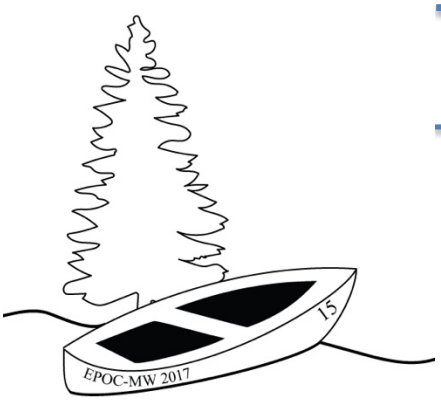

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"I'm Not a Scientist" Community Knowledge-Sharing During Uncertainty: Induced Seismicity and Hydraulic Fracturing

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“I’M NOT A SCIENTIST” COMMUNITY KNOWLEDGE-SHARING DURING UNCERTAINTY: INDUCED SEISMICITY AND HYDRAULIC FRACTURING

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ABSTRACT

In Oklahoma, the frequency of earthquakes has risen significantly in the past decade with many scientists believing that these earthquakes are induced by injecting vast quantities of salty wastewater, a byproduct of petroleum production, deep underground. Because the cause is still being debated publicly, communities impacted by these quakes often face uncertainty when it comes to understanding the earthquakes and the subsequent effects on their lives, and share information related to the causes and impacts of the quakes. In order to understand how information is being shared and how it is being used, it is first necessary to examine what types or categories of information are being shared by varying stakeholder groups. Through semi-structured interviews with different stakeholders, we have found that there is a difference between the type of information shared by different groups, with the most notable difference being between lay Community members and those with a background working in oil & gas, government, or academia & the physical sciences.

KEYWORDS

Knowledge seeking, induced seismicity, hydraulic fracturing.

INTRODUCTION

MOTIVATION AND BACKGROUND

The United States is currently experiencing an energy boom due, in large part, to the widespread advancement of petroleum extraction techniques, including hydraulic fracturing and horizontal drilling (Pless 2012). This process allows for the extraction of oil and gas that was previously unobtainable and has resulted in increased production across the country. The oil and gas produced through hydraulic fracturing

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is brought to the surface, bringing with it a salty brine. To dispose of the brine, this wastewater is often injected deeper into the earth, far below where it originated.

In recent years, the occurrence of earthquakes is on the rise in areas across the country with high rates of hydraulic fracturing, with earthquakes occurring in Texas, Kansas, Colorado, and Ohio (Choy et al. 2016; Hornbach et al. 2015; Skoumal et al. 2015; Walsh and Zoback 2015; Walter et al. 2016). One of the regions with the most dramatic increase in seismic activity is the state of Oklahoma (Darold et al. 2015). As a whole, the state of Oklahoma has, from 2014 to 2016 alone, experienced more than 2,100 earthquakes of magnitude 3.0 or above including the largest earthquake in Oklahoma's history, a magnitude 5.8 earthquake occurring in 2016 near Pawnee, OK. This is compared with less than 290 in the 15 years prior to 2014 and an average of less than 2 per year between 1978 and 1999 (USGS 2016b). Many in the scientific community believe that these earthquakes are induced by humans and that wastewater injection is, at least in part, responsible for the increase in seismic events in regions where wastewater injection occurs (Andrews and Holland 2015; Keranen et al. 2014; Yeck et al. 2016). Research has shown for decades that deep fluid injection can trigger earthquakes (Evans 1966), though it is not until recently that the injection of wastewater from hydraulic fracturing was thought to induce seismic events. However, there is not a widespread consensus regarding the link between seismicity and wastewater injection. Early theories as to the cause of the earthquakes that were unrelated to injection, including hydraulic fracturing itself and the increased level of a local reservoir, have given skeptics other theories to believe and promote (National Research Council 2013; Oklahoma Geological Survey 2013). This lack of consensus and promotion of different theories increases uncertainty about a risk that is already new and unknown to stakeholders in the region.

This uncertainty is problematic because the earthquakes, being caused by human actions, can be addressed and mitigated by changing behavior regarding disposal of produced wastewater. Those with the ability to change disposal practices may be reluctant to do so given the uncertainty regarding the cause of the earthquakes that exists outside of academic circles, exacerbating the hazards and preventing mitigation.

Past research around oil and gas development has shown that often the public discourse focuses on economic and environmental impacts, and thus the information traditionally shared about hydraulic fracturing falls into these two categories (e.g. Bomberg 2015). No studies have looked at the kind of information shared regarding oil and gas within the context of communities impacted by induced seismicity, however. Natural hazard literature does explore information deficits and knowledge seeking and sharing after a disaster, but in this context it is not a single event causing the risk. We also look to sense-making literature to serve as a guide to understanding the information seeking process of stakeholder groups in these communities. This work eventually seeks to understand how stakeholder groups and networks use their information in the debate surrounding the earthquakes and their cause, but in order to understand how they utilize information, and to better understand why the uncertainty regarding the cause of the quakes exists, we must first know what information is being shared. Thus, this paper seeks to address the question: *What types of information are sought and shared by different stakeholder groups in communities*

impacted by induced seismicity? Why do these stakeholders seek and share these types of information?

THEORETICAL BACKGROUND

After a disaster, affected stakeholders are more likely to seek information regarding the risks associated with the event (Guo and Li 2016; Li and Guo 2016). Recently, research has begun to examine the types of information desired by, but unavailable to, stakeholder groups following a disaster (Arneson et al. 2016). In such scenarios, often there is information available, but community members either don't know what information they would need or want, or they do not know where to access it (Gares 2002, Faulkner et al 2007). Oftentimes there may be barriers to communication between community members, experts, and decision makers (Faulkner et al 2007, Fiorino 1990).

This work builds on the natural hazard literature, but deviates from it, in that the context of this research is centered on "tech-na" hazards, which are human-induced events, as opposed to "natural" events. Technological hazards pose a different set of risks than natural hazards (Kasperson and Pijawka 1985), and may cause different information distribution and seeking patterns due to invested interests that often diverge between protecting the built and natural environment and increasing economic growth through the implemented technology.

Though oil and gas development is not a single event in time like disasters often are, research has shown that such development can be a disruptive force when it arrives in a region, creating jobs while also often creating stress, increasing crime, and bringing the potential for environmental damage (Meng 2017; Opsal and O'Connor Shelley 2014; Wilkinson et al. 1982). In many ways oil and gas development has the potential for similar impacts as a natural hazard event. Many of these impacts have been explored in "boomtown" literature in the past, particularly with regards to how community and industry organizations try to communicate these risks and benefits among and between different groups (Bomberg 2015; Cotton et al. 2014; Dodge and Lee 2017; Schirrmeister 2014).

However, the recent earthquakes associated with oil and gas are outside the normal bounds of boomtown discourse literature. A branch of communications research known as *sense-making* examines how individuals make sense of disruptions to what they believe to be the normal state of the world (Weick et al. 2005). As a whole, sense-making seeks to understand how individuals use information in order to address issues or problems in their lives. The process begins with identifying the situation that drives individuals to seek answers, followed by understanding what information they seek to come to an answer, and how that information is used and synthesized to generate an answer or response to the situation that started them on this process (Savolainen 1993). This model can be applied to disaster scenarios. To apply this to the situation in Oklahoma, the disruption to the standard state of the world is the recent increase in earthquakes. In order to then understand how individuals make sense of these earthquakes, it is important to first understand what information is being sought and shared regarding these earthquakes.

What makes the situation in this research different from past disaster research contexts is that it is not a single event that is causing interest and information seeking, but a new, gradually developing environment of risk and uncertainty that did not exist

before. Though there have been instances of induced earthquakes going back decades (e.g. Evans 1966), the connection between oil and gas development and seismic events is often only discussed within the geological community. Because of this, there is a lack of literature discussing how induced seismicity influences community perceptions of oil and gas, or how information about induced seismicity is shared. This work hopes to begin addressing the gap in the literature between the physical sciences and the social sciences.

RESEARCH METHODOLOGY

RESEARCH CONTEXT

In order to address these questions, case studies were conducted in Edmond and Fairview, Oklahoma, two communities that have experienced high levels of seismicity in recent years and are exemplary of the state-wide increase in seismic activity (USGS 2016a). Both locations have a history of oil and gas development stretching back decades.

DATA COLLECTION

Qualitative interviews were chosen for data collection as they allow the researcher to elicit a deeper understanding of the interview subject's experience within a given context than would be achieved through a more positivist approach (Lindlof and Taylor 2011; Rubin and Rubin 2012).

To identify interviewees, we reviewed, news publications, social media, press releases, scientific studies, public events, and other archival documents. This allowed us to identify groups and individuals who were active in sharing information about the earthquakes and related oil and gas activities. Additional participants were solicited through snowball sampling and referrals from our initial contacts in the communities. This archival analysis also shaped the content of the interview questions so that they were tailored to the community and the type of stakeholder being interviewed.

Interview respondents were initially categorized into four categories of stakeholders: *Elected and Government Officials, Academics and Scientists, Oil & Gas Professionals,* and *Community Members*. These codes were developed inductively based on the respondent's stated position or profession, how other interviewees identified them, and how they spoke of themselves in their interview. Categories were condensed and consolidated if after the initial coding there was major overlap between two categories or if we were "splitting hairs" and ended up with categories of only one or two individuals with results that did not differ from other groups. Where individuals could fit into more than one stakeholder group, a primary category was chosen based primarily on how they most identified themselves during the interview and how other interviewees identified the individual, when possible. For example, one individual was an elected official but also lived in the community and experienced many of the same events as their community members. This individual also talked often of their role of representing their constituents to the rest of the state, and other members of the community talked of this individual in a similar manner. This informant was categorized under both.

Elected and Government Officials include elected members of state or local government, as well as individuals who represented or worked for government agencies, such as the Oklahoma Corporation Commission (OCC). *Academics and Scientists* include professors at local universities as well as those working in a capacity where they considered themselves scientists. These stakeholders were either seismologists, geologists, or hydrogeologists whose work directly relates to the topic being discussed. *Oil & Gas Professional* refers to individuals currently or recently employed in the petroleum industry. *Community Members* include residents of either of the areas of interest. This was often the primary code when a second code did not fit them well. For example, an individual in Edmond who worked for a natural gas company in the past could be coded under both *Community Member* and *Oil & Gas Professional*, but if they primarily identified with fellow Edmond residents over the oil companies they were coded under *Community Members*.

Though some of the individuals interviewed acted effectively only as a source of information to others, such as the academics, others, such as community members, acted only as a receiver, or sink, of information, receiving but not sharing information with other stakeholders. Many of the individuals interviewed acted as both a source and sink in some capacity.

In total, the first author conducted semi-structured interviews with 35 individuals. These interviews lasted anywhere from 30 to over 90 minutes. Questions included: *What kinds of information (regarding induced seismicity and oil and gas development) do you share with others? What would you like to know more about that you don't, regarding induced seismicity?*

DATA ANALYSIS

Interviews were transcribed and imported into NVivo, a qualitative analysis software that allows the researchers to use qualitative and quantitative coding techniques, run queries between codes, and run matrix coding queries (Bazely 2014; *NVivo* 2016). The first and third author coded the transcripts using an inductive coding process to build themes and codes from the transcribed interviews. An inductive coding approach allowed for the researchers to account for the breadth of responses from interviewees, as opposed to sorting responses into pre-determined categories (Charmaz 2006). Memos on individual and groups of interviews were written throughout the initial coding process, from which an updated coding scheme was developed.

In total, fourteen major code categories were developed using inductive coding methods. This paper focuses on the intersection of two: *Stakeholder Type* and *Categorization of Information*. *Stakeholder Type* was coded for each interviewee per the description above. The *Categorization of Information* category accounted for information that was received by the interviewee or that they stated they had shared with others. We performed deductive coding within this category, where we coded types of information being discussed and transferred in each community. For this coding process, we coded when an interviewee mentioned information that had been transferred, not any kind of opinion. For instance, if a respondent said "I think the earthquakes are natural," we did not code that as *Information* on its own, as without any other context this is an opinion only. If an interviewee said "I think the earthquakes are natural. I heard a report on the radio debunking their connection to oil

and gas," that would show a transfer of information, and that information ("a report debunking their connection to oil and gas,") would be coded as appropriate. Coding categories are described further in the Results section.

We then compared and contrasted the categories to determine what types of information were exchanged the most by the different stakeholder groups and how this varied in each of the case study communities.

RESULTS

Six central types of information were identified as actively sought and shared among stakeholders in our areas of interest. The information coded under *Categorization of Information* included: *Insurance Information; Laws, Rules, and Regulations; Seismic Risk Information; Technical Information & Data; Personal Stories;* and *General Information on Oil & Gas and Seismicity*. The following section presents the description of each category and the primary groups that discussed it. Sample interview excerpts and how they were coded are shown in Table 1.

Table 1: Example interview excerpts coded by information type

Insurance Information	Laws, Rules, and Regulations	Seismic Risk Information	Technical Information & Data	Personal Stories	General information
"The Oklahoma Insurance commissioner, came out and clarified that companies need to come out and say if they're covering man made [earthquakes] or not."	*"[The] Corporation Commission came out a couple of years ago and said 'well we don't have the authority to [act].'"*	*"The engineers …h ave determined that if there was something as big as 6.1 the building's probably going to come in."*	*"Then I put our two cases, that at the time, had gotten through peer-reviewed literature… one was like eight times higher than these base cases and the other one was like 72 times higher injection rate…"*	*"Yeah the most interesting group of people that I share with are wives of people who work for the oil companies because they are all thinking the same thing but they have – it is like they are all very quiet about it, so it is like don't [talk about it]"*	*"[Newspapers] would cover the number of quakes, maybe not so much the energy sector correlation... [The papers] published earthquake maps you know, 20 earthquakes in 7 days."*

Passages were coded under *Insurance Information* when the respondent talked about receiving or sharing information related specifically to earthquake insurance such as premiums, coverage, and actions taken by the state insurance commissioner. This information was discussed exclusively by the *Community Member* stakeholder group.

Laws, Rules, and Regulations accounted for information regarding steps taken by elected officials or regulators to address the earthquakes, including measures to

regulate oil and gas production and wastewater injection. This was one of the most frequent types of information being shared in the communities studied in this paper, and was discussed by all groups, though this information was shared by all *Elected and Government Officials* and *Oil & Gas Professionals*.

Seismic Risk Information encompassed seismic hazard information including the potential magnitude of earthquakes in the area and the damage that can occur, such as what is included in the USGS Seismic Hazard Forecast (Petersen et al. 2017). This type of information was shared across all stakeholder groups.

Technical Information and Data included raw data sets from ground motion sensors and injections data, as well as peer reviewed journal articles. The data that was shared included proprietary information, such as 3D underground surveys of faults and petroleum reserves, as well as wastewater injection rates, volumes, and depths. The following excerpt, which explains the exchange of data between petroleum companies, the regulators, and the state geological survey, is an example of what would fall under this code:

> *I said 'We need a fault map' well fine, who does that? [The state] geologic[al] survey. Geologic[al] survey says 'Yes we have a fault map, it's not going to do you any good because… you need Arbuckle and deep basement faults'… And so what you need for that type of research is you need just a whole lot of 3D seismic [surveys] and we don't have the seismic and we don't have the budget' so I said okay, the industry has reams of data on this stuff.*

Though individuals in every stakeholder category told of getting or sharing information of this type, it was overwhelmingly cited by *Oil & Gas Professionals* and *Academics and Scientists*.

Personal Stories included accounts of other people's experience with earthquakes and oil and gas. This could include stories shared that tell of the damage a friend's house experienced in that last big quake, or sharing information of concerned citizens or activists taking action. Though this type of information was shared and received by *Elected and Government Officials* and *Oil and Gas Professionals*, it should be noted that those interviewees in these categories that utilized this information were also categorized as *Community Members* as their secondary code. Thus the only individuals who cited using this information were in some way a part of the community themselves.

General Information on Oil & Gas and Seismicity included any other information about the earthquakes or petroleum development generally. Often this meant information related to oil and gas and induced seismicity, but that was stripped down. Regarding induced seismicity, this *General Information* would include the multiple times respondents mentioned sharing or hearing that wastewater injection was the cause of the earthquakes, without necessarily having the scientific or technical information that goes lead to that conclusion. Similarly, when people talked about other impacts of oil and gas development, such as possible impacts on air and water quality, this was coded under this category. All stakeholder groups shared or used this information, though it was cited much more by *Community Members*, followed by *Elected and Government Officials*.

Table 2 below shows the relative frequency for each category of information broken out by stakeholder group. For clarity, when the table shows "100%" at the intersection of *Elected and Government Officials* and *Laws, rules, and regulations*,

that means that 100% of the members of this group that were interviewed received or shared this type of information.

Table 2: Relative frequencies of information transferred by stakeholder type

	Elected and Government Officials	Academics and Scientists	Oil & Gas Professionals	Community Members
Insurance Information	0%	0%	0%	24%
Laws, rules, and regulations	100%	33%	100%	57%
Seismic risk information	40%	33%	25%	38%
Technical information and data	40%	100%	100%	14%
Personal stories	20%	0%	25%	67%
General information on O&G and seismicity	80%	33%	75%	95%

DISCUSSION

As shown in the results, the information discussed varied according to the stakeholder group. While some information, such as *Seismic Risk Information,* was shared fairly equally by all groups, there is much to be learned by looking at what information seeking and sharing trends set the groups apart and why the groups use that information.

Elected and Government Officials were far more likely to focus their information seeking and sharing around L*aws, Rules, & Regulations* than any other group with the exception of the *Oil and Gas Professionals*, which may be expected as these are the stakeholders most immediately affected by such government actions. When they discussed receiving or sharing *General Information on Oil & Gas and Seismicity* it was also mostly so they could better communicate with their constituents. The few individuals in this category who did seek or share *Technical Information or* Data did so to aid them in making decisions in their capacity as a government official, as they believed they needed the more formal information to make the best decisions.

Academics and Scientists were interested in and frequently sought *Technical Information & Data,* and barely used any of the other information types. While this makes sense, it is important to know why they sought it and how they viewed sharing this information. One scientist said that she did not share this kind of information with others because "*It's not something that you talk about with people who don't understand the science. It's not like I'd talk to my neighbor about it because they had no idea what was going on*." A different scientist on explaining why they did not

want other types of information said "*I can go get the data for myself; I don't need to listen to somebody who doesn't know anything about geology try to say something [about the earthquakes.*" When the former interviewee did talk about receiving *General Information on Oil & Gas and Seismicity*, she said "*I might get leads to articles and I'll go read those articles and then I'll read the article and say 'No, that's not right'!*" They valued this type of information in part because they saw it as more valid than other types of information. This may be expected, but the implications from these stakeholders alone suggest there may be barriers to communicating between *Academics and Scientists* and the other stakeholder groups.

Oil & Gas Professionals had great amounts of overlap with the *Elected and Government Officials* and the *Academics and Scientists*. All the interviewees in this stakeholder group discussed seeking and sharing *Technical Information and Data* and all either sought or shared information on *Laws, Rules, and Regulations*. As mentioned before, these stakeholders are the most affected by and measures the government puts forth so it makes sense that they seek out this information. They share and seek the technical information because they often are the *source* of this information. They have access to data that the *Academics and Scientists* need, and often try to share this information with the public and *Community Members*. However, as is seen by the relative frequencies there is a disconnect in the information used by this group and by the *Community Members*. One interviewee from this group discussed speaking with news agencies about all they had been doing to help investigate the earthquakes and their connection, but that the message was not received by the public. After the interview someone told him that he was trying to "educate" the public, but that "'Education is the cure for ignorance. [These people are afraid.] The cure for fear is reassurance.' And I said 'I can't reassure them because this is really complex and we don't understand it very well.'" He saw the disconnect, but still valued the technical, complex information that those he was trying to communicate with did not.

Lastly *Community Members* all seek *General Information* because they want to know what's happening and want "answers." Though some individuals brought up sentiments such as "I don't need to understand the quakes so long as they stop," others mentioned wanting to know more, but saw limits to their capacity to understand the information being share, often saying, verbatim, "I'm not a scientist." Here we perhaps see why there is this disconnect surrounding *Technical Information and Data*. It's not that this is not valued by *Community Members* but rather they cannot understand it as it is being presented, and as shown above the true "sources" of information, the *Academics and Scientists* and *Oil & Gas Professionals* do not know, or sometimes care, to discuss this with non-experts. *Community Members* were also the only group to seek *Insurance Information* and were far more likely to discuss *Personal Stories*, showing that they also valued information that was not utilized by the "sources" in academia or industry or by the ostensible decision makers in government.

CONCLUSION

This work demonstrates that different stakeholders seek and share different types of information in times of uncertainty, with this case being an evolving hazard environment. The lack of a common information type being shared, and the quotes that show explicitly how different stakeholders value that information, may point to a

disconnect between these stakeholder groups. This lack of common language may again increase tensions and uncertainty in communities. Future work will examine why and how stakeholders use and share information on oil and gas development.

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