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Induced Earthquakes and Public Safety

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Abstract

Like the number of earthquakes felt in Oklahoma, the number of media reports regarding large-magnitude earthquakes in Oklahoma has increased in recent years. News headlines that mention property damage and question who is responsible have sparked heated debated. In this document, a discussion is presented over the responsibility of engineers for the public's safety in relation to earthquakes. Input from various groups is discussed, the action taken in Oklahoma is outlined, and ethical obligations presented by the American Society of Civil Engineers are considered. The United States Geological Survey (USGS) has reported a major grievance against building-code committees, but many factors are at play in the organizational structure missing to ensure the public's safety within an evolving world of induced seismicity. This report was prepared to increase awareness about public safety, the amount of hazard to the public, the methods currently being used to reduce the amount of hazard to the public – in the area of interest and in other areas, and to answer questions about what types of improvements need to be made and by whom.

Introduction

National headlines are currently reflecting the recent interest in the amount of earthquake activity in Oklahoma (Fitzpatrick and Petersen, 2016; Philips, 2016). The probability of damage caused by natural or induced earthquakes in Oklahoma has increased by as much as 12 percent, according to the USGS as presented by Fitzpatrick and Petersen (2016). As presented in Figure 1, the forecasted amount of damage in Oklahoma, as determined by the USGS, includes natural and induced earthquakes.

Within this document, the *2016 Hazard Forecast* report will be discussed and background information about the USGS report and the reported chances of damage from natural and induced earthquakes in the Oklahoma area will be presented. The responsibility of the public's safety in relation to earthquakes, input from other entities, the action taken in Oklahoma, and ethics will then be discussed. This review of the current mitigation methods that are being used to ensure public safety, in the area of interest and in other areas with higher earthquake frequency, may stimulate new ideas to better ensure the public's safety. However, as discovered through this review, the current and proposed earthquake hazard mitigation strategies may not be enough to protect the public. Gaps are being unveiled through new research into building codes; based on this research, various government agencies may need to be updated in order to adequately protect the public. An adequate understanding of the updated earthquake data and forecasted earthquake hazards will aid in this effort.

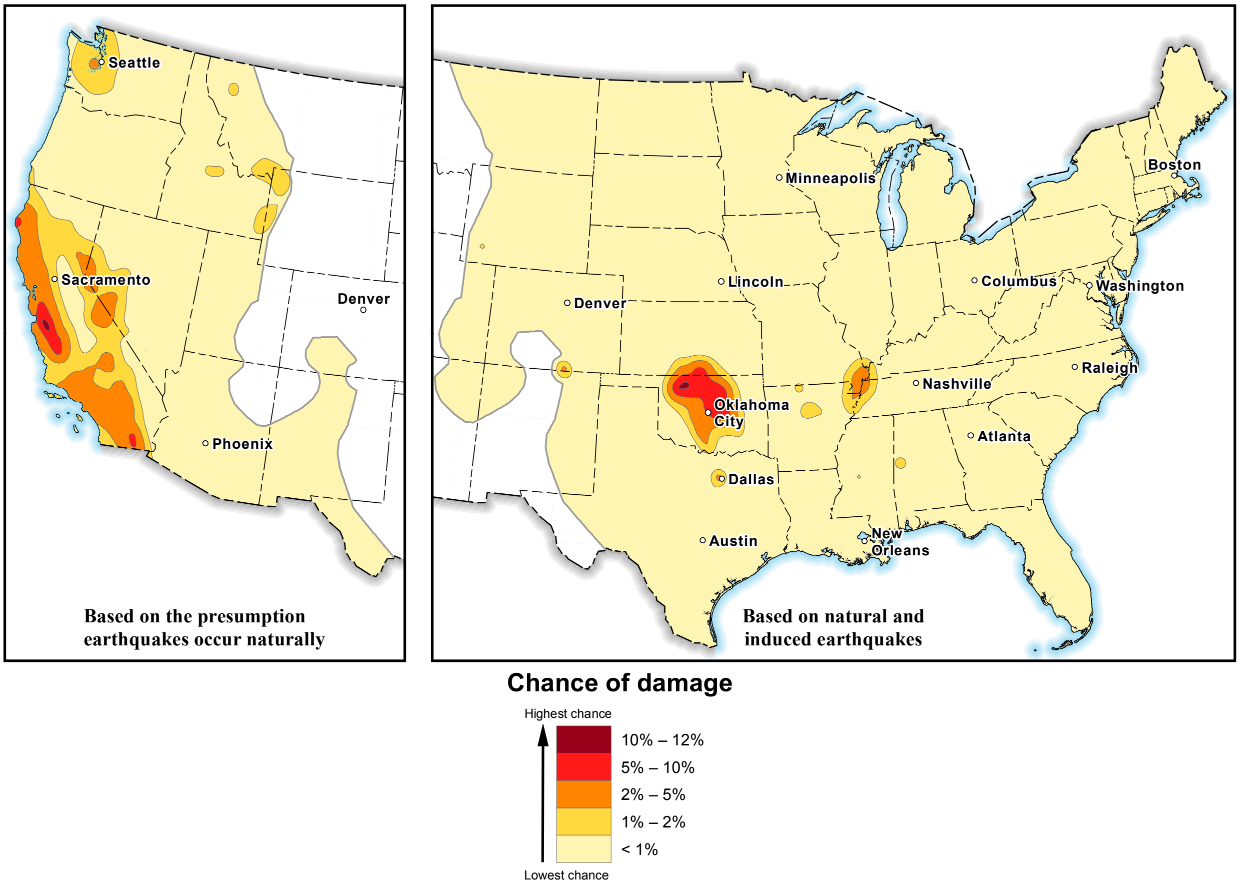

Figure 1. The USGS forecast map for chance of damages from both induced earthquakes and naturally occurring earthquakes in 2016 (USGS, 2016).

Background

The difference between natural and induced earthquakes has been discussed among the scientific community for many years (Segall, 1989; Petersen et al., 2016). The general consensus is earthquakes can be induced by human activity (Petersen et al., 2016). However, when the Department of Energy asked the National Research Council (NRC) to address induced earthquakes related to energy production, the NRC reported that a direct correlation between various energy harvesting technologies and earthquakes was difficult to obtain (National Research Council, 2013). In June of 2016, the USGS released a report entitled "*2016 One-Year Seismic Hazard Forecast for the Central and Eastern United States from Induced and Natural Earthquakes*" (USGS, 2016). In this report, the USGS did not explore the causes of increased seismicity, but recognized that scientific studies have linked the majority of increased seismic activity to wastewater injection in deep disposal wells (Walsh, 2015; Weingarten, 2015; Petersen et al., 2016). Induced earthquakes have been identified by statistical based differences in the frequency of occurrence, in the seismic position and in the activity level consistent with injection location. Induced earthquakes have also been identified through seismic activity as relating to injection volume. According to the USGS *2016 Hazard Forecast* (USGS, 2016), induced earthquakes exhibit more swarm-like behavior than natural earthquakes and occur at shallower depths.

Two models were developed by the USGS to forecast damage from seismic hazards (Petersen et al., 2016). The first model, or the informed model, was dependent upon the 1-year and 2-year earthquake catalog and separated induced earthquakes from naturally occurring earthquakes. The second model, or the adaptive model, observed the maximum earthquake rate in the short and long-term intervals and did not separate induced earthquakes from naturally occurring earthquakes. Examples of short to long-term intervals are 1-year and 2-year to 36-year. The agreement margin between the two different models was fifty percent or less for the area of interest. The forecasted hazard, as obtained from the *2016 Hazard Forecast*, was three times higher than the previously established 2014 National Seismic Hazard Maps (Petersen et al., 2014; Petersen et al., 2016).

The intensity of the earthquakes forecasted in the Oklahoma area for 2016 compared to the 2014 National Seismic Hazard Model along the San Andreas fault in California was also highlighted in another map produced by the USGS (Petersen et al., 2016). The Modified Mercalli Intensity (MMI) forecasted within Oklahoma in the *2016 Hazard Forecast* does not appear substantially different from the MMI for the San Andreas fault in the 2014 National Seismic Hazard Map (Figure 2). The maximum MMI referenced on this map is VIII+. An MMI of VIII refers to the generally accepted term “severe” shaking, where the greatest MMI is X and generally accepted as “extreme” shaking.

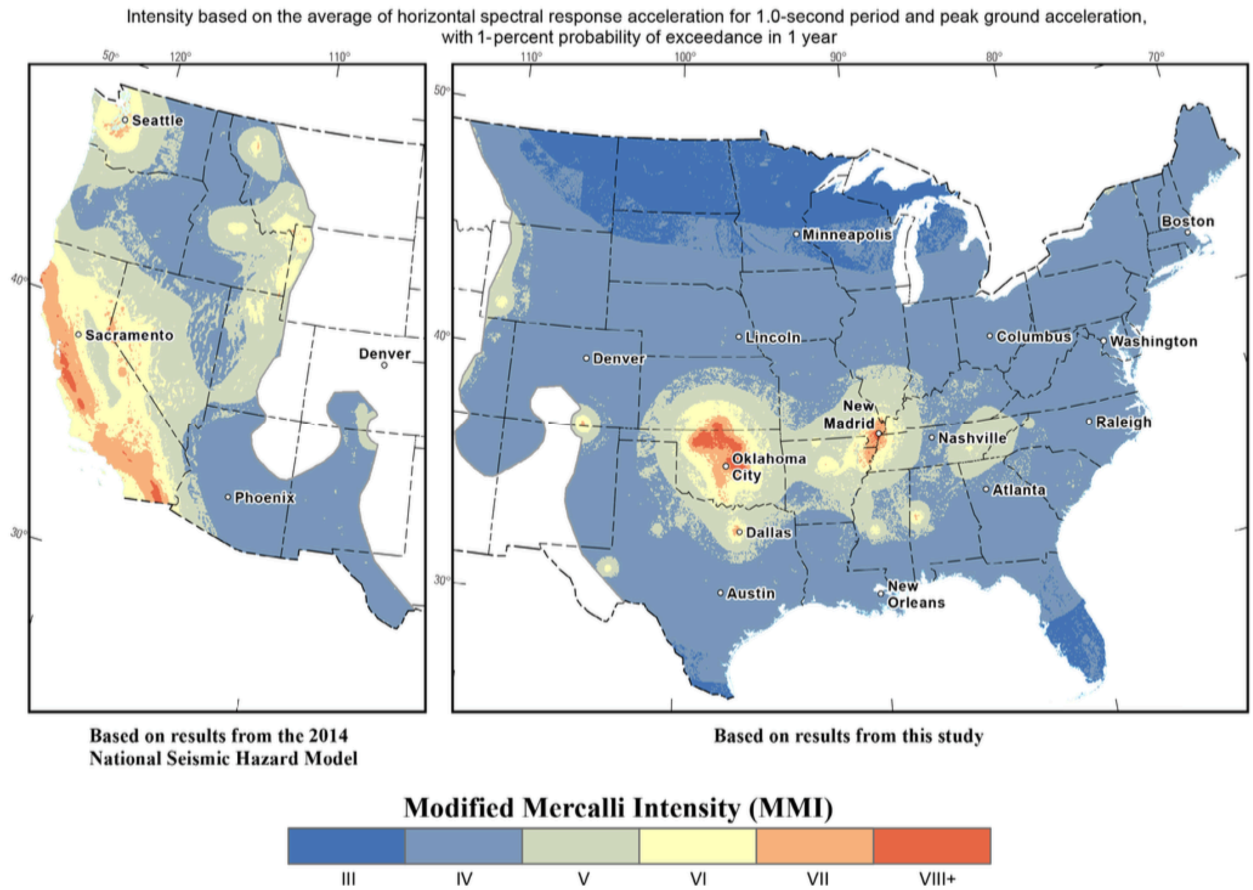

Figure 2. The USGS map highlighting the earthquake magnitudes forecasted in Oklahoma for 2016 in comparison to the 2014 National Seismic Hazard Model earthquake magnitudes along the San Andreas fault (Petersen et al., 2016).

Discussion

Responsibility

With such a great risk increase in the past two years, one must consider who is responsible for ensuring the public's safety. In 2012, the National Academy of Sciences (NAS) released a publication entitled "*Induced Seismicity Potential in Energy Technologies*." In the NAS document, four federal agencies (the U.S. Environmental Protection Agency, the Bureau of Land Management, the U.S. Department of Agriculture Forest Service, and the U.S. Geological Survey) were recognized to have regulatory oversight and research responsibilities for energy related underground injection. No agency was identified as being responsible for coordinating the United States government's response to induced seismic activity (National Research Council, 2012).

The State of Oklahoma may be considered to be a responsible party for protecting the citizens of Oklahoma from the apparent increased risk of earthquakes. The building codes currently adopted by Oklahoma's Uniform Building Code Commission are the International Building Code (IBC) 2015 and the International Residential Code (IRC) 2015 (State of Oklahoma, 2017). When adopted, Oklahoma did not include any changes to the IBC Chapter 16 structural design or to the Section 1613 design earthquake loads. When compared to the State of California, the lack of modification to the Oklahoma Uniform Building Code to consider the increased hazard is unconventional. The ASCE 7-10 for seismic design is included in the IBC 2015, excluding ASCE 7-10 Chapter 14 and Appendix 11A (Oklahoma Uniform Building Code Commission, 2015). For reference, Chapter 14 includes material specific to seismic design and detailing requirements and Appendix 11A includes quality assurance provisions. In following the seismic design procedures of IBC 2015 and ASCE 7-10, an engineer is directed to use Figures 1613.3.1(1) through 1613.3.1(8) in the IBC 2015. Through the use of these figures, the engineer is directed to the USGS website for updated values. The values correlatively provided on the USGS website were derived from 2008 hazard data (Figure 3). Within the IBC 2015, Figure 1613.3.1(2), the Risk Targeted Maximum Considered earthquake MCE_R is generally four (4) on the Eastern side of Oklahoma to eight (8) on the Western side of Oklahoma with a small area in Southwest Oklahoma designated at ten (10) or eight (8).

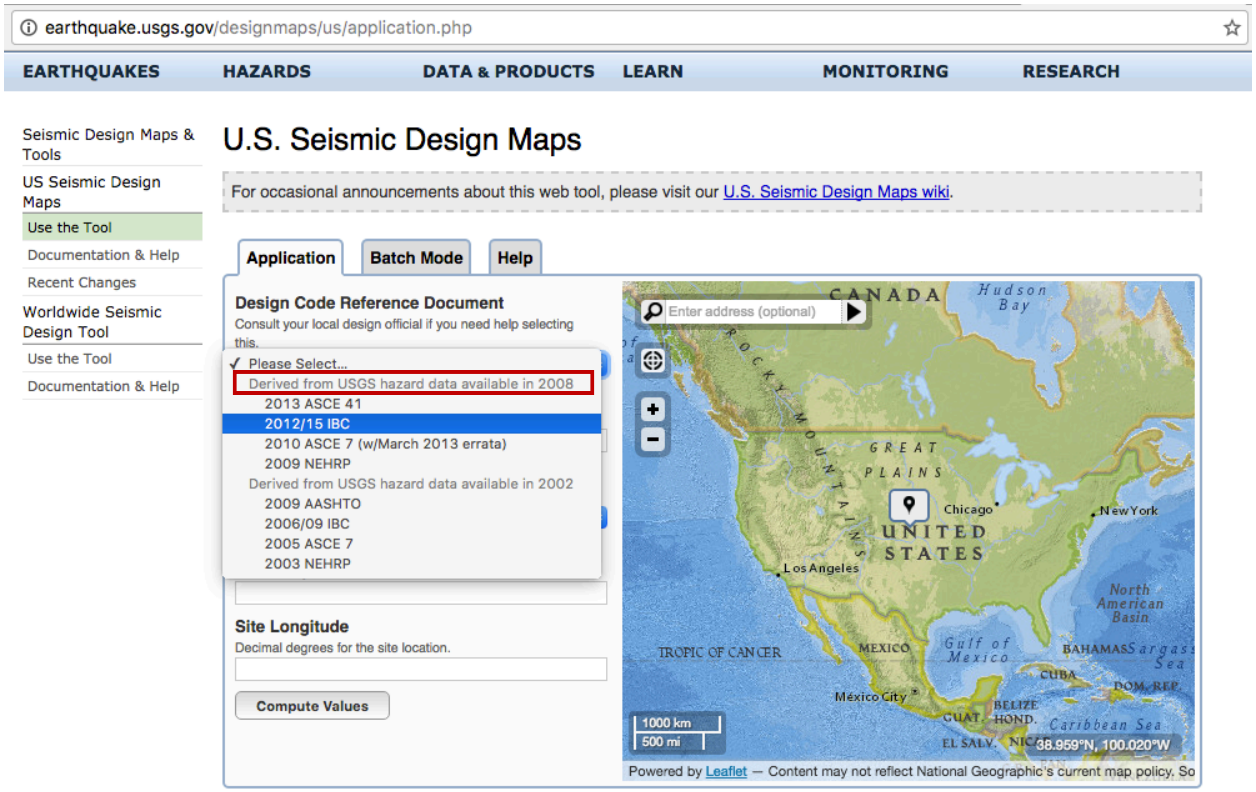

Figure 3. USGS Website Containing 2008 Hazard Data (modified from USGS, 2016); modified with red rectangle to show based on 2008 data.

Input from Other Entities

Other entities, such as federal agencies, state governments, and businesses have provided input to the public and scientific community regarding earthquake hazard through reports, websites, and actions. For example, the Federal Emergency Management Agency's (FEMA) website emphasizes the importance of structural preventive measures or seismic retrofitting (FEMA, 2015). However, preventive measures have not been taken by updating the building code, by adopting changes to the current building code, or by inspecting buildings for seismic risk. Only reactive measures have been taken by Oklahoma's Department of Transportation (ODOT). ODOT will inspect bridges after a 4.7 magnitude earthquake has been recorded. At this magnitude, the radius of inspection is limited to five (5) miles. At a 6.3 magnitude or greater, the radius is increased to 120 miles (Oklahoma Department of Transportation, 2016). Unlike Oklahoma, California, through Caltrans, the Department of Transportation for the State of California, has a robust preventive program that includes a Seismic Retrofit Program for protecting bridges across the state against future earthquakes (California Department of Transportation, 2017). Moreover, unlike California, Oklahoma did not adopt changes to the IBC structural design Chapter 16 and the sections on seismic design (Oklahoma Uniform Building Code Commission, 2015).

Exxon Mobil Corporation recently published a paper on the *Technical Considerations Associated with Risk Management of Potential Induced Seismicity in Injection Operations*. A section in the report is entitled "Risk Management Considerations." In this section of the ExxonMobil report a framework is presented for addressing the risk of induced seismicity factors, including: the seismic history at a given location, regulation compliance, factors affecting probability of occurrence, an "Initial Risk Screening" with a "Stoplight System," an injection plan considering previous operating experience, "public sensitivity/tolerance to nuisance seismicity," local construction standards, and historic structures are identified within this document. In this example, the industry has proposed a risk framework that takes into account proximity to historical structures and the tolerance of seismic activity by the public. Also noteworthy, in this example, is the similarity of the "stoplight system," to the "traffic light" permitting system, to be implemented by the industry if not implemented by the state.

Action in Oklahoma

The Oklahoma Corporation Commission (OCC) serves as the regulatory agency for the petroleum industry within the State of Oklahoma. The OCC has exclusive jurisdiction to regulate underground injection control (UIC) Class II wells (The Oklahoma State Courts Network, 2017). Class II wells include disposal wells, enhanced recovery wells, and hydrocarbon storage wells. The OCC has statutory authority to change and update monitoring, reporting, and permitting requirements. In 2014 the OCC adopted a "traffic light" permitting system (Oklahoma Corporation Commission, 2016). The "traffic light" permitting system allows the OCC to investigate well location relative to stress faults, seismic swarms, or areas of interest. Using this system, the OCC may require the operator to demonstrate the level of risk of induced seismicity through the use of technical data (Baker, 2015). In general, the permits can be 1) temporary, 2) based on seismicity concerns, 3) made more stringent at any time, 4) require public court process, and 5) include mandatory shut down of a given well in the event of seismic activity (Oklahoma Corporation Commission, 2016). Also in 2014, the OCC began 1) requiring mechanical integrity tests for 20,000 barrels/day disposal wells and 2) requiring a record of well pressure and disposal volume for disposal wells in the Arbuckle formation.

In 2015, the OCC performed localized response plans and enforced a large “traffic light” system reduction in disposal volumes for area of interests in Oklahoma and Logan Counties. In March of 2015, operators were required to plug wells to stop injecting into crystalline basement rock formations (Baker, 2015). By November of 2015, the State reacted to increased earthquake frequency as state regulators "directed five companies to limit operations at nine disposal wells North of Medford after more than two dozen earthquakes shook the area over the past four days." In January of 2016, the OCC agreed to settle a dispute with Sandridge Energy by allowing Sandridge Energy to end disposal in seven wells and donate five wells to an Oklahoma Geological Survey (OGS) research project. Sandridge Energy suffered economically from the imposed regulation, but the reputation of the company was promoted upon the donation of the wells for research. By February of 2016, the largest cutback in total volume was implemented in western Oklahoma as a response to seismic activity and to prevent seismic activity in other areas (Skinner, 2016). The forty percent reduction of disposal into the Arbuckle formation was suggested to be distributed over two months and in four phases. To accomplish the task, emergency funding and staff were provided by Oklahoma Governor Fallin, the Oklahoma Energy Resources Board, and the Groundwater Protection Council. In March of 2016, an additional area of interest – Central Oklahoma – was added to the February 2016 volume cutback with the goal to reduce volume disposal in the Arbuckle formation to forty percent below the 2014 total (Figure 4).

As of September 12, 2016, the EPA shut down 5 wells and the OCC shut down 27 wells in their respective jurisdictions in the Pawnee, Oklahoma area in response to new fault data provided by the OGS and the USGS after the September 3, 2016 magnitude 5.8 earthquake in Pawnee (Skinner, 2016). After the magnitude 4.3 earthquake in Pawnee, on November 3, 2016, the OCC required a site specific radial plan from the earthquake location including closing four Arbuckle disposal wells, decreasing volume by twenty-five percent of ten Arbuckle disposal wells, and limiting volume of eight other Arbuckle wells. The EPA directed twenty wells to limit volume and six wells to reduce volume by twenty-five percent (Skinner, 2016).

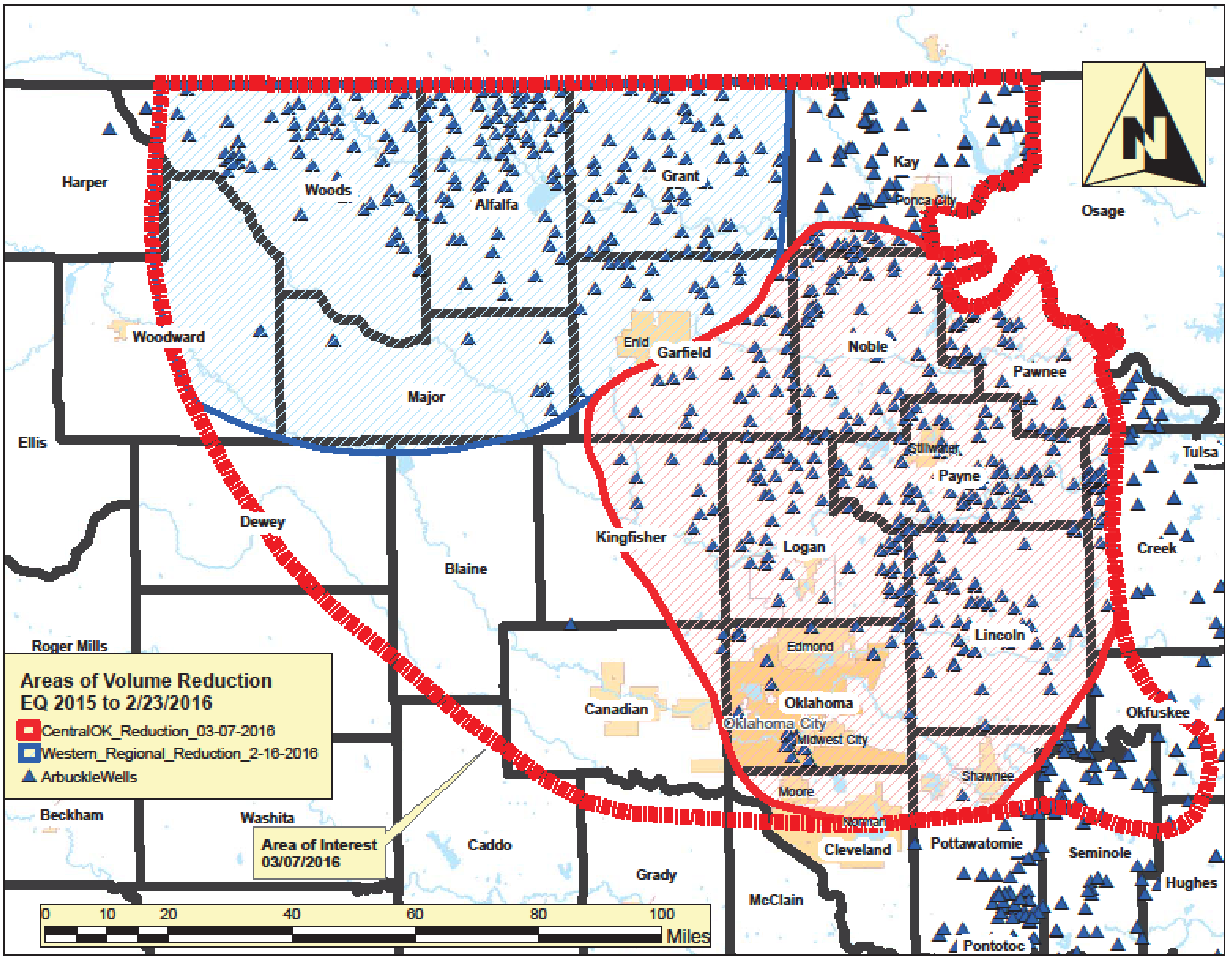

Figure 4. Western and Central Areas of Disposal Reduction (Skinner, 2016).

Ethics

The International Code Council (ICC) and IBC refer to ASCE 7-10 for design standards and procedures. ASCE 7-10 is produced by the American Society of Civil Engineers (ASCE). ASCE upholds the Code of Ethics and seven Fundamental Canons to assist engineers and businesses in protecting the public and making ethical decisions.

The first fundamental canon provided by ASCE is, "Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties." Many methods may be applied, at this time, to protect the public including performing structural preventative measures, writing new, more stringent design criteria for the increased earthquake frequency in Oklahoma and updating the magnitude value tables for earthquakes in Oklahoma.

Structural preventive measures are strongly suggested by the FEMA building codes website (FEMA, 2015). FEMA has a QuakeSmart program to assist businesses in identifying buildings with seismic hazards and mitigating the hazards through retrofitting. The website also identifies building codes related to seismic design and provides documents with new research results to change or add to the current building codes. For example, the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures (FEMA P-750) are included for comparison purposes.

The fourth fundamental canon provided by ASCE states, "Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest." This canon is being questioned by the USGS. The USGS released a report entitled "*2016 One-Year Seismic Hazard Forecast for the Central and Eastern United States from Induced and Natural Earthquakes*" and stated,

> "Building-code committees are reluctant to consider induced seismicity in their current design codes because the hazard from induced earthquakes will change before the building regulations are enacted, which causes confusion in the design process. Conversely, officials will not be able to rely on standard building codes when making decisions regarding the mitigation of damage from induced earthquakes. Even though induced earthquakes are not considered in building-code maps, they create seismic hazard to buildings, bridges, pipelines, and other important structures and are a concern for about 7.9 million people living in the vicinity of these events."

Several major allegations were presented in this reported statement. Conflicts of interest may be taking place within the individuals on the building-code committees. Conflicts of interest may have also existed, as engineers attempted to be faithful agents to clients and to the public. The substantial amount of income – $898 million annually in severance taxes (Snead and Jones, 2016) – that the State of Oklahoma receives from the petroleum industry may also be a source of a conflict of interests. No actions against conflicts of interest have been found in the reviewed literature.

Conclusion

Experts within the engineering, governmental agency, and building-code committee communities are working to ensure and improve the public's safety. While arguments may be made that the current seismic design standards in Oklahoma are sufficient to protect the public, arguments may also be made the current design standards do not reflect current conditions and a new or modified system may be needed based on current data. It appears that only reactive measures have been taken by the State of Oklahoma; however, the State of Oklahoma has not historically experienced seismic activity like this and was not prepared for preventive measures in the way that seismic active states like California and Washington have prepared.

The consensus among experts is that there is an increased seismic hazard in the state of Oklahoma. However, the scientific experts who made these conclusions were not involved in the design regulations imposed by building-codes or federal agencies. An unforeseen need for coordination among federal agencies has been exposed and an organizational gap needs to be filled. The challenge now is how to structure the agencies for coordination. Currently, the situation appears as though all parties want to help, but do not know how to coordinate on one front. Legal liabilities may be restraining agencies or groups from leading a coordination effort. I believe one of the four federal agencies identified by the NAS should lead the effort in setting defined communication channels and responsibilities from federal agency to federal agency and from federal agency to state agency. I believe allowing the state agencies to take initiative with the oversight and guidance of a corresponding federal agency will produce fast and effective results. With some passion, mutual concessions and compromises, a solution is sure to be found.

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