Underground Wastewater Disposal from Oil and Gas Operations: Regulating Our Way to Earthquake Free

Kayleen Glaser, Indiana Maurer School of Law[1]
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I. Introduction

In recent years, unconventional oil and gas production activities increased the need for wastewater disposal capacity in the United States.[2] Oil and gas producers usually inject this wastewater into underground disposal wells,[3] and to keep up with the waste generation of the industry, they drilled more wells that were located in geographic areas where disposal has not previously occurred.[4] Scientist suspect a growing number of wells, some of which are in these new geographical areas, induced recent seismicity activity.

Within central and eastern United States, the number of earthquakes has increased dramatically over the past five years. Magnitude 3.0 or greater earthquakes are occurring 14 times more frequently from 2010 to 2012 than from 1967 to 2000.[5] From 2010 to 2012, more than 300 earthquakes above a magnitude 3.0 occurred within the central and eastern United States, compared with an average rate of 21 events per year observed from 1967 to 2000.[6] Scientists found the increase in seismic activity to coincide with the location of injection of

[1] Draft prepared as an independent study project for the Intermountain Oil and Gas Best Management Practice Project of the Getches-Wilkinson Center for Natural Resources, Energy and the Environment, at the University of Colorado Law School.
[2] Underground Injection Control National Technical Workgroup, *Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells: Practical Approaches*, U.S. E.P.A, ES-1 (2014), *available at* http://www.epa.gov/Region5/water/uic/ntwg/pdfs/induced-seismicity-201502.pdf.
[3] *Id.*
[4] *Id.*
[5] Bill Ellsworth et al., *Induced Earthquakes*, U.S.G.S. EARTHQUAKES HAZARDS PROGRAM, http://earthquake.usgs.gov/research/induced/ (last visited Mar. 22, 2014). From 2010 to 2012, more than 300 earthquakes above a magnitude 3.0 occurred within the central and eastern United States, compared with an average rate of 21 events per year observed from 1967 to 2000.
[6] Bill Ellsworth et al., *Induced Earthquakes*, U.S.G.S. EARTHQUAKES HAZARDS PROGRAM, http://earthquake.usgs.gov/research/induced/ (last visited Mar. 22, 2014).

wastewater in deep disposal wells in many states, including Colorado, Texas, Arkansas, Oklahoma, and Ohio.[7] Scientists believe that underground wastewater disposal induced the magnitude 5.3 earthquake in the Raton Basin in Colorado in 2011, as well as the magnitude 5.6 earthquake that struck Prague, Oklahoma in 2011 that lead to a few injuries and damage to more than a dozen homes.[8] Other earthquakes potentially induced by wastewater disposal include the 2011 magnitude 4.0 earthquake in Youngstown, Ohio; the 2011 magnitude 5.3 earthquake in Trinidad, Colorado; the 2011 magnitude 4.7 earthquake in Guy-Greenbrier, Arkansas; the 2012 magnitude 4.8 earthquake in Timpson, Texas; and the 2013 magnitude 3.9 in Paradox Valley, Colorado.[9]

Many of these states did not experience earthquakes of these magnitudes prior to wastewater disposal of oil and gas operations. Oklahoma illustrates how wastewater disposal can dramatically change the earthquake activity in a state. For example, there were more earthquakes in 2014 of magnitude 3 or higher in Oklahoma than in California.[10] From 1978 to 2008, the state felt, on average, one to three earthquakes of magnitude 3 or greater every year.[11] In 2014, it faced 562, more than three times the 180 in California.[12] The problem is so prevalent that Oklahomans have started seeking earthquake insurance.[13]

This paper explores various legal and policy avenues to eliminate or minimize induced seismicity associated with wastewater disposal activities from oil and gas development. It

[7] *Id.*
[8] *Id.* Wastewater disposal has not yet been linked to earthquakes with a magnitude of greater than 6.0.
[9] *Induced Earthquakes Throughout the United States*, VA. TECH SEISMOLOGICAL OBSERVATORY, http://www.magma.geos.vt.edu/vtso/induced_quakes.html (last visited Mar. 2, 2014).
[10] Mike Gaworecki, *USGS: Fracking Wastewater Disposal Wells Are Causing Oklahoma Earthquakes*, DESMOG BLOG (Feb. 26, 2015 4:58 PM), http://www.desmogblog.com/2015/02/26/usgs-fracking-wastewater-disposal-wells-are-causing-oklahoma-earthquakes.
[11] *Id.*
[12] *Id.*
[13] *Id.*

focuses on Underground Injection Control regulation under the Safe Drinking Water Act, as implemented by various states. The paper first gives background information on the wastewater disposal process for oil and gas development. Next, the paper examines the federal government's best practices for managing and mitigating induced seismicity. It then summarizes recent induced seismicity events from oil and gas wastewater disposal in the United States and explores how governments have regulated wastewater operations to avoid induced seismicity. This section examines moratoriums and bans, executive orders, permitting systems, and regulations.[14] Last, the paper examines how state action has measured up to the federal government's listed best practices. To evaluate state action, the paper compares the actions with recommendations contained in the 2015 UIC National Technical Workgroup report, titled "Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells: Practical Approaches."

II. Background

Before diving into wastewater disposal law and policy, it is important to have a precise understanding of the terms and processes associated with the oil and gas production process and the wastewater disposal process. First, the paper explains conventional and unconventional oil and gas extraction processes. Second, it details how oil and gas operations generate wastewater. Third, the paper explains the mechanics of induced seismicity.

a. Oil and Gas Operations – The Process

[14] This paper in no way is meant to be a comprehensive review of what every state is doing to regulate induced seismicity from the underground disposal of wastewater from oil and gas operations. Rather, it provides an overview of the ways in which states may regulate.

Oil is formed from plant and animal material that accumulates at the bottom of a water supply such as an ocean, river, lake, or coral reef.[15] Over time, this material is buried by accumulating sediment and is pushed deeper into the earth's surface from increased pressure from the weight of the overlying sediment and increased temperature due to the heat from the earth's core.[16] Oil exists underground as small droplets trapped inside the small void spaces in rock.[17] When oil and gas developers drill a well into an oil reservoir, the high pressure that exists in the reservoir pushes oil out of the small voids and to the surface.[18]

Oil and gas may be found in large pools underground, where the small voids are connected pore spaces, or in small voids in rock.[19] How the oil and gas is trapped underground determines how the oil and gas industry can extract it.[20] When the oil or gas forms pools, developers use "conventional processes," and oil and gas may flow naturally to the surface or drillers may pump it to the surface.[21] Decades of oil and gas extraction reduced the availability of conventional sources; as a result, the oil and gas industry turned to unconventional methods to extract previously unobtainable oil and gas deposits. Developers need nonconventional oil and gas operations to recover extra heavy oil, oil sand, tight gas, coal bed methane, oil shale[22], shale

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[15] Katie Guerra, Katharine Dahm & Steve Dundorf, U.S. D.O.I. Bureau of Reclamation, *Oil and Gas Produced Water Management and Beneficial Use in the Western United States*, SCI. & TECH. REP. NO. 157, 3 (2011), *available at* http://www.usbr.gov/research/AWT/reportpdfs/report157.pdf.
[16] *Id.*
[17] *Id.*
[18] *Id.*
[19] *Id.*
[20] *Id.*
[21] *What is Unconventional Oil and Gas?*, ALBERTA ENERGY REGULATOR, https://www.aer.ca/about-aer/spotlight-on/unconventional-regulatory-framework/what-is-unconventional-oil-and-gas (last visited on Mar. 22, 2015).
[22] *Oil Shale vs. Shale Oil*, COLO. OIL & GAS ASS'N (June 18, 2013), http://www.coga.org/pdf_Basics/Basics_OilShale.pdf. Not to be confused with shale oil. Shale oil, more accurately named oil-bearing shale, contains oil and gas, trapped in relatively low porosity and permeability rock, commonly shale or tight siltstone limestone or dolomite, that typically resides a mile below the earth's surface. Producers can unlock shale oil by horizontal drilling and hydraulic fracturing Oil shale is an organic-rich, fine-grained sedimentary rock that contains a solid organic compound known as kerogen. Oil shale generally contains enough oil that it will burn, hence its nickname, "the rock that burns." To generate oil, the kerogen-rich rock is heated in the absence of oxygen. Under these conditions, the kerogen chemically reacts and creates a vapor which ultimately condenses into oil.

gas, and natural gas hydrates.[23] These types of oil and gas are frequently located in small void spaces in the rock, instead of large pools or pockets. Nonconventional or unconventional processes include hydraulic fracturing and horizontal drilling, among others.[24]

The oil and gas extraction life cycle includes four major processes: (1) exploration; (2) well development; (3) production; and (4) site abandonment.[25] First, exploration includes searching for economically recoverable rock formations associated with crude petroleum and natural gas, prospecting, and exploratory drilling.[26] Second, well development includes construction of one or more wells; well development lasts from the initial well construction to either abandonment, if developers fail to find economically recoverable hydrocarbons, to well completion, if they find hydrocarbons in sufficient quantities.[27] Third, production is the process of extracting the hydrocarbons, separating the mixture of liquid hydrocarbons, gas, water, and solids, removing the constituents that are non-saleable, and selling the liquid hydrocarbons and gas.[28] Oil and gas extractors usually process oil off-site at a refinery, while they may process natural gas to remove impurities either on-site or at a natural gas processing plant.[29] Finally, site abandonment involves plugging the wells and restoring the site.[30]

b. Wastewater Disposal from Oil and Gas Operations

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[23] Pernille Seljom, Int'l Energy Agency, *Unconventional Oil & Gas Production*, ENERGY TECH. SYST. ANALYSIS PROGRAMME TECH. BRIEF P02 (May 2010), *available at* http://www.iea-etsap.org/web/E-TechDS/PDF/P02-Uncon%20oil&gas-GS-gct.pdf. Extra heavy oil is oil with high viscosity. Oil sand is sand containing extra heavy oil (bitumen). Oil shale, explained in the above footnote, is rock containing a solid bituminous material (kerogen). Tight gas is natural gas with low permeability. Coal bed methane is natural gas associated with coal in non-profitable coal mines. Shale gas is natural gas with low permeability associated with oil shale. Natural gas hydrates is natural gas trapped in the structure of water ice.

[24] http://www.iea-etsap.org/web/E-TechDS/PDF/P02-Uncon%20oil&gas-GS-gct.pdf Other unconventional processes include steam injection, multilateral wells and upgrading, surface mining, retorting, depressurization, thermal injection, and inhibitor injection.

[25] *The Development Process*, Intermountain Oil and Gas BMP Project http://www.oilandgasbmps.org/resources/development.php (last visited Mar. 22, 2015).

[26] *Id.*

[27] *Id.*

[28] *Id.*

[29] *Id.*

[30] *Id.*

Produced water from oil and gas extraction is the largest volume waste generated in oil and gas operations.[31] Oil and gas operations generate approximately 21 billion barrels of produced water each year.[32] On average, each crude barrel extracted via conventional processes yields 280 to 400 gallons of water.[33] Traditional wells bring produced water to the surface along with oil or gas;[34] this water, called formation water (or connate water), exists naturally in the porous aquifer with the hydrocarbons.[35] The generation of produced water commonly increases over time in conventional reservoirs as extraction depletes oil and gas levels.[36]

In some unconventional drilling processes, developers pump water below ground to force out hydrocarbons. These wells are "drier" and do not contain as much underground water as conventional wells; as a result, water is brought onsite for fracturing operations.[37] Water used to force out the hydrocarbon is called flow back or frac water when it returns from fracturing applications.[38] In most unconventional oil and gas operations, frac water is considered the

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[31] U.S. E.P.A. Office of Compliance, *Profile of Oil and Gas Extraction Industry*, SECTOR NOTEBOOK PROJECT, 45 (Oct. 2000), *available at* http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/oilgas.pdf; Katie Guerra, Katharine Dahm & Steve Dundorf, U.S. D.O.I. Bureau of Reclamation, *Oil and Gas Produced Water Management and Beneficial Use in the Western United States*, SCI. & TECH. REP. NO. 157, 5 (2011), *available at* http://www.usbr.gov/research/AWT/reportpdfs/report157.pdf. Produced water can also be called "brine," "saltwater," or "formation water."

[32] Colorado School of Mines Advanced Water Technology Center, *About Produced Water (Produced Water 101)*, PRODUCED WATER TREATMENT & BENEFICIAL USE INFO. CENTER, http://aqwatec.mines.edu/produced_water/intro/pw/ (last visisted Mar. 22, 2015). One barrel is equal to 42 U.S. gallons. Thus, approximately 37,800,000 gallons of waste water are produced by the oil and gas industry.

[33] Katie Guerra, Katharine Dahm & Steve Dundorf, U.S. D.O.I. Bureau of Reclamation, *Oil and Gas Produced Water Management and Beneficial Use in the Western United States*, SCI. & TECH. REP. NO. 157, 5 (2011), *available at* http://www.usbr.gov/research/AWT/reportpdfs/report157.pdf.

[34] Colorado School of Mines Advanced Water Technology Center, *About Produced Water (Produced Water 101)*, PRODUCED WATER TREATMENT & BENEFICIAL USE INFO. CENTER, http://aqwatec.mines.edu/produced_water/intro/pw/ (last visisted Mar. 22, 2015).

[35] Katie Guerra, Katharine Dahm & Steve Dundorf, U.S. D.O.I. Bureau of Reclamation, *Oil and Gas Produced Water Management and Beneficial Use in the Western United States*, SCI. & TECH. REP. NO. 157, 5 (2011), *available at* http://www.usbr.gov/research/AWT/reportpdfs/report157.pdf. Formation water generally reflects the water quality associated with the depositional environment for the reservoir – marine, brackish, or continental fresh water

[36] *Id.*

[37] *Id.*

[38] *Id.*

largest waste stream of production.[39] Produced water may include water from the reservoir, water injected into the formation, and any chemicals added during the drilling, production, and treatment processes.[40]

Many activities relating to oil and gas extraction create wastewater. In the well development process, wastewater can occur from drilling muds, organic acids, alkalis, diesel oil, crankcase oils, and acidic stimulation fluids.[41] In the production process, wastewater can occur from produced water containing heavy metals, radionuclides, dissolved solids, oxygen demanding organic compounds, and high levels of salts.[42] During this phase, wastewater may also may contain additives including biocides, lubricants, corrosion inhibitors, glycol, amines, salts, and untreatable emulsions.[43] In the maintenance process, wastewater can occur from completion fluid, wastewater containing well-cleaning solvents (detergents and degreasers), paint, and stimulation agents.[44] Spills, blowouts, and escaping oil and brine may create wastewater from abandoned wells.[45]

The primary methods used to dispose of produced water are: (1) injection for enhanced recovery, (2) injection for disposal; (3) beneficial use; (4) evaporation and percolation ponds; (5) treat and discharge; and (6) roadspreading. [46] Drillers dispose of over 90% of produced water

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[39] *Id.* at 6.
[40] *Id.*
[41] U.S. E.P.A. Office of Compliance, *Profile of Oil and Gas Extraction Industry*, SECTOR NOTEBOOK PROJECT (Oct. 2000), *available at* http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/oilgas.pdf.
[42] *Id.*
[43] *Id.*
[44] *Id.*
[45] *Id.*
[46] *Id.* at 48. Injection for enhanced recovery is using produced water for enhanced (secondary or tertiary) recovery of oil and natural gas. It is recognized as a form of recycling the waste. Produced water may be used as a beneficial use with agriculture if it meets certain water quality standards it then may be released directly to agricultural canals for use in irrigation or livestock watering. Produced water may be placed in a pit and allowed either to evaporate to the air or percolate into the surrounding soil. These pits can only be used when the fluid will not adversely impact groundwater or surface water, and restrictions may be imposed on water salinity, hydrocarbon content, pH, and radionuclide content. The treat and discharge method of disposal requires oil and gas operators to treat the wastewater to meet standards for oil and grease content as well as pass a toxicity test prior to discharge into a water

through underground injection.[47] They can use inject it underground in two ways: as part of a waterflooding effort for enhanced recovery or for waste disposal.[48] Drillers can re-inject produced water into the oil- and gas-producing formation to recover more hydrocarbons; they implement this first method in locations where formation pressure may be relatively low to increase force oil toward the well.[49] However, this method does not create sustained increases in pressure, as does the latter method of wastewater disposal, which involves injecting the wastewater underground.

c. Induced Seismicity

Human-induced earthquakes, also known as induced seismicity, are an increasing concern in regions of the United States where drillers inject produced fluids into the subsurface through underground disposal wells.[50] The immediate concern is that this practice may be responsible for damaging earthquakes in regions that typically do not experience much seismic activity.[51] Induced seismicity has garnered increased media attention recently because of the rapid development of unconventional oil and gas resources, in part due to the industry's use of hydraulic fracturing (often referred to as fracking).[52] It is important to distinguish between seismic activity possibly related to hydraulic fracturing itself and the possibility of human-induced earthquakes related to injecting fluids down disposal wells, which may not be located near where wells were fracked.[53] This paper focuses solely on seismic activity related to the

system. If the fluid has the characteristics of materials used for dust suppressants, road oils, deicing materials, or road compaction, the fluid may be used for roadspreading. In this procedure, water is applied to roads at approved rates, in order to prevent pooling or runoff and to minimize the risk of surface water or groundwater contamination.

[47] *Id.* at 46.

[48] *Id.*

[49] *Id.*

[50] Peter Folger & Mary Tiemann, *Human-Induced Earthquakes from Deep-Well Injection: A Brief Overview*, Congressional Research Service (2014), *available at* http://fas.org/sgp/crs/misc/R43836.pdf.

[51] *Id.*

[52] *Id.*

[53] *Id.*

underground injection of fluids via disposal wells because science has linked these two events together. On the other hand, scientists cannot say as certainly that hydraulic fracturing activities induce seismicity.[54]

While the physics behind injection-induced seismicity are complex, the general concept is relatively simple. There are many natural cracks in the earth of varying sizes; all of these cracks are under some amount of shear stress that can potentially cause rocks on either side of the crack to slip past each other.[55] To cause slippage and generate a seismic event, the shear stress must surpass a critical threshold to overcome friction.[56] Injected fluid essentially reduces the frictional resistance and allows rocks along the crack to slip more easily.[57] The size of a crack (i.e., a fault) that can be induced to slip is dependent on how much fluid is injected.[58] The more fluid injected into a fault segment, the larger the portion of the fault that can potentially be induced to slip.[59] Where injection continues over long periods, the injected fluids will cause a cumulative rise in formation pressure.[60] Increased formation pressure by itself does not necessarily induce earthquakes, but if faults that are already near failure or susceptible to slippage are located near the site of increased pressure, an earthquake may be triggered.[61]

To make a finding of human-induced seismicity scientists examine: (1) geographic relationship between the wellbore depth and the location of the earthquake, (2) exceedance of the theoretical friction threshold for fault slippage, and (3) lack of historical seismicity in an area

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[54] Mitigating and Managing.
[55] Mark Fitzsimmons, Samuel A. Flewelling & Matthew P. Tymchak, Will Earthquakes Shake Up The Shale Wastewater Debate?, Law360 (May 27, 2014).
[56] *Id.*
[57] *Id.*
[58] *Id.*
[59] *Id.*
[60] John Veil, *A White Paper Summarizing a Special Session on Induced Seismicity*, GROUND WATER RES. & EDUC. FOUND. (Feb. 2013), *available at* http://www.gwpc.org/sites/default/files/events/white%20paper%20-%20final_0.pdf.
[61] *Id.*

prior to the activity in question.[62] The Environmental Protection Agency (EPA) developed a series of questions to evaluate the likelihood of induced seismicity, which includes: (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 near wells (within five kilometers [km])? (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?[63] While this approach is qualitative and does not result in positive proof of injection-induced seismicity, state and federal governments should use these questions as useful preliminary screening tools when making these evaluations.

III. Regulating Oil and Gas Operations to Avoid Induced Seismicity

a. Federal Oversight

EPA's Underground Injection Control (UIC) program, authorized by the Safe Drinking Water Act (SWDA), protects underground sources of United States drinking water (USDW).[64] The UIC program protects USDW from risks associated with underground waste disposal, which include threats from seismic events. Seismic events could cause changes in USDW water level or turbidity, USDW contamination from a direct communication with the fault inducing

[62] *Id.*
[63] Underground Injection Control National Technical Workgroup, *Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells: Practical Approaches*, U.S. E.P.A, ES-4 (2014), *available at* http://www.epa.gov/Region5/water/uic/ntwg/pdfs/induced-seismicity-201502.pdf.
[64] 42 U.S.C. §300f et seq. Title 40 CFR; Underground Injection Control National Technical Workgroup, *Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells: Practical Approaches*, U.S. E.P.A, ES-4 (2014), *available at* http://www.epa.gov/Region5/water/uic/ntwg/pdfs/induced-seismicity-201502.pdf. The SWDA does not include a definition for United States drinking water; rather, it provides contaminant levels for waters coming forth from public water system; however, section 1422 of SDWA requires "a State underground injection control program . . . to assure that underground injection will not endanger drinking water sources." 40 CFR 144.1.

seismicity, or contamination from earthquake-damaged surface sources.[65] Currently, EPA is unaware of any USDW contamination resulting from seismic events related to injection-induced seismicity; however, the UIC program is needed to "prevent underground injection which endangers drinking water sources."[66]

EPA established regulations for six classes of injection wells, including Class II wells for the regulation of injection of fluids related to oil and gas production into Class II wells.[67] Class II injection wells include wells used for enhanced recovery, oil and gas production wastewater disposal, and hydrocarbon storage wells.[68] Disposal wells inject brines and other produced fluids associated with the production of oil and natural gas or natural gas storage operations.[69] Drillers can only use these well to dispose of fluids associated with oil and gas production and represent about 20% of Class II wells.[70] Disposal wells do not offset withdrawal like wells associated with enhanced recovery and therefore, have a greater potential for pressure to build up and induced seismic activity.[71]

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[65] *Id.*

[66] *Id.* 42 USC §300h (b)(1).

[67] Peter Folger & Mary Tiemann, *Human-Induced Earthquakes from Deep-Well Injection: A Brief Overview*, Congressional Research Service (2014), *available at* http://fas.org/sgp/crs/misc/R43836.pdf.

[68] Underground Injection Control National Technical Workgroup, *Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells: Practical Approaches*, U.S. E.P.A, ES-4 (2014), *available at* http://www.epa.gov/Region5/water/uic/ntwg/pdfs/induced-seismicity-201502.pdf. Enhanced recovery wells inject brine, water, steam, polymers, or carbon dioxide into oil bearing formations to recover residual oil and occasionally natural gas. The UIC program does not regulate wells that are solely used for production; however, EPA does have the authority to regulate hydraulic fracturing when diesel fuels are used in fluids or propping agents.http://water.epa.gov/type/groundwater/uic/class2/index.cfm Injection for enhanced recovery projects, such generally poses less potential to induce seismicity than wastewater disposal because pressure increases resulting from injection for enhanced recovery are partially offset by nearby production wells. Underground Injection Control National Technical Workgroup, *Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells: Practical Approaches*, U.S. E.P.A, ES-4 (2014), *available at* http://www.epa.gov/Region5/water/uic/ntwg/pdfs/induced-seismicity-201502.pdf.

[69] http://water.epa.gov/type/groundwater/uic/class2/index.cfm

[70] http://water.epa.gov/type/groundwater/uic/class2/index.cfm

[71] Underground Injection Control National Technical Workgroup, *Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells: Practical Approaches*, U.S. E.P.A, ES-4 (2014), *available at* http://www.epa.gov/Region5/water/uic/ntwg/pdfs/induced-seismicity-201502.pdf. Enhanced recovery wells remove underground water (decreasing the subsurface pressure), but ultimately replace the water (restoring the subsurface pressure). With enhanced recovery, the subsurface pressure returns to its original pressure. On the other

The SDWA fails to explicitly address or prevent induced seismicity. While the Class II regulatory framework allows the EPA the flexibility to decide on a case-by-case basis whether a permittee should evaluate the potential for induced seismicity, the framework fails to *require* such evaluation.[72] Examples of this discretionary authority include placing additional permit requirements for construction, corrective action, operation, monitoring or reporting (including well closure) as necessary to protect USDWs.[73]

EPA formed the National Technical Workgroup (NTW) in 1995 to discuss technical issues related to the UIC Program and recently tasked the NTW with providing suggestions for managing induced seismicity within the context of the Class II UIC program.[74] In early 2015, the NTW released a report finding that "no single recommendation [could] address[] all the complexities related to managing or minimizing injection-induced seismicity" and instead offered a variety of suggestions that could be implemented throughout the entire permitting process.[75] First, NTW recommended conducting a preliminary assessment, which includes: (1) assessing disposal history of the permit area for correlation with area seismicity; (2) reviewing area seismicity for increases in frequency or magnitude; (3) identifying changes in disposal well operating conditions that may influence seismicity; and (4) determining the depth to basement rock and potential connectivity to the disposal zone.[76] The preliminary assessment will provide

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hand, underground disposal wells increase the subsurface pressure by disposing of water that was not removed from the area. Seismic activity is thus more likely from underground disposal wells.

[72] Peter Folger & Mary Tiemann, *Human-Induced Earthquakes from Deep-Well Injection: A Brief Overview*, Congressional Research Service (2014), *available at* http://fas.org/sgp/crs/misc/R43836.pdf; Underground Injection Control National Technical Workgroup, *Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells: Practical Approaches*, U.S. E.P.A (2014), *available at* http://www.epa.gov/Region5/water/uic/ntwg/pdfs/induced-seismicity-201502.pdf. Regulations for Class I hazardous and Class VI siting provisions require some evaluation of seismic risk

[73] Underground Injection Control National Technical Workgroup, *Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells: Practical Approaches*, U.S. E.P.A (2014), *available at* http://www.epa.gov/Region5/water/uic/ntwg/pdfs/induced-seismicity-201502.pdf.

[74] *Id.*

[75] *Id.*

[76] *Id.* at 33.

initial data to make more informed site and operations considerations later in the permitting process.

Second, NTW made recommendation for three technical categories: site assessment, operational, and monitoring considerations. Site assessment considerations evaluate specific site characteristics that may represent potential issues for injection-induced seismicity. Permit applicants should evaluate regional and local area geoscience information to assess the likelihood of activating faults and causing seismic events. Permit applicants should assess the initial static pressure and potential pressure buildup in the reservoir, review available data to characterize reservoir pathways that could allow pressure communication from disposal activities to a Fault of Concern and determine the proximity of the disposal zone to basement rock.[77] Importantly, NTW recommends performing these activities at all potential disposal sites, including sites that have no history of seismic activity. Many of these activities are not standard procedures for the permitting process. While these steps would require review of more data collection and data review, their addition would allow for more perfect information and therefore more informed, safer decision making.

Operational recommendations address seismicity concerns that may arise from the site assessment evaluation. EPA's operational recommendations are proactive, but as the NTW identifies, "proof of induced seismicity is difficult to achieve and may be time-consuming but is not a prerequisite for taking *early prudent action* to address the possibility of induced seismicity."[78] Permit applicants, under NTW's suggestions, conduct pressure transient testing in disposal wells suspected of causing seismic events to obtain information about injection zone characteristics near the well, and applicants should perform periodic static bottomhole pressure

[77] *Id.* at 33.
[78] *Id.* at 16.

monitoring to assess reservoir pressures.[79] Pressure transient testing and periodic state bottomhole pressure monitoring allow drillers to have accurate information about the wells in which they drill; accurate information will allow drillers to determine how the well changes the surrounding substrate and alerts them to potential induced seismicity markers. The EPA should modify the injection well permit operational parameters as needed to minimize or manage seismicity issues and operate wells below fracture pressure to maintain the integrity of the disposal zone and confining layers.[80] Examples of modifications include: reducing injection rates, starting at lower rates and increasing gradually; injecting intermittently to allow time for pressure dissipation; separating multiple injection wells by a larger distance for pressure distribution; and implementing contingency measures in the event seismicity occurs over a specified level.[81] Operating recommendations are highly fact-specific and may require trial and error.[82] Increased data gathering and operational modifications allow EPA to take the early prudent action outlined in the NTW recommendations.

Monitoring recommendations insure that seismicity concerns are addressed over a well's lifetime. Monitoring recommendations include: (1) increasing frequency of monitoring for injection parameters, such as formation pressure and rates, to increase the accuracy of analysis; (2) monitoring static reservoir pressure to evaluate pressure buildup in the formation over time; and (3) installing seismic monitoring instruments in areas of concern to allow more accurate location determination and increased sensitivity for seismic event magnitude.[83] Monitoring recommendations, like the two previous recommendations, will require fact specific, case-by-

[79] *Id.*
[80] *Id.* at 34.
[81] *Id.* at 34.
[82] *Id.*
[83] *Id.* at 34.

case determinations. While this would require more time from federal and state agencies, the payoff would be well worth it – tailored permits designed to avoid potentially harmful or devastating seismic activity.

Third, the working group recommended a new management approach. The management approach includes: (1) for wells suspected of induced seismicity, taking early actions, such as acquiring more frequent reports of injection volumes and pressures, reducing injection rates, and/or increasing seismic monitoring, rather than waiting on definitive proof of the causal relationship, and engage the operators early in the process; (2) employing a multidisciplinary team for future research to address possible links between disposal well and reservoir behavior, geology, and area seismicity; and (3) including a seismic threshold based on the magnitude or frequency of events as a condition of the permit describing action to be taken in the event of initiation of or increase in seismic events. The management recommendations are essentially best management practices and provide a seamless integration of earlier, more technical recommendations.

From the NTW report, it is unclear that these recommendations will ever be requirements or included in the regulations. Without this, there is no way to ensure that the federal governments, or the states in the federal government's stead, adequately address seismic concerns as related to underground wastewater disposal. It is also important to keep in mind that the UIC program is operating within the constraint of the Safe Drinking Water Act, and until the agency can definitively conclude that seismic activity occurring as a result of underground injection will detrimentally impact United States drinking water, the agency does not have much impetus to do anything. Without a federal baseline, the oil and gas industry may face a patchwork legal landscape, which is more time intensive for the industry because it must adopt different processes for each state.

b. State Oversight

Within central and eastern United States, the number of earthquakes has increased dramatically over the past five years. Scientists have found the increase in seismic activity to coincide with the location of injection of wastewater in deep disposal wells in many states, including Colorado, Texas, Arkansas, Oklahoma, and Ohio.[84] These states have all taken action to address induced seismicity in their boundaries and will be examined here. Texas amended its underground wastewater regulations to allow for permit modification and well shut down. Arkansas implemented a permanent moratorium in part of the state. Oklahoma initiated a "traffic light" to modify permits that may be triggering induced seismicity. Ohio also overhauled its regulatory system. Last, the state of North Carolina has also been examined because the state currently has a complete ban on oil and gas underground wastewater disposal.

i. Colorado

[Need research]

ii. Texas

In 2012, Timpson, Texas experienced an earthquake with a magnitude of 4.8.[85] In February 2013, Timpson experienced an another earthquake with a magnitude of 4.1, and in September 2013, two more earthquakes hit on the same day, measuring 4.1 and 4.3.[86] Shelby

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[84] *Id.*

[85] Mose Buchele, *A Labor Day of Earthquakes for Timpson, Texas*, STATEIMPACTNPR (Sept. 3. 2013), http://stateimpact.npr.org/texas/2013/09/03/a-labor-day-of-earthquakes-for-timpson-texas/. Until 2012, Timpson had not felt an earthquake since January 1891. Cliff Frohlich, et al., *The 17 May 2012 M4.8 Earthquake Near Timpson, East Texas: An Event Possibly Triggered By Fluid Injection*, J. GEOPHYSICAL RES. (Jan. 2014), *available at* https://pangea.stanford.edu/researchgroups/scits/sites/default/files/2014FrohlichEtal.JGR_.pdf.

[86] Mose Buchele, *A Labor Day of Earthquakes for Timpson, Texas*, STATEIMPACTNPR (Sept. 3. 2013), http://stateimpact.npr.org/texas/2013/09/03/a-labor-day-of-earthquakes-for-timpson-texas/.

County, the county in which Timpson resides, is also the home of 27 active injection well sites for storing wastewater produced from hydraulic fracturing.[87] The Timpson earthquakes were the first known earthquakes in modern times in the area and began only after injection began.[88] Scientists studying the Timpson area have determined that the earthquakes were likely triggered by underground wastewater disposal.[89] After the 2012-2013 series of earthquakes, Texas addressed induced seismicity in the state by promulgating new statutes. On the local level, a Texas city has enacted a complete ban on hydraulic fracturing.

The Texas Railroad Commission was established in 1891 to regulate the rail.[90] The Commission currently oversees the activities of many different industries, including the oil and gas industry.[91] In addition, two of the primary responsibilities of the Commission are protection of the environment and preservation of individual property rights.[92] In 2014, the Texas Railroad Commission (RRC) unanimously adopted Class II injection well amendments, which focus on addressing induced seismicity in the state.[93]

Pursuant to the amendments, permit applicants must conduct a search of the U.S. Geological Survey seismic database for historical earthquakes within a circular area of 100 square miles around a proposed, new disposal well.[94] The amendments require a screen-shot or

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[87] *Id.*
[88] Cliff Frohlich, et al., *The 17 May 2012 M4.8 Earthquake Near Timpson, East Texas: An Event Possibly Triggered By Fluid Injection*, J. GEOPHYSICAL RES. (Jan. 2014), *available at* https://pangea.stanford.edu/researchgroups/scits/sites/default/files/2014FrohlichEtal.JGR_.pdf.
[89] *Id.*
[90] *History of the Railroad Commission*, R.R. COMM'N TEX., http://www.rrc.state.tx.us/about-us/history/ (last vitisted Apr. 19, 2015).
[91] *Id.*
[92] *Id.*
[93] *Railroad Commission Adopts Disposal Well Rule Amendments Today*, R.R. COMM'N TEX. (Oct. 28, 2014), http://www.rrc.state.tx.us/all-news/102814b/. The amendments went into effect in November 2014. "Any person who disposes of saltwater or other oil and gas waste by injection into a porous formation not productive of oil, gas, or geothermal resources shall be responsible for complying with this section, Texas Water Code, Chapter 27, and Title 3 of the Natural Resources Code." 16 Tex. Admin. Code § 3.9.
[94] *Id.*

printed copy of the results of a survey review of this information from USGS regarding the locations of any historical seismic events within the survey area.[95] The RRC may also require a permit applicant to provide additional information such as logs, geologic cross-sections, pressure front boundary calculations, and/or structure maps, to demonstrate that fluids will remain confined to the injection site.[96] RRC considers several additional factors for determining whether conditions exist that may increase the risk that fluids will escape: geology, proximity of the basement rock to the injection interval, and existence of transmissive faults.[97]

The amendments clarify the Commission's authority to modify, suspend, or terminate a disposal well permit; this authority includes the authority to modify disposal volumes and pressures and the authority to shut in a well if scientific data indicates a disposal well is likely to be or determined to be contributing to seismic activity.[98] The RRC has this authority if:

> (i) a material change of conditions occurs in the operation or completion of the disposal well, or there are material changes in the information originally furnished;
> (ii) freshwater is likely to be polluted as a result of continued operation of the well;
> (iii) there are substantial violations of the terms and provisions of the permit or of commission rules;
> (iv) the applicant has misrepresented any material facts during the permit issuance process;
> (v) injected fluids are escaping from the permitted disposal zone;
> (vi) injection is likely to be or determined to be contributing to seismic activity; or
> (vii) waste of oil, gas, or geothermal resources is occurring or is likely to occur as a result of the permitted operations.[99]

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[95] 16 Tex. Admin.Code §3.9 (3)(b); Cristina Self, *Adoption of Amendments to 16 Tex. Admin. Code §3.9, Relating to Disposal Wells, and §3.46, Relating to Fluid Injection into Productive Reservoirs; Oil & Gas Docket No. 20-0290951*, R.R. COMM'N TEX. OFFICE GEN. COUN. (Oct. 21, 2014), *available at* http://www.rrc.state.tx.us/media/24613/adopt-amend-3-9and3-46-seismic-activity-102814-sig.pdf.
[96] 16 Tex. Admin.Code § 3.9(3)(c).
[97] *Id.*
[98] *Railroad Commission Adopts Disposal Well Rule Amendments Today*, R.R. COMM'N TEX. (Oct. 28, 2014), http://www.rrc.state.tx.us/all-news/102814b/.
[99] 16 Tex. Admin.Code § 3.9(6)(a).

The amendments allow the Commissioner to require operators to disclose annually reported volumes and pressures on a more frequent basis, if staff determines a need for this information.[100] The new amendments allow RRC staff to require an applicant for a disposal well permit to provide pressure front boundary calculations and a demonstration that disposal fluids will remain confined if the well is to be located in an area where conditions exist that may increase the risk that the fluids may not be confined.[101]

In November 2014, the city of Denton, Texas banned hydraulic fracturing by a public vote.[102] Supporters of the ban state that the connection with wastewater injection wells and induced seismicity are part of the reason they support the ban.[103] In April 2015, the Texas House passed a bill that would effectively prohibit cities and counties from banning hydraulic fracturing.[104] The bill, awaiting Senate approval, permits municipalities to adopt ordinances that mitigate, traffic, noise and some setbacks, but effectively overturns Denton's ban.[105] Democrats attempted to add amendments to allow cities to regulate drilling waste disposal wells but the authors of the bill shut down all amendments.[106]

The legislative amendments in Texas give the state a responsive and flexible system under which it can address induced seismicity. The amendments give Texas the ability to modify disposal volumes and pressures, as well as shut in wells; this ability allows Texas to take

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[100] *Railroad Commission Adopts Disposal Well Rule Amendments Today*, R.R. COMM'N TEX. (Oct. 28, 2014), http://www.rrc.state.tx.us/all-news/102814b/.
[101] *Id.*
[102] *Fracking Banned in Its Birthplace: Texas Town Votes to Outlaw Hydraulic Fracturing*, RT (Nov. 5, 2014), http://rt.com/usa/202543-texas-fracking-ban-denton/.
[103] *Why a Texas City May Ban Fracking*, NPR (July 13, 2014), http://www.npr.org/2014/07/13/331133817/why-a-texas-city-may-ban-fracking; John Eick, *Lawsuits Filed in Response to Fracking Ban in Denton, TX*, AM. LEGISLATOR (Nov. 10, 2014), http://www.americanlegislator.org/lawsuits-filed-response-fracking-ban-denton-tx/.
[104] *Texas: Bill Prohibiting Cities from Banning Fracking Advances*, NY TIMES (Apr. 17, 2015), http://www.nytimes.com/2015/04/18/us/politics/texas-bill-prohibiting-cities-from-banning-fracking-advances.html.
[105] Marissa Barnett, *Texas House Approves So-Called 'Denton Fracking Ban' Bill*, DAILY MORNING NEWS (Apr. 17, 2015), http://trailblazersblog.dallasnews.com/2015/04/texas-house-handedly-approves-so-called-anti-fracking-ban-bill.html/.
[106] *Id.*

control of wastewater disposal operations causing induced seismicity. It is positive that the Texas RRC can require data collection through the wastewater disposal process, but it is suspect that it is not a requirement. The RRC should consider the potential effect on seismicity on each disposal well *before* it becomes operational. In a similar vein, conducting a search of the USGS seismic database, while positive on some level, is inadequate because induced seismicity is frequently occurring on unknown fault lines, and thus, a search of the USGS seismic database would be inadequate.

iii. Arkansas

A magnitude 4.7 earthquake shook Greenbrier, Arkansas in February 2011.[107] Dozens of small earthquakes, including magnitude 3.8 and 3.4 aftershocks, followed the mainshock for the next several hours.[108] This event, now called the Guy earthquake swarm, was the largest earthquake at the time to strike in the Guy-Greenbrier area in Arkansas.[109] To date, more than 1,300 earthquakes have occurred along the Guy-Greenbrier fault.[110] In early 2011, as the number of earthquakes rose sharply, Arkansas addressed induced seismicity in the state by first enacting a temporary moratorium and ultimately enacting a permanent ban. Arkansas also minimally increased monitoring and reporting requirements to address the problem.

In July and August 2010, two major wells, the SRE and Clarita SWD, went online.[111] Also in August 2010, the number of earthquakes began to increase in Arkansas.[112] By the end of February 2011, 894 earthquakes had shaken the state, including one earthquake with a magnitude

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[107] *Poster of the 2010-2011 Arkansas Earthquake Swarm*, USGS, http://earthquake.usgs.gov/earthquakes/eqarchives/poster/2011/20110228.php (last visited Apr. 21, 2015).
[108] *Id.*
[109] *Id.*
[110] Scott M. Ausbrooks & Steve Horton, *Disposal of Hydrofracking-Waste Fluid Injection into Subsurface Aquifers Triggers Earthquake Swarm in Central Arkansas with Potential for Damaging Earthquakes*, ARK. GEOLOGICAL SURVEY, http://www.gwpc.org/sites/default/files/event-sessions/Ausbrooks_Scott.pdf (last visited Apr. 21, 2014).
[111] *Id.*
[112] *Id.*

of 4.7.[113] The Arkansas Oil and Gas Commission (AOGC) approved a temporary moratorium for any new or additional Class II disposal on January 26, 2011.[114] The moratorium allowed the AOGC time to investigate potential correlation between the seismic activity and disposal wells operating in the Guy-Greenbrier Arkansas area.[115] The moratorium covered the Guy-Greenbrier seismically active region, an area of over 1,150 square miles.[116] Other changes accompanied the moratorium. In the Fayetteville Shale development area outside the moratorium area, the AOGC may propose additional requirements for any new disposal wells.[117] Operators with existing Class II wells are also required to submit bi-weekly reports detailing the daily amounts of barrels of water injected per zone and the maximum daily injection pressure per zone.[118]

The AOGC took implemented the moratorium without "evidence that the[] earthquakes are related to the drilling, or completion (including fracture stimulation) of production wells."[119] The AOGC enacted the temporary moratorium on "circumstantial evidence that recent earthquakes within the proposed area may be either enhanced or potentially induced by the operation of Class II Commercial Disposal wells and Class II Disposal wells."[120]

In March 2011, the AOGC worked with operators to reach an agreement to cease all disposal operations in the SRE and Clarita SWD wells which were disposing along the Guy-

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[113] *Id.*
[114] Order No. 602A-2010-12, ARK. OIL &GAS COMM'N (Feb. 8,2011), *available at* http://www.aogc2.state.ar.us/Hearing%20Orders/2011/Jan/602A-2010-12.pdf; COMMITTEE ON INDUCED SEISMICITY POTENTIAL IN ENERGY TECHNOLOGIES ET. AL, INDUCED SEISMICITY POTENTIAL IN ENERGY TECHNOLOGIES (2013), *available at* https://books.google.com/books?id=Xo8t_y0ieW8C&pg=PA120&lpg=PA120&dq=guy-greenbrier+arkansas+induced+seismicity&source=bl&ots=m0UrQN4e_5&sig=RkFSU5_Ggex532pKTcQkxl0_2-o&hl=en&sa=X&ei=nLg2VcqJNdbSoASj8YCoBg&ved=0CB4Q6AEwAA#v=onepage&q=guy-greenbrier%20arkansas%20induced%20seismicity&f=false.
[115] *Id.*
[116] *Id.*
[117] *Id.*
[118] *Id.*
[119] Order No. 602A-2010-12, ARK. OIL &GAS COMM'N (Feb. 8,2011), *available at* http://www.aogc2.state.ar.us/Hearing%20Orders/2011/Jan/602A-2010-12.pdf.
[120] *Id.*

Greenbrier fault.[121] However, by July 2011, 367 more earthquakes had occurred.[122] In July 2011, the AOGC reached an agreement to shut down another major well and forced another to shut down.[123] Since AOGC shut down those four wells, only 86 earthquakes have occurred.[124] The Arkansas Geological Survey found that the Guy-Greenbrier fault was critically stressed prior to the start on injection; however "[g]iven the spatial and temporal correlation between the UIC wells and activity on the fault, it would be an extraordinary coincidence if the earthquakes were not triggered by fluid injection."[125] All but 2% of the earthquake activity in 2011 was within a 6 kilometers radius of these injection wells.[126]

Arkansas dramatically decreased induced seismicity in the state, primarily through a permanent moratorium in the Guy-Greenbrier area. The state has not adopted new permit requirements to address new wells that could cause seismic activity. Without a new regulatory program, the oil and gas industry does not have any guidance in the state, and the state agency cannot effectively insure that more seismic activity will be avoided. Both are concerning issues as wastewater disposal will continue to grow in the state.

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[121] *Id.*

[122] Scott M. Ausbrooks & Steve Horton, *Disposal of Hydrofracking-Waste Fluid Injection into Subsurface Aquifers Triggers Earthquake Swarm in Central Arkansas with Potential for Damaging Earthquakes*, ARK. GEOLOGICAL SURVEY, http://www.gwpc.org/sites/default/files/event-sessions/Ausbrooks_Scott.pdf (last visited Apr. 21, 2014).

[123] Scott M. Ausbrooks & Steve Horton, *Disposal of Hydrofracking-Waste Fluid Injection into Subsurface Aquifers Triggers Earthquake Swarm in Central Arkansas with Potential for Damaging Earthquakes*, ARK. GEOLOGICAL SURVEY, http://www.gwpc.org/sites/default/files/event-sessions/Ausbrooks_Scott.pdf (last visited Apr. 21, 2014); Order No. 180-2-2011-07, ARK. OIL & GAS COMM'N (Aug. 2, 2011), *available at* http://www.aogc2.state.ar.us/Hearing%20Orders/2011/July/180A-2-2011-07.pdf; Arkansas Pollution Control and Ecology Commission, Regulation No. 17 Arkansas Underground Injection Control Code (Jan. 28, 2005), *available at* https://www.adeq.state.ar.us/regs/files/reg17_final_050214.pdf.

[124] Scott M. Ausbrooks & Steve Horton, *Disposal of Hydrofracking-Waste Fluid Injection into Subsurface Aquifers Triggers Earthquake Swarm in Central Arkansas with Potential for Damaging Earthquakes*, ARK. GEOLOGICAL SURVEY, http://www.gwpc.org/sites/default/files/event-sessions/Ausbrooks_Scott.pdf (last visited Apr. 21, 2014).

[125] *Id.*

[126] COMMITTEE ON INDUCED SEISMICITY POTENTIAL IN ENERGY TECHNOLOGIES ET. AL, INDUCED SEISMICITY POTENTIAL IN ENERGY TECHNOLOGIES (2013), *available at* https://books.google.com/books?id=Xo8t_y0ieW8C&pg=PA120&lpg=PA120&dq=guy-greenbrier+arkansas+induced+seismicity&source=bl&ots=m0UrQN4e_5&sig=RkFSU5_Ggex532pKTcQkxl0_2-o&hl=en&sa=X&ei=nLg2VcqJNdbSoASj8YCoBg&ved=0CB4Q6AEwAA#v=onepage&q=guy-greenbrier%20arkansas%20induced%20seismicity&f=false.

iv. Oklahoma

In November 2011, a magnitude 5.0 earthquake shook the earth near Prague, Oklahoma. Less than a day later, a larger 5.7 earthquake that lead to a few injuries and damage to more than a dozen homes hit the town.[127] USGS scientists determined that the M5.7 earthquake was the largest human-caused earthquake associated with wastewater injection.[128] The M5.7 earthquake triggered thousands of smaller aftershocks along the Wilzetta fault system near Prague, including a M5.0 aftershock several days later.[129] Unlike in other states, Oklahoma has been using injection wells for wastewater disposal for 70 years.[130] In recent years, however, the Oklahoma Corporation Commission (OCC) made policy changes to address induced seismicity. The OCC increased research on induced seismicity in the state, adopted a "traffic light" system for adjusting permits parameters, shut wells down in high-risk areas, and increased monitoring and inspections.

In 1907, Article 9 of the Oklahoma Constitution established the OCC.[131] Its mission is "[t]o regulate, enforce laws, and supervise activities associated with the exploration and production of oil and gas, the storage and dispensing of petroleum-based fuels. . ."[132] The First Legislature gave OCC the authority to regulate those businesses whose services are considered to be essential to the public welfare, and the OCC began regulating oil and gas in 1914.[133] In

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[127]Susan Garcia, *2011 Oklahoma Induced Earthquake May Have Triggered Larger Quake*, USGS NEWSROOM (Mar. 6, 2014), http://www.usgs.gov/newsroom/article.asp?ID=3819#.VTU3uyHBzGc.
[128] *Id.*
[129] *Id.*
[130] Oklahoma Corporation Commission, UIC policy document, https://www.occeweb.com/OCC_SESMICITY5.pdf (last visited May 10, 2015).
[131] *Annual Report Fiscal Year 2013*, Oklahoma Corporation Commission, available at http://www.occeweb.com/FY13%20Annual%20Report%20FOR%20PRINTING.pdf.
[132] *Id.*
[133] *Id.*

addition to the regulation of state oil and gas law, the OCC also enforces federal regulations for underground disposal of certain oil and gas waste fluids.[134]

The OCC began working with the Oklahoma Geological Survey (OGS) on wastewater disposal induced seismicity before the Prague earthquake of 2011. It continues to work closely with OGS and other researchers.[135] The OCC also worked with stakeholders to develop best practices for areas of potential concern and assisted OGS and researchers at Stanford University in developing maps that could be used to quickly identify areas of concern in regards to induced seismicity risk.[136] The OCC assisted OGS in seeking a large federal grant to fund more research, providing $70 thousand in required matching funds. OCC will use the grant to improve the state's earthquake monitoring network.[137]

The OCC recently augmented its wastewater disposal permitting system by adding a "traffic light" policy. The traffic light policy comes from the recommendations outlined in a 2013 report by the National Academy of Sciences (NAS) for Class II injection wells.[138] The NAS report outlines the basic approach of the traffic light policy and establishes three levels of concern for seismic activity:

> "If the level of seismic impacts becomes unacceptable, direct mitigation measures are needed to further control the seismicity. A 'traffic light' system can allow operations to continue as is (GREEN), or require changes in the operations to reduce the seismic impact (AMBER[in Oklahoma, YELLOW]), or require a suspension of operations (RED) to allow time for further analysis. Indirect mitigation may include community support and compensation."[139]

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[134] http://www.occeweb.com/FY13%20Annual%20Report%20FOR%20PRINTING.pdf
[135] Oklahoma Corporation Commission, UIC policy document, https://www.occeweb.com/OCC_SESMICITY5.pdf (last visited May 10, 2015).
[136] *Id.*
[137] *Id.*
[138] Katie Brown, *States Well Ahead of EPA on Underground Wastewater Disposal Regulations*, ENERGYINDEPTH (Feb. 13, 2015), http://energyindepth.org/national/states-well-ahead-of-epa-on-underground-wastewater-injection-regulations/.
[139] *Id.*

Oklahoma did not formalize the traffic light system through regulation, but the OCC has been using the three levels of concern to address seismic activity.[140] Under the current traffic light system, wells in an earthquake-prone area are "amber" or "yellow," and their wastewater disposal permits may include restrictions for disposal volume and pressure.[141] If an earthquake occurs, OCC can tighten the restrictions or shut the well down.[142] Eight disposal wells have received the conditional "yellow light" permits.[143] In 2015, OCC ordered the operator of a new drill wastewater disposal well to shut down while state officials investigate whether it triggered a series of damaging earthquakes nearby.[144] Injection at the well began two weeks before the earthquakes started near Marietta, Oklahoma.[145] Additionally, the OCC has limited wells in yellow areas; for one well, the agency limited it to 1,000 barrels a day (42,000 gallons) at a maximum pressure of 375 pounds per square inch (psi).[146] OCC drastically restricted the wells injection rate because the drillers designed the well to take as much as 19,000 barrels per day (798,000 gallons) at a pressure of up to 2,200 psi.[147]

Under the traffic light system, OCC checks the locations of proposed wells against a frequently updated map of earthquake-prone areas.[148] Extra scrutiny applies to permits for wells proposed within 3 miles of a stressed fault; within 6 miles of a seismic swarm; or within 6 miles of a recorded magnitude-4.0 or greater earthquake.[149] If oil and gas developers dispose of

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[140] Mike Soraghan, *Okla. Disposal Wel Shuts Down After Tremors*, E&E PUBL'G, LLC (Oct. 2, 2013) http://www.eenews.net/stories/1059988189.
[141] *Id.*
[142] *Id.*
[143] *Id.*
[144] *Id.*
[145] *Id.*
[146] *Id.*
[147] *Id.*
[148] Mike Soraghan, *Okla. Disposal Wel Shuts Down After Tremors*, E&E PUBL'G, LLC (Oct. 2, 2013) http://www.eenews.net/stories/1059988189.
[149] *Id.* A seismic swarm is defined as earthquakes within a quarter mile of each other.

wastewater in any such areas, operators receive a conditional permit that requires renewal every six months.[150] Even if the operators meet the conditions of the permit, the OCC does not guarantee that the permit will issue.[151] OCC effectively utilizes this system to manage earthquakes in the state. OCC has ordered wells to shut down after nearby earthquakes, modified permit conditions, then allowed the wells to reopen after decreasing the injection depth.[152] In at least two cases, operators decided to keep the wells permanently closed after OCC modified the permit conditions.[153]

In September of 2014, the OCC increased its monitoring and inspections of disposal wells in areas prone to seismic activity by expanding yellow zones.[154] Oklahoma strengthened its oversight by doubling the number of counties in its "areas of interest," and well operators have been directed to reduce disposal volumes if earthquakes continue to occur.[155] The previous areas of interest covered portions of eight northern and central Oklahoma counties: Alfalfa, Grant, Garfield, Noble, Logan, Payne, Lincoln and Oklahoma.[156] The new system adds portions of 10 new counties, primarily in south-central Oklahoma, to the earthquake watch list.[157] The OCC recently sent letters to 92 companies holding permits to operate waste-water disposal wells in the areas of interest.[158] The letters direct the companies to provide evidence that their wells

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150 *Id.*
151 *Id.*
152 *Id.*
153 *Id.*
154 Katie Brown, *States Well Ahead of EPA on Underground Wastewater Disposal Regulations*, ENERGYINDEPTH (Feb. 13, 2015), http://energyindepth.org/national/states-well-ahead-of-epa-on-underground-wastewater-injection-regulations/.
155 Ziva Bransetter, *State Adds New Earthquake Zones, Requirements for Well Operators*, TULSA WORLD (Mar. 26, 2015), http://www.tulsaworld.com/newshomepage3/state-adds-new-earthquake-zones-requirements-for-well-operators/article_1a70dbde-0cc0-5d7a-8874-dd8061d23555.html.
156 Ziva Bransetter, *State Adds New Earthquake Zones, Requirements for Well Operators*, TULSA WORLD (Mar. 26, 2015), http://www.tulsaworld.com/newshomepage3/state-adds-new-earthquake-zones-requirements-for-well-operators/article_1a70dbde-0cc0-5d7a-8874-dd8061d23555.html.
157 *Id.*
158 *Id.*

are not at a depth most likely to trigger earthquakes — at or just above the granite "basement" layer of rock.[159] OCC gave disposal well operators in the expanded areas of interest 30 days to conduct well depth tests, though many were already conducting the test.[160] Operators whose wells are touching the basement rock must inject solid material into the well, until it no longer reaches the layer.[161] Operators not in compliance by April 18, 2015 had to cut their disposal volumes in half.[162]

OCC approved new rules, subject to approval of the legislature, increasing injection well testing and data gathering requirements.[163] The agency requires daily volume recording in areas of interest, regardless of the rock formation in which the wells dispose wastewater.[164] New rules increase the required recording of well pressure and volume of disposal wells that dispose into the Arbuckle formation (the state's deepest injection formation) from monthly to daily.[165] Under the new rules, Mechanical Integrity Tests for wells disposing of volumes of 20,000 barrels a day or more have increased from once every five years to every year, or more often if so directed by OCC.[166] Permit holders also must monitor for background seismicity in the area.[167] Further, well operators must shut down their wells every two months to test pressure at the bottom of the

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[159] *Id.*
[160] Michael Corey, *Oklahoma Unveils New Wastewater Restrictions as Quakes Keep Coming*, REVEAL NEWS (Mar. 25, 2015), http://www.revealnews.org/article/oklahoma-unveils-new-wastewater-restrictions-as-quakes-keep-coming/.
[161] *Id.*
[162] *Id.*
[163] Oklahoma Corporation Commission, UIC policy document, https://www.occeweb.com/OCC_SESMICITY5.pdf (last visited May 10, 2015).
[164] *Id.*
[165] *Id.* These rules took effect September 12, 2014
[166] Oklahoma Corporation Commission, UIC policy document, https://www.occeweb.com/SeismicStatementB.pdf (last visited May 10, 2015).
[167] Mike Soraghan, *Okla. Disposal Wel Shuts Down After Tremors*, E&E PUBL'G, LLC (Oct. 2, 2013) http://www.eenews.net/stories/1059988189.

well.[168] Operators must install a digital pressure reader on the well to give seismologists and oil and gas officials' precise, up-to-the minute readings.[169]

Oklahoma has a proactive system in place for combatting induced seismicity from wastewater disposal from oil and gas operations. Although the state chose not to enact any kind of temporary or permanent moratorium, it shut down wells in high risk areas. Oklahoma increased monitoring and reporting requirements, in addition to increasing injection well testing and data gathering requirements. The real gem of the Oklahoma system, however, is the traffic light system. It gives the state flexibility to address induced seismicity, while also giving the oil and gas industry clearly defined parameters and expectations.

v. Ohio

On July 12, 2010, the Ohio Natural Resources Department (ODNR) issued a Class II disposal well permit for a well, Northstar 1.[170] The first injection commenced on December 22, 2010.[171] On December 24, 2011, Ohio felt a 2.7 magnitude earthquake near the injection well.[172] Data indicated the seismic event depth was within reach of the Northstar 1 injection well.[173] Following the initial earthquake, there was a series of low-magnitude seismic events, culminating in a 4.0 magnitude seismic event.[174] The Northstar 1 operator voluntarily agreed to

[168] *Id.*
[169] *Id.*
[170] *Preliminary Report on the Northstar 1 Class II Injection Well and the Seismic Events in the Youngstown, Ohio, Area*, OHIO DEP'T NAT. RES. (Mar. 2012), *available at* http://www.oilandgaslawreport.com/files/2013/04/ODNR-UIC-Report.pdf. The well was initially approved for an injection pressure of 1890 pounds per square inch (psi). By May 2011, the permit's injection pressure was increased to 2,500 psi.
[171] *Id.*
[172] *Id.*
[173] *Id.*
[174] *Preliminary Report on the Northstar 1 Class II Injection Well and the Seismic Events in the Youngstown, Ohio, Area*, OHIO DEP'T NAT. RES. (Mar. 2012), *available at* http://www.oilandgaslawreport.com/files/2013/04/ODNR-UIC-Report.pdf; Jason Hutt & Michael Weller, *Ohio's On Top of Underground and Injection Control Activity*, Law360 (Apr. 21, 2015), *available at* http://www.law360.com/articles/360565/ohio-s-on-top-of-underground-injection-control-activity.

halt all activity at the well shortly thereafter.[175] Prior to March 2011, there was no record of felt earthquake activity in the area in modern times.[176] Ohio addressed induced seismicity in the state by executive order to jumpstart ODNR's ability to address seismicity issues in oil and gas wastewater disposal wells, a moratorium, and legislation to codify seismicity considerations into the permitting process.

On July 10, 2012, Governor John Kasich signed Executive Order 2012-09K, ordering that two draft underground injection control rules, UIC Rules 1501:9-3-06 and 1501:9-3-07 of the Ohio Administrative Code, become effective immediately as "emergency rules."[177] The executive order also permitted the Ohio Division of Oil and Gas Resources Management (ODRM) to immediately amend applicable state regulations and enforce new rules, thereby avoiding the typical administrative process of soliciting stakeholder input.[178] Under the emergency rules, ODRM was permitted to: (1) outline tests that an applicant must satisfy to obtain a UIC permit; (2) withhold authority to permit injection fluids if the results of required tests were negative; (3) set a graduated maximum allowable injection pressure; (4) require installation of an automatic shutoff device; and (5) require continuous monitoring of the space between the casing and tubing in a well.[179] These emergency rules allowed ODRM to address

[175] *Preliminary Report on the Northstar 1 Class II Injection Well and the Seismic Events in the Youngstown, Ohio, Area*, OHIO DEP'T NAT. RES. (Mar. 2012), *available at* http://www.oilandgaslawreport.com/files/2013/04/ODNR-UIC-Report.pdf.

[176] *Id.*

[177] Ohio Exec. Order No.2012-09K (July 10, 2012), *available at* http://www.governor.ohio.gov/Portals/0/EO%202012-09K.pdf; Jason Hutt & Michael Weller, *Ohio's On Top of Underground and Injection Control Activity*, Law360 (Apr. 21, 2015), *available at* http://www.law360.com/articles/360565/ohio-s-on-top-of-underground-injection-control-activity.

[178] *Id.*

[179] *Id.* Under the emergency rules, DRM may require any combination of the following tests or evaluations of a proposed brine injection well: (1) pressure falloff testing; (2) geological investigation of potential faulting within the immediate vicinity of the proposed injection well location, which may include seismic surveys or other methods; (3) submittal of a plan for monitoring seismic activity; (4) testing and recording the original bottomhole injection interval pressure; Gamma ray, compensated density neutron and resistivity geophysical logging suite on all newly drilled injection wells; (5) radioactive tracer or spinner survey; and (6) any such other tests that the chief deems necessary.

induced seismicity in the state by giving the agency more discretion in issuing permits and increasing monitoring requirements.

On December 31, 2011, ODNR's director issued a moratorium for the disposal of waste from oil and natural-gas drilling in wells within a 5 mile radius of the Northstar 1 well.[180] The moratorium closed four other wells, none of them active at the time.[181]

In Ohio, rules filed as emergency rules remain in effect for 90 days.[182] To make the executive order rules permanent, ODNR went through the regular rule-filing procedure.[183] The new UIC Class II injection well rules proceeded through the legislative process, passed, and went into effect on October 1, 2012.[184] The ODNR began issuing new Class II injection well permits in November 2012, which included the new regulations added as conditions.[185] ODNR added the requirements of the new regulations to each permit on a well-by-well evaluation basis.[186]

Through the new legislation, Ohio has added strong background research and seismic evaluation requirements to its Class II deep injection well program to evaluate seismic risk.[187] ODNR now requires a review of existing geologic data for known faulted areas within the state

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[180] Joe Vardon, *State Links Quakes to Work on Wells*, COLUMBUS DISPATCH (Jan. 1, 2012), http://www.dispatch.com//content/stories/local/2012/01/01/state-links-quakes-to-work-on-wells.html; *Preliminary Report on the Northstar 1 Class II Injection Well and the Seismic Events in the Youngstown, Ohio, Area*, OHIO DEP'T NAT. RES. (Mar. 2012), *available at* http://www.oilandgaslawreport.com/files/2013/04/ODNR-UIC-Report.pdf.

[181] Joe Vardon, *State Links Quakes to Work on Wells*, COLUMBUS DISPATCH (Jan. 1, 2012), http://www.dispatch.com//content/stories/local/2012/01/01/state-links-quakes-to-work-on-wells.html.

[182] *Northstar I Class II Injection Well UIC Rule Reforms*, ODNR DIV. OIL & GAS RES., http://oilandgas.ohiodnr.gov/resources/investigations-reports-violations-reforms#REP (last visited Apr. 22, 2015).

[183] *Id.* ODNR filed the rules with the Joint Committee on Agency Rule Review (JCARR) as an Original Filing on July 11, 2012. A public hearing on the rules was held on Wednesday, August 15, 2012. ODNR filed the rules with JCARR as a Final Filing on Sept 21, 2012.

[184] Tom Tomastik, *Ohio's New Class II Regulations and Its Proactive Approach to Seismic Monitoring and Induced Seismicity*, ODNR DIV. OIL & GAS RES., http://www.gwpc.org/sites/default/files/event-sessions/Tomastik_Tom_1.pdf (last visited Apr.22, 2015).

[185] *Id.*

[186] *Id.*

[187] *Preliminary Report on the Northstar 1 Class II Injection Well and the Seismic Events in the Youngstown, Ohio, Area*, OHIO DEP'T NAT. RES. (Mar. 2012), *available at* http://www.oilandgaslawreport.com/files/2013/04/ODNR-UIC-Report.pdf.

and avoid the locating of new Class II disposal wells within these areas.[188] Injection volumes with greater than 200 barrels per day require a ½ mil area of review of all other wells, and injection volumes with less than 200 barrels per day is a ¼ mile radius.[189] ODNR can require a variety of testing to determine if a fault exists in an area where a disposal well is planned.[190] ODNR requires the submission, at time of permit application, of any information available concerning the existence of known geological faults within a specified distance of the proposed well location.[191]

Ohio has added more detailed planning, testing, and monitoring requirements to the deep injection well program.[192] ODNR has the authority to require seismic testing and monitoring,[193] and well operators must submit a plan for monitoring any seismic activity that may occur.[194] ODNR requires a measurement or calculation of original downhole reservoir pressure prior to initial injection.[195] Operators must conduct a step-rate injection test to establish formation parting pressure and injection rates.[196] ODNR also requires the installation of a continuous pressure monitoring system, with results being electronically available to ODNR for review and requires the installation of an automatic shut-off system set to operate if the fluid injection

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188 *Id.*
189 Ohio Admin. Code § 1501:9-3-06, *available at* http://codes.ohio.gov/oac/1501%3A9-3-06. Tests include: pressure fall-off testing to ensure tight seals in the reservoir and casing; geological investigation of potential faulting within the immediate vicinity of the proposed injection well location, which may include seismic surveys or other methods determined by the chief; monitoring seismic activity; radioactive tracer or spinner survey; and gamma ray, compensated density-neutron, and resistivity geophysical logging suite on all newly drilled injection wells to determine slight fractures in unknown geological regions of the state.
190 *Id.*
191 *Id.*
192 *Id.*
193 Ohio Admin. Code § 1501:9-3-06, *available at* http://codes.ohio.gov/oac/1501%3A9-3-06.
194 *Preliminary Report on the Northstar 1 Class II Injection Well and the Seismic Events in the Youngstown, Ohio, Area*, OHIO DEP'T NAT. RES. (Mar. 2012), *available at* http://www.oilandgaslawreport.com/files/2013/04/ODNR-UIC-Report.pdf.
195 *Id.*
196 *Id.*

pressure exceeds a maximum pressure to be set by ODNR.[197] Last, operators must install an electronic data recording system for purposes of tracking all fluids brought by a brine transporter for injection.[198] When mechanical failures or downhole problems cause contamination of the land, surface waters, or subsurface waters, the injection well owner must cease all injection operations immediately until the chief determines that the problems have been corrected.[199]

In April 2013, Ohio state representatives Bob Hagan and Denise Driehaus introduced House Bill 148 that would completely ban the use of Class II injection wells for the disposal of fracking wastewater into deep injection wells.[200] The House Bill died in committee.[201]

Ohio aggressively responded to induced seismicity in the state by crafting a carefully monitored and stringently regulated disposal well program. It used executive action to take action on induced seismicity concerns. The state used a temporary moratorium in the Youngstown area to give it time to make an informed, safe decision on how underground water disposal would affect the welfare of the state. Last, the state enacted very extensive legislation to create a clear, robust program to prevent further harm in the state. The enacted legislation gives the oil and gas industry in Ohio clear guidelines and enough flexibility to make well-by-well decisions.

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[197] Ohio Admin.Code § 1501:9-3-07, *available at* http://codes.ohio.gov/oac/1501%3A9-3-07; *Preliminary Report on the Northstar 1 Class II Injection Well and the Seismic Events in the Youngstown, Ohio, Area*, OHIO DEP'T NAT. RES. (Mar. 2012), *available at* http://www.oilandgaslawreport.com/files/2013/04/ODNR-UIC-Report.pdf.
[198] *Id.*
[199] Ohio Admin. Code § 1501:9-3-07, *available at* http://codes.ohio.gov/oac/1501%3A9-3-07.
[200] *Ohio House Bill 148 (Prior Session Legislation)*, LEGISCAN, https://legiscan.com/OH/bill/HB148/2013 (last visited Apr. 22, 2015); *Ohio House Bill 148*, LEGISCAN, https://legiscan.com/OH/text/HB148/2013 (last visited Apr. 22, 2015); Rachel Morgan, *Ohio Legislators Trying to Ban Injection Wells*, SHALE REPORTER (Jun. 4, 2013), http://www.shalereporter.com/government/article_4063cb3e-cd14-11e2-986b-0019bb30f31a.html.
[201] *Id.*

vi. North Carolina

On March 17, 2015, North Carolina opened its doors for natural gas drilling for the first time in three years.[202] The Energy Modernization Act (Act) authorizes the Department of Environment and Natural Resources to issue permits for oil and gas exploration and development activities using horizontal drilling and hydraulic fracturing treatments for the first time in the states.[203]

Despite opening the state up to oil and gas drilling, North Carolina state law still provides for a total ban of underground wastewater disposal.[204] Because of the moratorium, North Carolina drillers, unlike drillers in most other states, are not be allowed to inject their wastes underground.[205] The Mining and Energy Commission gives drillers four options to dispose of wastewater: drillers can reuse the water in other wells; they can treat it onsite; they can send it to

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[202] Jon Camp, *Permitting for North Carolina Fracking Begins*, ABC 11 (Mar. 18, 2015), http://abc11.com/news/permitting-for-north-carolina-fracking-begins/561602/; Katie Valentine, *North Carolina to Lift Fracking Ban and Criminalize the Disclosure of Fracking Chemicals*, CLIMATEPROGRESS (June 5, 2014), http://thinkprogress.org/climate/2014/06/05/3445260/north-carolina-fracking-criminalize-chemical-disclosure/. The 2012 moratorium was put into place to provide time for fracking-specific environmental protection rules to be drafted in the state.

[203] S. 786, 2013 Gen. Assemb., Reg. Sess. (N.C. 2014) (ratified), *available at* http://www.ncleg.net/Sessions/2013/Bills/Senate/PDF/S786v8.pdf. *See also* O. Walker Reagan, *Summaries of Substantive Ratified Legislation*, RES. DIV. N.C. GEN. ASSEMBL., *available at* http://www.ncleg.net/documentsites/legislativepublications/Research%20Division/Summaries%20of%20Substantive%20Ratified%20Legislation/Summaries%20of%20Substantive%20Ratified%20Legislation%20for%202014.pdf;Katie Valentine, *North Carolina to Lift Fracking Ban and Criminalize the Disclosure of Fracking Chemicals*, CLIMATEPROGRESS (June 5, 2014), http://thinkprogress.org/climate/2014/06/05/3445260/north-carolina-fracking-criminalize-chemical-disclosure/. The Act also terminates the Mining and Energy Commission and creates a North Carolina Oil and Gas Commission within the Department of Environment and Natural Resources. The Commission will have the authority to make determinations and issue orders pursuant to the Oil and Gas Conservation Act to (i) regulate the spacing of wells and to establish drilling units as provided in G.S. 113-393; (ii) require the operation of wells with efficient gas-oil ratios and to fix such ratios; (iii) limit and prorate the production of oil or gas, or both, from any pool or field for the prevention of waste as provided in G.S. 113-394; and (iii) classify wells for taxing purposes.

[204] N.C. Gen. Stat. §§ 113-395.2, 143-214.2. Gabe Rivin, *Options Are Limited For Fracking Wastewater*, NORTH CAROLINA HEALTH NEWS (Apr. 28, 2014), http://www.northcarolinahealthnews.org/2014/04/28/options-are-limited-for-fracking-wastewater/.

[205] 29 N.C. REG. 147 (July 15, 2014), *available at* http://portal.ncdenr.org/c/document_library/get_file?uuid=8a21a439-fe86-4571-90e5-f428d62bf075&groupId=8198095; *Options Are Limited for Fracking Wastewater*, N.C. HEALTH NEWS (Apr. 28, 2014), http://www.northcarolinahealthnews.org/2014/04/28/options-are-limited-for-fracking-wastewater/.

a specialized wastewater-treatment plant; or they can send it to another state's treatment plant.[206] North Carolina currently does not have any wastewater-treatment plants that are equipped – or permitted – to handle fracking wastewater.[207] Drillers usually choose to treat their wastewater onsite to remove radioactive elements and other problematic chemicals and then release the treated water into state waterways, like rivers, or send the water to municipal treatment plants.[208]

North Carolina has had no induced seismicity in the state, in part, because it does not permit wastewater disposal within state boundaries. This decision has been a hot-button issue recently in the state, but for now, North Carolina is a strong example of complete prohibition.

IV. A Critique on Wastewater Disposal and Regulation of Induced Seismicity

This section examines how effectively states have regulated induced seismicity. It will compare state action to the NTW 2015 report that summarized the available information on induced seismicity and provided specific suggestions for managing induced seismicity within the context the Class II UIC program. The sections below evaluate the state's induced seismicity programs by evaluating them in the categories of (a) site assessment; (b) operational adjustments; (c) monitoring improvements; and (d) best management practices, as outlined in the NTW report. Currently, the NTW report is the only indication from the EPA as to what it considers to be valuable assessment and action for preventing induced seismicity. The NTW report also may indicate how the EPA will regulate injection-induced seismicity in the future, and it will be important that the states measure up to EPA's recommendations.

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[206] *Id.*
[207] *Id.*
[208] *Id.*

a. Site Assessment

Site assessment considerations identify and evaluate specific site characteristics that trigger injection-induced seismicity. These considerations include: (1) evaluating regional and local area geoscience information to assess the likelihood of activating faults and causing seismic events; (2) assessing initial static pressure and potential pressure buildup in the reservoir; (3) reviewing the available data to characterize reservoir pathways that could allow pressure communication from disposal activities to a Fault of Concern; (4) consulting with external geoscience or engineering experts as needed to acquire or evaluate additional site information; (5) determining the proximity of the disposal zone to basement rock; and (6) considering collecting additional site assessment information in areas with no previous disposal activity and limited geoscience data or reservoir characterization, prior to authorizing disposal.[209]

Of the states studied, Ohio, Oklahoma, Texas include site assessment provisions in their wastewater disposal schemes. Ohio requires a review of existing geological data for known faulted areas within either a ½ or ¼ mile depending on the well. The state avoids placing new wells in these areas. Ohio law permits the ODNR to require a variety of testing procedures to determine if a fault exists. Texas requires operators to conduct a search of the U.S.G.S. seismic database for historical earthquakes within 100 square miles. Texas may also require the applicant to provide other additional information. Oklahoma requires that drillers in areas of interest conduct well depth tests; however, these tests may occur after the well has been drilled.[210] Both Ohio and Texas's site assessment provision have the shortcoming that they both only search seismic databases for *known* faults. Texas may be able to test where unknown faults are likely through the addition information and testing, but all states should consider adding site

[209] *Id.* at 33.
[210] This is unclear from the policy documents.

assessments that require operators to look for signs that an area may be susceptible to induced seismicity.

b. Operational Adjustments

Operational recommendations address seismicity concerns that may arise from the site assessment evaluation. Operational recommendations include: (1) conducting a petroleum engineering analysis of operational data on wells in areas where seismicity has occurred to identify potential correlation; (2) conducting pressure transient testing in disposal wells suspected of causing seismic events to obtain information about injection zone characteristics near the well; (3) performing periodic static bottomhole pressure monitoring to assess current reservoir pressures; (4) modifying injection well permit operational parameters as needed to minimize or manage seismicity issues; (5) operating wells below fracture pressure to maintain the integrity of the disposal zone and confining layers; and (6) performing annular pressure tests and production logging if mechanical integrity is a concern.[211]

Ohio, Texas, and Oklahoma have added operational adjustment provisions to their wastewater disposal schemes. In Ohio, operators must conduct a step-rate injection test to establish formation parting pressure and injection rates. Texas has the authority to modify, suspend, or terminate a disposal well permit; this authority includes the ability to modify disposal volumes and pressures. Oklahoma modifies permits through its traffic light system. Operations are permitted to continue as normal in a Green phase. During Yellow, Oklahoma reduces injection speed or volume, and during Red, Oklahoma may suspend operations to allow

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[211] Examples of modifications may include: reducing injection rates, starting at lower rates and increasing gradually; injecting intermittently to allow time for pressure dissipation, with the amount of shut-in time needed being site-specific; separate multiple injection wells by a larger distance for pressure distribution since pressure buildup effects in the subsurface are additive; and implementing contingency measures in the event seismicity occurs over a specified level.

time for further analysis of the operations. In Oklahoma, well operators must shut down every two months to test pressure at the bottom of the well. The Ohio and Oklahoma regimes do a good job of testing pressure at the bottom of the well to monitor for fault pressure buildup. All three states have the ability to modify the disposal permits, which is positive. From an operational adjustment standpoint, Texas, Ohio, and Oklahoma are doing a great job of leaving flexibility in their permitting system to adjust for potential induced seismicity.

c. Monitoring Improvements

Monitoring recommendations insure that seismicity concerns are addressed over a well's lifetime. Monitoring recommendations include: (1) increasing frequency of monitoring for injection parameters, such as formation pressure and rates, to increase the accuracy of analysis; (2) monitoring static reservoir pressure to evaluate pressure buildup in the formation over time; (3) installing seismic monitoring instruments in areas of concern to allow more accurate location determination and increased sensitivity for seismic event magnitude; (4) increasing monitoring of fluid specific gravities in commercial disposal wells with disposal fluids of variable density since the density impacts the bottomhole pressure in the well.[212]

The addition of monitoring requirements was the most popular new addition to the states' permitting scheme. In Ohio, well operators must submit a plan for monitoring any seismic activity that may occur. Ohio requires the installation of a continuous pressure monitoring system and must track all fluids brought to the well. Ohio is also working with oil and gas operators to increase the number of seismic monitoring devices in the states. In Texas, operators must disclose volumes and pressures annually. Some applicants may be required to provide pressure front boundary calculations and a demonstration that disposal fluids will remain

[212] *Id.* at 34.

confined in the well is to be located in an area where conditions exist that may increase the risk that the fluids may not be confined. In Arkansas, operators are required to submit bi-weekly reports detailing the daily amounts of barrels of water injected per zone and the maximum daily injection pressure per zone. Oklahoma has also increased its monitoring practices. In Yellow zones, operators must conduct well depth tests and in wells where the operators are injecting into the basement rock, must inject solid material into the well until it no longer reaches the basement layer. Operators must also record the daily injected volume and well pressure and monitor for background seismicity. In Oklahoma, well operators must shut down every two months to test pressure at the bottom of the well. The states are offering the fullest protection against induced seismicity in this category. Interestingly, none of the states address the NTW's last recommendation to increase monitoring of fluid specific gravities in commercial disposal wells with disposal fluids of variable density since the density impacts the bottomhole pressure in the well.

d. Best Management Practices

The NTW recommended a new management approach, which included. The management approach includes: (1) for wells suspected of induced seismicity, taking early actions, such as acquiring more frequent reports of injection volumes and pressures, reducing injection rates, and/or increasing seismic monitoring, rather than waiting on definitive proof of the causal relationship, and engage the operators early in the process; (2) engaging external multidisciplinary experts from other agencies or institutions; (3) providing training for UIC Directors on new reservoir operational analysis techniques to help them understand the spreadsheet parameters; (4) employing a multidisciplinary team for future research to address possible links between disposal well and reservoir behavior, geology, and area seismicity; (5)

including a seismic threshold based on the magnitude or frequency of events as a condition of the permit describing action to be taken in the event of initiation of or increase in seismic events; and (6) developing public outreach programs to explain the complexities of injection-induced seismicity.

All of the states studied have adopted new best management practices to address wastewater disposal and induced seismicity. Ohio has adopted the best management practice of taking early action. The ODNR reserves the right to shut down wells as soon as they may be causing induced seismicity; also, the executive branch and the ODNR are not hesitant to initiate emergency procedures, like moratoriums. Texas has adopted the best management practice of modifying, suspending, or terminating the disposal well permit if "injection is likely to be or determined to be contributing to seismic activity." Arkansas has adopted the best management practice of issuing a moratorium on areas that have proven to be vulnerable to induced seismicity. Oklahoma has used a variety of best management practices, namely the traffic light system but also including some not seen in others states. Oklahoma has partnered with Oklahoma Geological Survey to address possible links between disposal and induced seismicity. In this category, states have shown their willingness to adapt to this new problem and a dedication to making their states safer places to work and live.

V. Conclusion

The states studied in this report are at the forefront of regulating induced seismicity from underground wastewater disposal. Ohio has shown that regulators in the state are not afraid to think outside of the box and use innovative tools, like executive orders, to accomplish reduction of seismic events quickly. Oklahoma adopted the traffic light and implemented a system that is defined and easy to follow while remaining highly flexible. Arkansas drastically reduced seismic activity in the state by creating a moratorium on wastewater disposal in part of the state. Texas used the legislative and administrative processes to amend its UIC program.

While states have worked to control and prevent induced seismicity, their UIC programs still lack certain qualities. Some of the programs, Oklahoma for example, are implemented through policy, instead of through regulation. UIC programs implemented through policy instead of regulation are often unpublished or hard to track down. They are not subject to the administrative process and may not include diverse stakeholder input. Further, they may increase adoption costs for the industry because the industry will need to work to determine what the permit system requires and how to meet the requirements. Further, one major critique of the UIC programs is that they rely on historical seismicity data to predict future events. This approach is has major oversights in the context of injection-induced seismicity, as wastewater disposal wells frequently trigger earthquakes on unknown or inactive faults. UIC programs should look at a variety of others factors to determine likelihood of injection-induced seismicity.

The new legal and policy regimes adopted by the states could have a broader application than just wastewater disposal. These regimes could be starting points for developing new regimes to regulate hydraulic fracturing and almost any operation that impacts the friction and pressure of the earth's subsurface. These best practices could be applied to mining, geothermal activities, and other extraction activities like tarsands and coalbed methane.