulic-Fracturing-Lawsuit.php [http://perma.cc/L9Z2-C8LN].

23. Darlene A. Cypser & Scott D. Davis, *Liability for Induced Earthquakes*, 9 J. ENVTL. L. & LITIG. 551 (1994); Thomas W. Merrill & David M. Schizer, *The Shale Oil and Gas Revolution, Hydraulic Fracturing, and Water Contamination: A Regulatory Strategy*, 98 MINN. L. REV. 145 (2013).

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

24. The UIC program regulates six classes of wells. Wells associated with oil and gas production operated for the purposes of disposal, enhanced oil recovery, and hydrocarbon storage are called Class II wells, of which there are over 150,000 in the U.S. An estimated thirty percent of Class II wells operate as wastewater disposal wells. *See COGCC Underground Injection Control and Seismicity in Colorado*, DEPARTMENT OF NATURAL RESOURCES (Jan. 19, 2012) [hereinafter COGCC Report], http://cogcc.state.co.us/Library/InducedSeismicityReview.pdf [http://perma.cc/NYV3-PHMJ].

25. The SDWA was passed before hydraulic fracturing became common and therefore did not contemplate EPA's regulation of hydraulic fracturing wastewater injection disposal.

26. Tiemann & Vann, *supra* note 19, at 14. Disposal of wastewater by means other than injection into underground disposal wells is regulated pursuant to the Clean Water Act.

27. This approval mechanism is limited to Class II wells only.

28. *Guidance for State Submissions Under Section 1425 of the Safe Drinking Water Act*, U.S. ENVTL PROT. AGENCY, http://www.epa.gov/ogwdw/uic/pdfs/guidance/guide_uic_guidance-19_primacy_app.pdf [http://perma.cc/54YA-MYUF]. These requirements are outlined in Section 1421. 42 U.S.C. § 300h (2005). Section 1421 directs the EPA Administrator to promulgate regulations for state UIC programs, and mandates that the EPA regulations "contain minimum requirements for effective programs to prevent

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

underground injection which endangers drinking water sources." 42 U.S.C. § 300h(b)(1). Section 1421(d), as amended by the Energy Policy Act of 2005 (EPAct 2005), specifies that the term "underground injection" as it is used in the SDWA means the subsurface emplacement of fluids by well injection, and specifically excludes the underground injection of fluids or propping agents associated with hydraulic fracturing operations related to oil, gas, or geothermal production activities. 42 U.S.C. § 300h(d). Under Section 1425, states may demonstrate to EPA that their existing programs for oil and gas injection wells are effective in preventing endangerment of underground sources of drinking water, providing states with an alternative to meeting the specific requirements contained in EPA regulations promulgated under Section 1421. 42 U.S.C. § 300h-4.

29. Tiemann & Vann, *supra* note 19, at 14.

30. Alabama, Alaska, Arkansas, California, Colorado, Illinois, Indiana, Kansas, Louisiana, Mississippi, Missouri, Montana, Nebraska, New Mexico, North Dakota, Ohio, Oklahoma, Oregon, South Dakota, Texas, Utah, West Virginia, and Wyoming. *Id.*

31. And some states (Alaska, California, Colorado, Indiana, Montana, and South Dakota) have received primacy only for Class II wells, while EPA retains primary authority over regulating all other classes of wells in those states. *Id.* This means that a state administrative agency may regulate induced seismicity risk associated with hydraulic fracturing wastewater disposal in a given state, whereas in that very same state the induced seismicity risk associated with carbon sequestration or geothermal energy could be regulated by EPA. Accordingly, well permitting authority may be allocated differently for different industrial uses between the state and federal levels within a given state.

32. Pennsylvania, New York, Michigan, Kentucky, Tennessee, Virginia, Arizona, Florida, Hawaii, Iowa, Minnesota, and D.C. *Id.*

33. *Id.*

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

34. Although it is appropriate to consider these regulations federal in a vertical sense, these regulations do not apply in all states, so they are not federal in terms of horizontal, national scope.

35. Tiemann & Vann, *supra* note 19.

36. The UIC Program Director may terminate a permit during its term, or deny a permit renewal application for the following cause: a determination that the permitted activity endangers human health or the environment and can only be regulated to acceptable levels by permit modification or termination. 40 C.F.R. 144.40(a)(3).

37. The well siting requirements focus not on reducing the risk that a well will induce seismicity, but on the risk that a well will be constructed in a manner or a location that makes it vulnerable to geophysical disturbance that could rupture the well, resulting in contamination of drinking water. The regulations state, "All new Class II wells shall be sited in such a fashion that they inject into a formation which is separated from any underground source of drinking water by a confining zone that is free of known open faults or fractures within the area of review." 40 C.F.R. 146.22(a). A "confining zone" is defined in the regulations as "a formation that is capable of limiting fluid movement above an injection zone"—demonstrating that the concern of the confining zone requirement is the risk of contamination, not earthquakes. 40

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]

C.F.R. 146.3. Nevertheless, this regulation may be read to require injection well siting in geologically stable confining zones in a way that would protect against induced seismicity under the guise of protecting against contamination that could potentially result from a well ruptured by induced seismicity, although the risk of contamination due to induced seismicity is thought to be unlikely. Notably, the siting requirement only prohibits well siting in an area with known open faults or fractures—well operators are not required to ascertain whether the area has these geological features which correlate to induced earthquake risk.

38. 40 C.F.R. 146.22(b)(1).

39. "At a minimum, the following information concerning the injection formation shall be determined or calculated for new Class II wells or projects: (1) Fluid pressure; (2) Estimated fracture pressure; (3) Physical and chemical characteristics of the injection zone." 40 C.F.R. 146.22(g). Additional information that must be considered by the UIC Program Director in authorizing Class II wells includes a map showing the injection well or project area for which a permit is sought and the applicable area of review. The map may show faults if they are known or suspected. 40 C.F.R. 146.24(a)(2). Injection pressure at the wellhead shall not exceed a maximum pressure, which shall be calculated so as to assure that the pressure during injection does not initiate new fractures or propagate existing fractures in the confining zone adjacent to the USDWs. 40 C.F.R. 146.23(a)(1). Injection between the outermost casing protecting underground sources of drinking water and the well bore shall be prohibited.

40. At issue is whether the SDWA gives states, the EPA, and state regulatory bodies implementing the UIC the authority to regulate induced seismicity risks in light of the fact that the jurisdiction of the program hinges on protecting safe drinking water for the public. It is conceivable that the impact of an earthquake on the structural integrity of an aquifer or other formation affecting groundwater (resulting in water loss, well disruption, pipe disruption, and water turbulence from an earthquake) could provide a justification for federal regulatory authority under the SDWA, albeit a tenuous one. The question of federal authority should only be an issue in states where the EPA manages the Class II well UIC program, and to a lesser extent possibly in states which obtained primacy for the Class II well UIC program pursuant to SDWA Section 1422. The UIC program does not inhibit states that derive primacy under SDWA Section 1422 from surpassing its minimum requirements for well permitting requirements with more stringent requirements, so regulations implemented in these

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

states are likely insulated from challenge to the extent that they have been adopted under the imprimatur of state law. In states that obtained primacy over Class II well UIC programs pursuant to SDWA Section 1425, the scope of authority to regulate induced seismicity risk will depend on the legislative authority of the state regulatory body that administers the UIC program in the state. Given the broad mandate to protect public safety and regulate oil and gas production activities under which most of these state regulatory bodies operate, it can be presumed that authority will be proper for regulating induced seismicity risk in states that obtained primacy for the Class II well UIC program under SDWA Section 1425.

41. Colorado, Arkansas, Texas, California, Ohio, Pennsylvania, South Dakota, New York, New Mexico, Oklahoma, Louisiana, Mississippi, and West Virginia.

42. Ohio, Colorado, Oklahoma, Texas, and Arkansas. Other states have considered legislation to protect against induced seismicity risk. *See* Pless, *infra* note 88.

43. *Underground Injection Wells in Region 5*, U.S. ENVTL. PROT. AGENCY, Mar. 5, 2014, http://www.epa.gov/r5water/uic/r5uicwells.htm [http://perma.cc/YZ8Q-H5AU].

44. Some of which may not have yet received such waste. Ted Auch, *Ohio Class II Injection Wells—2012 Year-in-Review*, FRACTRACKER ALLIANCE, Aug. 15, 2013, http://www.fractracker.org/2013/08/oh-year-in-review/ [http://perma.cc/49JC-M2QC].

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.

45. *See* Auch, *supra* note 44.

46. Jeff Fort, *Exploring the Disposal of Fracking Waste Water—UIC Class II Wells in Ohio*, OIL & GAS LAW REPORT, Apr. 13, 2013, http://www.oilandgaslawreport.com/2013/04/13/exploring-the-disposal-of-fracking-waste-water-uic-class-ii-wells-in-ohio/ [http://perma.cc/TW4B-RFGP]. Ohio takes the position that limiting or regulating out-of-state oilfield fluid wastes would violate the Dormant Commerce Clause. *Ohio Preliminary Report*, *supra* note 13, at 11.

47. Michael Wines, *New Research Links Scores of Earthquakes to Fracking Wells Near a Fault in Ohio*, N.Y. TIMES, Jan. 7, 2015, at A10, *available at* http://www.nytimes.com/2015/01/08/us/new-research-links-scores-of-earthquakes-to-fracking-wells-near-a-fault-in-ohio.html?_r=0 [http://perma.cc/KG67-LB5D]; Tom Tomastik, *Development of Shale Plays and Disposal of Oilfield Wastes in Ohio*, OHIO DEP'T OF NATURAL RES., Nov. 2011, http://www.ohgeosoc.org/presentations/201111/Tomastik_ShalePlays_ClassIIWells.pdf [http://perma.cc/B9FL-AEY5].

48. Ohio's Class II regulations are more stringent than those required by the EPA. *Ohio Preliminary Report*, *supra* note 13. Ohio's primacy for administering the state's underground injection control program for Class II wells remains in force and does not appear to be under any considerable threat, although Ohio environmental groups have petitioned the EPA to withdraw Ohio's primacy for Class II injection well permitting and oversight, and to apply more stringent auditing procedures to the state-administered UIC programs. Teresa B. Mills, Letter to Susan Hedman, EPA Region 5 Administrator, Mar. 14, 2013, http://www.acfan.org/wp-content/uploads/2013/03/3-14-13-Citizens-UIC-letter-US-EPA-1.pdf [http://perma.cc/597B-G8T7]; *see also* Ryan D. Elliott, *Petition to U.S. EPA—Withdrawal of Ohio's Class II UIC Program*, VORYS SHALE REPORT, Apr. 2013, http://www.vorys.com/newsletter-139.html [http://perma.cc/W9G-TTPL]. The EPA announced it would apply more stringent audit procedures, though the exact nature of those procedures remains unknown. Scott J. Bent, *The EPA Claims it Will More Closely Examine and Assess Ohio's Oversight of Injection Wells*, BAKER HOSTETLER CLIENT UPDATE, July 22, 2013, http://www.lexology.com/library/detail.aspx?g=6ff85ceb-2fd4-4c2a-bd72-4c01cf193c7f [http://perma.cc/6587-TVYK].

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

49. The Northstar 1 well began operating in December 2010, and before the well induced felt earthquakes, state geologists and regulators had performed thirty-five separate inspections of the well from April 26 to December 15, 2011, yet they lacked sufficient data to determine a link between injection activities and induced seismicity. *Ohio Preliminary Report*, *supra* note 13.

50. In November 2011, the director of the ODNR ordered the Ohio Geological Survey to hire an outside research partner, the Lamont-Doherty Earth Observatory at Columbia University, to collect the necessary data. Researchers began seismic monitoring on December 1, 2011. *Ohio Preliminary Report*, *supra* note 13.

51. On December 24, a 2.7-magnitude earthquake near the well was observed, and on December 29, researchers provided the ODNR with their preliminary findings. *Ohio Preliminary Report*s, *supra* note 13. The ODNR director ordered regulators to seek the immediate halt of injection either voluntarily by the operator or by agency order, and on December 30, ODNR inspectors witnessed the voluntary shutdown of the well. *Id.*

52. On December 31, the Youngstown area experienced a magnitude 4.0 earthquake, and the Ohio governor immediately imposed an indefinite moratorium on four additional wells in the vicinity: three drilled wells and one pending well. *Id.*

53. Bell & McKay, *supra* note 16; *Ohio Preliminary Report*, *supra* note 13; *Ohio's New Rules for Brine Disposal Among Nation's Toughest*, OHIO DEP'T OF NATURAL RES., Mar. 9, 2012, http://www.ohiooilfield.com/odnryoungstownreport.pdf [http://perma.cc/TBV2-8VVV]; Fort, *supra* note 47.

54. Governor John R. Kasich, State of Ohio, Executive Order 2012-09K, July 10, 2012, http://www.ohiomemory.org/cdm/singleitem/collection/p267401ccp2/id/8264/rec/10 [http://perma.cc/68BS-U633] (amending Sections 1501:9-03-06 and -07 of the Ohio Administrative Code).

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

55. Operators must also submit a complete suite of geophysical logs including gamma ray, compensated density-neutron, and resistivity logs with analytical interpretation; evaluate the potential for conducting seismic surveys; and conduct cement plug back of any well drilled in Precambrian basement rock before testing.

56. Operators must now report original downhole reservoir pressure prior to initial injection, conduct a step-rate injection test to establish formation parting pressure and injection rates, install a continuous pressure monitoring system with electronic results available to regulators, install an automatic system to shut-off injection if pressure exceeds a maximum level, and install an electronic data system for tracking fluids brought to the well by a wastewater transporter.

57. Operators must submit an annual report disclosing monthly total volume injected, monthly maximum injection pressure, and average daily injection pressure by month. Operators that continuously monitor annulus pressure must report the date and pressure level for the maximum and minimum pressure points during each month. Operators who instead conduct monthly testing of pressure must report the pressure amount at the beginning of the test as well as the amount at the end of the test.

58. Ohio Rev. Code Ann. § 1509.07 (West 2012).

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

59. Mike Gauntner, *D&L Energy Files for Bankruptcy, Company More Than $1 Million in Debt*, WFMJ (July 21, 2013, 12:21 AM), http://www.wfmj.com/story/21999525/dl-energy-files-for-bankruptcy-company-more-than-1-million-in-debt [http://perma.cc/34MB-NDRU].

60. *See generally Bonding*, BUREAU OF OCEAN & ENERGY MGMT., http://www.boem.gov/Oil-and-Gas-Energy-Program/Leasing/Regional-Leasing/Gulf-of-Mexico-Region/Bonding.aspx [http://perma.cc/3V7F-UBPT] (last visited Nov. 22, 2014).

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

61. Ohio courts have only imposed liability for concussion damages on strict liability and negligence theories. In *Banford v. Aldrich Chem. Co., Inc.*, 932 N.E.2d 313 (Ohio 2010), the court dismissed a nuisance theory for concussion damage because the offending activity was not ongoing. Such analysis similarly applies to concussion damage caused by earthquakes even more persuasively, because although cessation of injection or reduction in injection pressures and volumes has been linked to a cessation of earthquakes, earthquake cessation cannot be guaranteed.

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

62. *But see* Held v. Red Malcuit, Inc., 230 N.E.2d 674, 675 (Ohio Com. Pl. 1967) (rejecting the principle that trespass by concussion results in liability for damages regardless of negligence). *See also* Laird v. Nelms, 406 U.S. 797, 800 (1972). In *Laird*, the U.S. Supreme Court held that strict liability for concussion damages should be analyzed as an ultrahazardous activity instead of as a trespass. However, the central issue in *Laird* was denial of jurisdiction under the Federal Tort Claims Act (FTCA). The court's dicta regarding ultrahazardous activity as the ideal strict liability doctrine for concussion damage sought to distinguish *Laird* from a previous case in which the court held trespass a cause of action for a suit under the FTCA. Accordingly, the weight of this authority is questionable.

63. *See, e.g.*, Walczesky v. Horvitz Co., 269 N.E.2d 844 (Ohio 1971) (affirming jury finding of trespass by concussion or vibration which proximately results in damages and holding liability for damages regardless of negligence); Louden v. City of Cincinnati, 106 N.E. 970, 974 (Ohio 1914) (holding that plaintiff was entitled to damages for trespass by concussion); Bluhm v. Blanck & Gargaro, 24 N.E.2d 615, 618

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

(Ohio Ct. App. 1939) ("[W]here one commits a trespass upon the property of another by the use of high explosives [which cause damage by concussion or vibration] he is liable for the resultant damages without proof of negligence."); Heilman v. France Stone Co., 151 N.E. 798, 799 (Ohio Ct. App. 1925) (stating that concussion from blasting which invades the rights of the owner of adjoining land constitutes trespass which may be enjoined if wrongful, even if damages are not substantial, although it cannot be enjoined if enjoyment of the property is not interfered with); Weaver v. Yoder, 184 N.E.2d 622 (Ohio Com. Pl. 1961) (holding that damage to residential property by concussion constitutes a trespass which will be enjoined from continuing).

64. *See* St. Marys' Woolen Mfg. Co. v. Bradford Glycerine Co., 7 Ohio Cir. Dec. 582 (1897) (involving concussion caused by an explosion and nitroglycerin deemed a dangerous substance likely to explode and liable to escape from the premises where stored), *aff'd,* 54 N.E. 528 (Ohio 1899) (imposing strict liability for concussion damage resulting from nitroglycerine explosion regardless of lawfulness of storage or proximity of property injured to explosion location).

65. *See* Walczesky, 269 N.E.2d at 846. Ohio imposes strict liability in blasting cases where damage to property is caused by vibration or concussion resulting from the use of explosives, an ultrahazardous activity.

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

66. *See* Ameritrust Co. Nat. Ass'n v. Lamson & Sessions Co., No. 1:92-CV-0087, 1992 WL 738774 (N.D. Ohio May 21, 1992) (citing *Walczesky v. Horvitz Co.* as establishing that the Second Restatement of Torts has been adopted in Ohio for the proposition that damage from vibration or concussion resulting from explosives is an abnormally dangerous activity); *see also* Chudzinski v. City of Sylvania, 372 N.E.2d 611, 616 (Ohio Ct. App. 1976), *judgment entered sub nom.* Chudzinski v. City of Sylvania & Southbriar, Inc., No. L-75-227, 1976 WL 188334 (Ohio Ct. App. May 14, 1976) (suggesting that where vibration is a nuisance it may be considered an abnormally dangerous activity). *But see* Slack v. Fort Defiance Const. & Supply, Inc., No. 03AP-1268, 2004 WL 2806310 (Ohio Ct. App. Dec. 7, 2004) (noting that damages proximately caused by the vibrations inherent to pile driving operations may give rise to strict liability, and applying the Second Restatement of Torts in holding that vibration damage caused by a mechanical shovel is not an abnormally dangerous activity).

67. *See* Ameritrust Co. Nat. Ass'n v. Lamson & Sessions Co., No. 1:92-cv-0087, 1992 WL 738774 (N.D. Ohio May 21, 1992).

68. *See* Slack v. Fort Defiance Const. & Supply, Inc., No. 03AP-1268, 2004 WL 2806310 (Ohio Ct. App. Dec. 7, 2004) (imposing standard of due care with operation of mechanical shovel).

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

69. COGCC Report, *supra* note 25.

70. *Id.* *See also* Darlene A. Cypser, Colorado Law & Induced Seismicity (1996) (unpublished manuscript) (on file with author), *available at* http://www.darlene cypser.com/induceq/ColoradoLawandInducedSeismicity.html [http://perma.cc/9MBE-ADPF]; Darlene A. Cypser & Scott D. Davis, *Liability for Induced Earthquakes*, 9 J. ENVTL. L. & LITIG. 551 (1994).

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

71. *See* 6 Colo. Code. Regs. § 404-1 (LexisNexis 2014). Rule 303 covers permits to Drill, Rule 324B exempt aquifers, Rule 325 underground disposal of water, and Rule 326 mechanical integrity testing. Together, they govern drilling and operational requirements for Class II wells, which require review and approval of Form 21 (Mechanical Integrity Test), Form 26 (Source of Produced Water for Disposal), Form 31 (Underground Injection Formation Permit Application), and Form 33 (Injection Well Permit Application).

72. 0.6 psi per foot of depth. COGCC Report, *supra* note 25, at 2.

73. Some injection wells do not need to inject under pressure because the formation takes water on a vacuum. *Id.*

74. This was the state's largest earthquake in four decades. *Colorado Earthquake Is Largest in Four Decades*, CHRISTIAN SCI. MONITOR (Aug. 23, 2011), http://www.csmonitor.com/USA/Latest-News-Wires/2011/0823/Colorado-earthquake-is-largest-in-four-decades [http://perma.cc/F6G2-596X]; *U.S. Geological Survey, U.S. Dep't of the Interior, Before the S. Comm. On Energy and Nat. Res.* 1 (June 19, 2012) (statement of Dr. William Leith, Senior Science Advisor for Earthquake and Geologic Hazards), *available at* http://www.energy.senate.gov/public/index.cfm/files/serve?File_id=7d03cfce-b4f6-4a3c-a048-d42c9583b96e [http://perma.cc/WEU2-WF56].

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

75. Jim Efstathiou, Jr., *Fracking-Linked Earthquakes Spurring State Regulations*, BLOOMBERG, (Apr. 20, 2012, 11:19 AM), http://www.bloomberg.com/news/2012-04-20/fracking-linked-earthquakes-spurring-state-regulations.html [http://perma.cc/2BZC-XSJC]; Julie Shemeta, Bill Goodway, Mark Willis & Werner Heigl, *An Introduction to This Special Section: Passive Seismic and Microseismic—Part 2*, THE LEADING EDGE, Dec. 2012, http://www.apachecorp.com/Resources/Upload/file/innovation/Shemeta-An_introduction-passive_and_microseismic.pdf [http://perma.cc/BV2M-SHVF].

76. Veil, *supra* note 19, at 34.

77. Veil, *supra* note 19, at 35.

78. 6 Colo. Code. Regs. § 404-1 (Rules 706, 707, and 712).

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.

79. *See, e.g.*, Garden of the Gods Vill. v. Hellman, 294 P.2d 597 (Colo. 1956) (en banc) (affirming holding that a showing of negligence is not necessary to impose liability for damage caused by vibration or concussion from blasting).

80. Cass Company-Contractors v. Colton, 279 P.2d 415 (Colo. 1955) (en banc) (affirming damages while reversing injunctive relief in suit that alleged strict liability and negligence theories, holding that blasting operations were inherently dangerous and that operator was negligent for failing to seek an appraisal of foreseeable natural consequences of its operations).

81. *Id.*

82. *See* Garden of the Gods Vill., 294 P.2d at 602 (citing Langrell v. Harrington, 41 A.2d 461 (Del. 1945)).

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

83. *Oklahoma Hydraulic Fracturing State Review*, STATE REVIEW OF OIL AND NATURAL GAS ENVIRONMENTAL REGULATIONS, Jan. 2011, at 7, http://www.stronger inc.org/sites/all/themes/stronger02/downloads/Final%20Report%20of%20OK%20HF%2 0Review%201-19-2011.pdf [http://perma.cc/CG2B-XM7M].

84. *See* Holland, *supra* note 5.

85. *See* Joe Eaton, *Scientists Say Oil Industry Likely Caused Largest Oklahoma Earthquake*, NAT'L GEOGRAPHIC NEWS, Mar. 29, 2013, http://news.national geographic.com/news/energy/2013/03/130329-wastewater-injection-likely-caused-quake/ [http://perma.cc/JRM7-4XHH]

86. *Id.*

87. Jacquelyn Pless, *Natural Gas Development and Hydraulic Fracturing: A Policymaker's Guide*, NATIONAL CONFERENCE OF STATE LEGISLATURES, June 2012, http://www.ncsl.org/documents/energy/frackingguide_060512.pdf [http://perma.cc/ 8CDW-WBEJ]; *Underground Injection Control (UIC) Permits*, OKLAHOMA DEP'T OF ENVTL. QUALITY http://www.deq.state.ok.us/lpdnew/UIC/UIC.html [http://perma.cc/ 96SS-4HDK] (last updated Sept. 22, 2014); *Oklahoma Underground Injection Wells: What You Need to Know*, BUS. AND LEGAL RES., http://www.blr.com/Environmental/ Water/Underground-Injection-Wells-in-Oklahoma [http://perma.cc/TP25-E4KG] (last visited Nov. 22, 2014). In addition, in response to induced earthquakes in Oklahoma, the state's Insurance Commissioner urged residents to purchase earthquake insurance, perhaps suggesting awareness that the recent earthquakes have been induced and that under traditional insurance policies Oklahomans will not be able to recover for damage caused by induced earthquakes since they would not constitute an act of God. Henry, *supra* note 15.

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.

88. Barry Porterfield, *It's a Wrap for Disposal Well Issue*, PAULS VALLEY DEMOCRAT (Sept. 6, 2012, 9:30 AM) http://www.paulsvalleydailydemocrat.com/news/local_news/it-s-a-wrap-for-disposal-well-issue/article_e396bdc9-c178-5a23-8c47-c9611da8a34a.html [http://perma.cc/46RH-EDDM].

89. *Id.*

90. *Id.*

91. *See* Muskogee v. Hancock, 158 P 622 (Okla. 1916) (finding liability for concussion damage caused by blasting was not dependent on the standard of care used); *see also* Tibbets & Pleasant v. Benedict, 261 P 551 (Okla. 1927) (affirming grant of new trial because plaintiffs had been denied opportunity to present strict liability theory to jury and only allowed to present negligence theory); *cf.* Stowell v. Engelson, 201 P2d 919 (Okla. 1948) (holding concussion damage not a taking for which just compensation was due, but a tort, leaving open the question of whether negligence or strict liability was the appropriate standard).

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]

92. *See* Henry, *supra* note 15.

93. *See* Frohlich, *supra* note 6.

94. 16 Tex. Admin. Code § 3.46, 3.9 (2014); *see also* Bob Greenslade, Eva Fromm O'Brien, and Jennifer Blair Caplan, *New Rules Address Earthquake and Fracking Concerns in Texas*, INT'L LAW OFFICE, Nov. 17, 2014, http://www.nortonrose fulbright.com/files/20150120-new-rules-address-earthquake-and-fracking-concerns-in-texas-125001.pdf [http://perma.cc/J9BY-35DA].

95. 16 Tex. Admin. Code § 3.46(d)(1)(F), 3.9(6)(A)(vi).

96. *Railroad Commission Hires Seismologist*, R.R. COMM'N OF TEX., Mar. 28, 2014, http://www.rrc.state.tx.us/all-news/032814/ [http://perma.cc/Z62H-J5H8].

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]

97. *See* H. L. Butler & Son v. Walpole, 239 S.W.2d 653 (Tex. Civ. App. 1951) (finding damage apparently by concussion and rocks and debris); Dellinger v. Skelly Oil Co., 236 S.W.2d 675 (Tex. Civ. App. 1951); McKay v. Kelly, 229 S.W.2d 117 (Tex. Civ. App. 1950); Stanolind Oil & Gas Co. v. Lambert, 222 S.W.2d 125 (Tex. Civ. App. 1949); Crain v. West Texas Utils. Co., 218 S.W.2d 512 (Tex. Civ. App. 1949); Kennedy v. Gen. Geophysical Co., 213 S.W.2d 707 (Tex. Civ. App. 1948); Indian Territory Illuminating Oil Co. v. Rainwater, 140 S.W.2d 491 (Tex. Civ. App. 1940); Dallas v. Newberg, 116 S.W.2d 476 (Tex. Civ. App. 1938); Comanche Duke Oil Co. v. Texas Pac. Coal & Oil Co., 298 S.W. 554 (Tex. Com. App. 1927).

98. *Magnitude 4.7 – Arkansas Earthquake Details*, U.S. GEOLOGICAL SURVEY (Feb. 28, 2011, 5:00 AM) http://earthquake.usgs.gov/earthquakes/eqinthenews/2011/nm022811a/#details [http://perma.cc/MXE9-F4ZA].

99. Hearn v. BHP Billiton Petroleum Inc., No. 4:11-cv-00474 (E.D. Ark. 2013). Clarita Operating LLC appears to have been a shell company for Chesapeake, the hydraulic fracturing company whose waste it disposed of, according to bankruptcy documents for Clarita. *Clarita Operating LLC-Arkansas*, BUSINESS BANKRUPTCIES (Oct. 17, 2011) http://business-bankruptcies.com/cases/clarita-operating-llc-arkansas [http://perma.cc/U5DJ-LTVV]. Deep Six Water Disposal Services appears to have been a thinly capitalized wastewater injection well operator, now bankrupt. Deep Six attempted to contest the AOGC moratorium imposed after one of its wells was among those implicated in causing the 4.7 magnitude earthquake experienced near Guy and Greenbrier. Gerard Matthews, *Deep Six Deep-Sixed by AOGC*, ARKANSAS TIMES (July 27, 2011, 1:09 PM) http://www.arktimes.com/ArkansasBlog/archives/2011/07/27/deep-six-deep-sixed-by-aogc [http://perma.cc/2CUW-GHCM].

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.

100. *General Rules and Regulations*, ARKANSAS OIL & GAS COMM'N, Aug. 1, 2014, *available at* http://www.aogc.state.ar.us/onlinedata/forms/rules%20and%20regulations.pdf [http://perma.cc/6HMM-66YQ].

101. *Id.*

102. *Id.* at 195 (Rule H-1(p)).

103. "Class II Commercial Disposal Well" means a permitted Class II well in which Class II Fluids are injected, for which the Permit Holder receives deliveries of Class II Fluids by tank truck from multiple oil and gas well operators, and either charges a fee at the disposal well facility or purchases the Class II Fluids at the source for subsequent transport to the disposal well facility for the specific purpose of disposal of the delivered Class II Fluids. *Id.* at 187 (Rule H-1(a)(2)).

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.

104. *See* General Rules and Regulations, *supra* note 101, at 40.

105. *See* Bennett v. Texas-Illinois Gas Pipeline Co., 113 F.Supp. 788 (E.D. Ark. 1953).

106. Jordan Fletcher, *The Fracking-Earthquake Connection*, DALLAS MORNING NEWS, Dec. 6, 2013, http://www.dallasnews.com/opinion/sunday-commentary/20131206-the-fracking-earthquake-connection.ece [http://perma.cc/MV3M-DM42]. Nuisance law may be inapposite because induced earthquakes may not present an ongoing harm, and the typical remedy, injunction, fails to account for damage caused.

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]

107. Strict liability presumably would ensure an "efficient" level of earthquake damage, yet a negligence rule might better avoid overburdening hydraulic fracturing operators. A key difference is also that a negligence rule would force property owners to bear the brunt of damage from an earthquake they neither caused nor benefited from.

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

108. Strict liability merely requires a finding of causation, whereas negligence requires the additional finding that a standard of due care was breached.

109. Strict liability can be imposed on the injection activity, or on the wastewater itself. The latter option provides a way to veil-pierce when commercial well operators dispose of wastewater generated by hydraulic fracturing operators.

110. It might be argued that legislatures and regulatory agencies have greater institutional competence than courts to determine the appropriate standard of care for injection practices such that negligence for inducing an earthquake should only be found after standards have been developed external to the judicial process.

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.