An Example of a Collaborative Effort Between Government, Industry, and Academia to Address Injection-Induced Seismicity

Ivan Wong

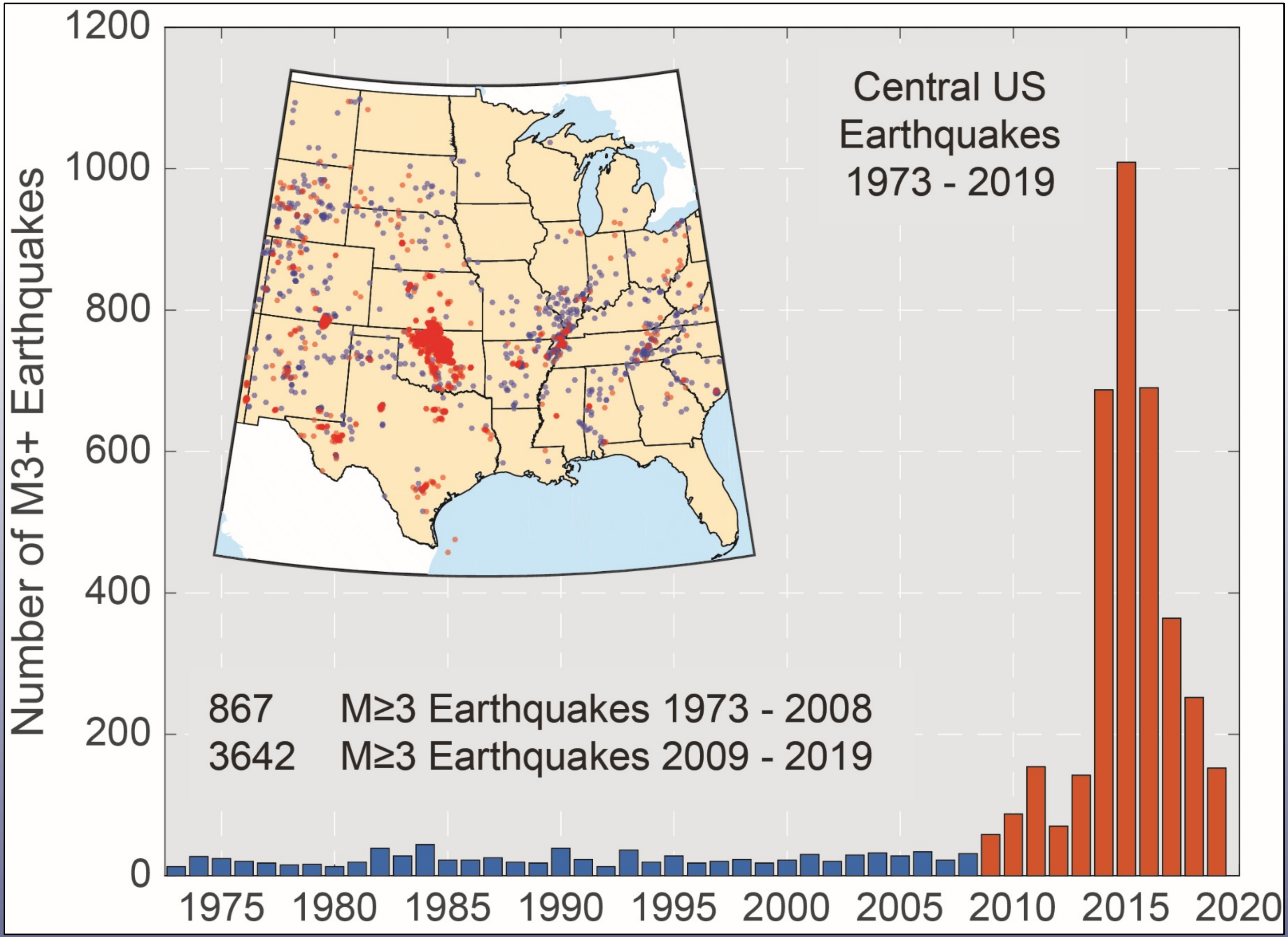
Senior Principal Seismologist
Lettis Consultants International

Commissioner, California Seismic Safety Commission

Regional Induced Seismicity Collaborative Webinar

4 February 2021

The Issue


Central US
Earthquakes
1973 - 2019
867 M≥3 Earthquakes 1973 - 2008
3642 M≥3 Earthquakes 2009 - 2019
Number of M3+ Earthquakes
0
200
400
600
800
1000
1200
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

2011 M 5.7 Prague, Oklahoma Earthquake

2011 M 5.3 Trinidad, Colorado Earthquake

2012 M 4.8 Timpson, Texas Earthquake

Signs of the Times

CBS DFW | Buy Tickets | Your Home | More | FOLLOW US

Local

Texas Proposes Tougher Rules On Wells After Quakes

August 25, 2014 5:50 PM

Share 13 | Tweet 10 | Share 3 | View Comments

(credit: Spencer Platt/Getty Images)

USA TODAY | Money | Subscribe | Mobile | Google USA TODAY stories, photos and mo

Home | News | Travel | Money | Sports

Money: Markets | Economy | Personal Finance | Stocks | Mutual Funds | ETFs | Cars | Real Estate | Small

Ohio: Fracking waste tied to earthquakes

By Julie Carr Smyth, Associated Press

Updated 3/9/2012 4:07 PM

Comment

COLUMBUS, Ohio – A dozen earthquakes in northeastern Ohio were almost certainly induced by injection of gas-drilling wastewater into the earth, Ohio oil and gas regulators said Friday as they announced a series of tough new regulations for drillers.

By Amy Sancetta, AP

Among the new regulations: Well operators must submit more comprehensive geological data when requesting a drill site, and the chemical makeup of all drilling wastewater must be tracked electronically.

Northeastern Ohio and large parts of adjacent states sit atop the Marcellus Shale geological formation, which contains vast reserves of natural gas that energy companies are rushing to drill using a process known as hydraulic fracturing.

THE EARTH INSTITUTE COLUMBIA UNIVERSITY

ABOUT | RESEARCH | EDUCATION | STUDENTS | EVENTS | NEWS | VIDEO | BLOG | SUPPORT | DIRECTORY

News

Archive

- 2014
- 2013
- 2012
- 2011
- 2010
- 2009
- 2008
- 2007
- 2006
- 2005
- 2004
- 2003
- 2002
- 2001

In the Media

Jeffrey Sachs, Director

Resources

RSS Feeds

NEWS ARCHIVE

Wastewater Injection Spurred Biggest Earthquake Yet, Says Study

2011 Oklahoma Temblor Came Amid Increased Manmade Seismicity

2013-03-26

A 2011 magnitude 5.7 quake near Prague, Okla., apparently triggered by

A new study in the journal Geology is the latest to tie a string of unusual earthquakes, in this case, in central Oklahoma, to the injection of wastewater deep underground. Researchers now say that the magnitude 5.7 earthquake near Prague, Okla., on Nov. 6, 2011, may also be the largest ever linked to wastewater injection. Felt as far away as Milwaukee, more than 800 miles away, the quake—the biggest ever recorded in Oklahoma--destroyed 14 homes, buckled a federal highway and left two people injured. Small earthquakes continue to be recorded in the area.

The recent boom in U.S. energy production has produced massive amounts of wastewater. The water is used both in hydrofracking, which cracks open rocks to release natural

Signs of the Times

CBS DFW | Buy Tickets | Your Home | More | FOLLOW US

Local

Texas Proposes Tougher Rules On Wells After Quakes

August 25, 2014 5:50 PM

Share 13 | Tweet 10 | Share 3 | View Comments

(credit: Spencer Platt/Getty Images)

USA TODAY | Money | Subscribe | Mobile | Google USA TODAY stories, photos and mo

Home | News | Travel | Money | Sports

Money: Markets | Economy | Personal Finance | Stocks | Mutual Funds | ETFs | Cars | Real Estate | Small B

Ohio: Fracking waste tied to earthquakes

By Julie Carr Smyth, Associated Press

Updated 3/9/2012 4:07 PM

Comment

COLUMBUS, Ohio – A dozen earthquakes in northeastern Ohio were almost certainly induced by injection of gas-drilling wastewater into the earth, Ohio oil and gas regulators said Friday as they announced a series of tough new regulations for drillers.

By Amy Sancetta, AP

Among the new regulations: Well operators must submit more comprehensive geological data when requesting a drill site, and the chemical makeup of all drilling wastewater must be tracked electronically.

Northeastern Ohio and large parts of adjacent states sit atop the Marcellus Shale geological formation, which contains vast reserves of natural gas that energy companies are rushing to drill using a process known as hydraulic fracturing.

THE EARTH INSTITUTE COLUMBIA UNIVERSITY

ABOUT | RESEARCH | EDUCATION | STUDENTS | EVENTS | NEWS | VIDEO | BLOG | SUPPORT | DIRECTORY

News
Archive
- 2014
- 2013
- 2012
- 2011
- 2010
- 2009
- 2008
- 2007
- 2006
- 2005
- 2004
- 2003
- 2002
- 2001

In the Media
Jeffrey Sachs, Director
Resources
RSS Feeds

NEWS ARCHIVE

Wastewater Injection Spurred Biggest Earthquake Yet, Says Study

2011 Oklahoma Temblor Came Amid Increased Manmade Seismicity

2013-03-26

A new study in the journal Geology is the latest to tie a string of unusual earthquakes, in this case, in central Oklahoma, to the injection of wastewater deep underground. Researchers now say that the magnitude 5.7 earthquake near Prague, Okla., on Nov. 6, 2011, may also be the largest ever linked to wastewater injection. Felt as far away as Milwaukee, more than 800 miles away, the quake—the biggest ever recorded in Oklahoma--destroyed 14 homes, buckled a federal highway and left two people injured. Small earthquakes continue to be recorded in the area.

The recent boom in U.S. energy production has produced massive amounts of wastewater. The water is used both in hydrofracking, which cracks open rocks to release natural

A 2011 magnitude 5.7 quake near Prague, Okla., apparently triggered by

Signs of the Times

Mother Jones

HOME POLITICS ENVIRONMENT CULTURE PHOTO ESSAYS BLOGS

Must Reads: Inside the Mammoth Backlash to Common Core | What It's Like to Be an NFL Wife

ENVIRONMENT
— Energy, Science, Top Stories

Page 1 of 3

Fracking's Latest Scandal? Earthquake Swarms

Turns out that when a barely regulated industry injects highly pressurized wastewater into faults, things can go terribly wrong.

—By *Michael Behar* | March/April 2013 Issue

Like Share 19k Tweet 3,430 Email 239

vladm/Shutterstock

RT QUESTION MORE. LIVE

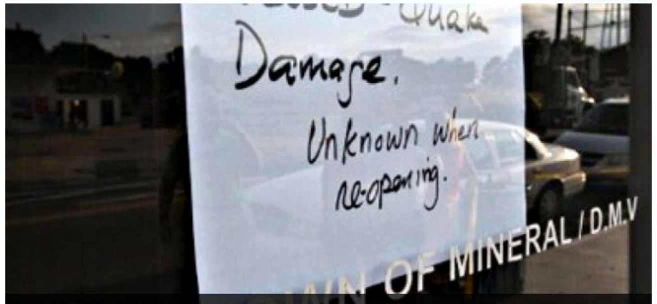
News USA UK Russian politics Business Op-Edge In vision In motion

Home / USA /

Fracking could have caused East Coast earthquake

Published time: August 24, 2011 16:36
Edited time: December 24, 2013 16:08

Get short URL



United States, Mineral: A sign on the door lets visitors know that City Hall, which shares a building with the local DMV office, was closed after the building was damged by yesterday's 5.8 earthquake August 24, 2011 in Mineral, Virginia. (AFP Photo / Scott Olson)

RT QUESTION MORE. LIVE

News USA UK Russian politics Business Op-Edge In vision In motion

Home / USA /

Fracking causes rumbles in California

Published time: July 05, 2012 21:39
Edited time: December 24, 2013 16:04

Get short URL

A gas flare burns at a fracking site (REUTERS/Stringer)

48 6

REUTERS EDITION: U.S.

HOME BUSINESS MARKETS WORLD POLITICS TECH OPINION BREAKINGVIEWS

Study raises new concern about earthquakes and fracking fluids

BY SHARON BEGLEY
NEW YORK | Thu Jul 11, 2013 4:56pm EDT

14 COMMENTS Tweet 238 Share 2 Share this 8+1 10 Email Print

1 OF 2. Filmmaker Josh Fox (C) joins a protest against fracking in California, in Los Angeles in this May 30, 2013 file photo.

CREDIT: REUTERS/LUCY NICHOLSON/FILES

CUSTOMER SERVICE OUR NETWORK OF SITES Partly sunny 85°F | Forecast Star-Telegram.com Archives

Star-Telegram Plus digital subscription sign-in

News Obituaries Sports Business Entertainment Life & Arts Opinion Cars Homes

Local Blogs Census Texas Dallas Crime Politics Legislature Schools Stock Show U.S.

Home > News > Local News

LOCAL NEWS RSS Mobile Newsletters MY YAHOO!

Quick links: Introducing: City by City

North Texas earthquakes more nuisance than crisis

Posted Saturday, Nov. 16, 2013 5 comments Print Reprints Share Like 108

ARTICLE PHOTOS (3) COMMENTS

BY BARRY SHLACHTER
barry@star-telegram.com

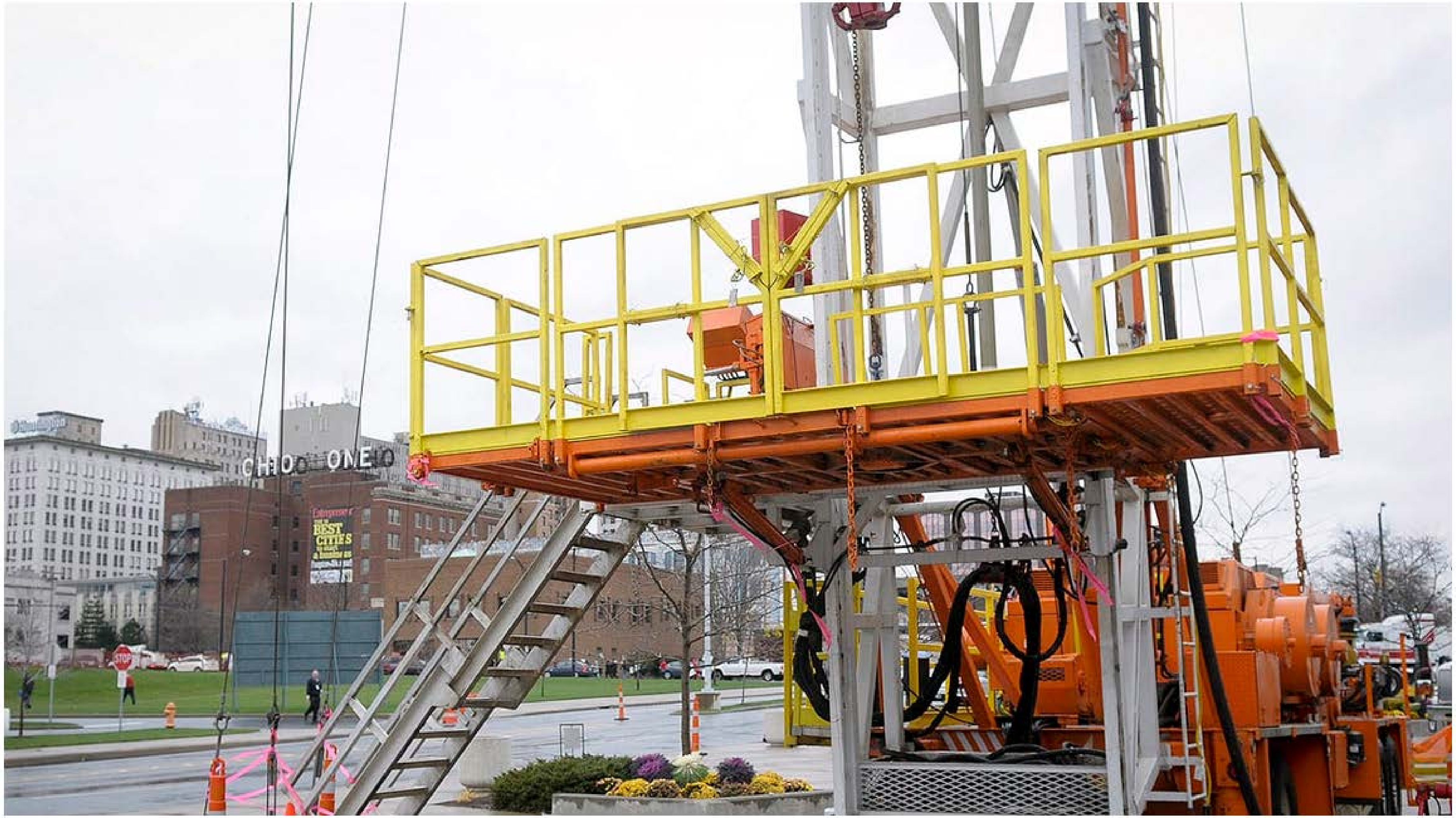
AZLE — The earth is literally jumping along a stretch of real estate from Fort Worth's Eagle Mountain Lake and Azle to the Parker County

Youngstown Rocks: Is Fracking Causing Earthquakes in Ohio?

Until 2011, Youngstown had never recorded an earthquake. Now it has registered 11. John Avlon investigates.

John Avlon

Updated Jul. 13, 2017 10:18AM ET
Published Jan. 03, 2012 6:30PM ET



Mark Stahl / AP Photo

Introduction

- In 2014, as the issue of induced seismicity due to the underground injection of oil and gas wastewater was becoming increasingly more controversial and contentious, several representatives from state regulatory agencies and geological surveys primarily from the central U.S. decided that information sharing was needed to assist them in addressing induced seismicity.
- Hence the Induced Seismicity by Injection Working Group (ISWG) was formed through an initiative of the Interstate Oil and Gas Compact Commission and the Ground Water Protection Council now known as the State Oil and Gas Regulatory Exchange (Exchange).
- The ISWG was composed of the representatives of the state regulatory agencies and geological surveys supported by subject matter experts from industry, academia, federal agencies, and environmental organizations.

Introduction

- The purpose of the ISWG was to produce a document which would help better inform stakeholders and the public on technical and regulatory considerations associated with the evaluation and response, seismic monitoring systems, information sharing, and the use of ground motion metrics.
- The document was also intended to summarize the range of approaches that have been used or are currently being used by states to manage and mitigate the risks associated with induced seismicity.

ISWG

- AK - Steve Masterman, Alaska Geological and Geophysical Survey
- AR - Lawrence Bengal and Scott Ausbrooks, Arkansas Oil & Gas Commission
- CA - John Parrish, California Geological Survey
- CO - Bob Koehler and Matt Lepore, Colorado Oil & Gas Conservation Commission
- OH - **Rick Simmers** and Bob Worstall, Ohio Department of Natural Resources, Division Oil & Gas Resources Management
- KS - **Rex Buchanan**, Kansas Geological Survey
  Ryan Hoffman, Kansas Corporation Commission
- OK - Tim Baker, Oklahoma Corporation Commission
  Austin Holland, Oklahoma Geological Survey
  Michael Teague, Oklahoma Secretary of Energy & Environment
- IL - Richard Berg and Robert Bauer, Illinois State Geologic Survey
- IN - Herschel McDivitt, Indiana Division of Oil and Gas
  John Rupp, Indiana Geological Survey
- TX - Leslie Savage and Craig Pearson, Railroad Commission of Texas
- UT - John Baza and John Robers, Utah Division of Oil, Gas, & Mining
- WV - Jason Harmon and Zac Stevison, West Virginia Department of Environmental Protection

2015/2017 Editorial Committee

Tim Baker, Oil & Gas Division, Oklahoma Corporation Commission (2015 & 2017)

Rex Buchanan, Kansas Geological Survey (Co-chair) (2015)

Charles Lord, Oklahoma Corporation Commission (2015)

Hal Macartney, Pioneer Natural Resources (2015 & 2017)

Herschel McDivitt, Oil & Gas Division, Indiana Depart. of Natural Resources (2015)

Kris Nygaard, ExxonMobil Upstream Research Company (2015 & 2017)

Leslie Savage, Oil & Gas Division, Railroad Commission of Texas (2015 & 2017)

Rick Simmers, Ohio Department of Natural Resources, Division of Oil & Gas (Co-chair) (2015 & 2017)

Ed Steele, GE Global Research, (2015 & 2017)

Ivan Wong, AECOM/Lettis Consultants (2015 & 2017)

Bob Worstall, Ohio Department of Natural Resources, Division Oil & Gas Resources (2015 & 2017)

Mike Nickolaus, GWPC

2021 Guide Contributors

Tara Gross - GWPC
Amy Childers - IOGCC
Mike Nickolaus - GWPC
Todd Shipman - Alberta Geol. Survey
Ed Steele - Consultant
Kris Nygaard - Exxon Mobil
Kurt Hildebrandt - USEPA
Leslie Savage - Texas Railroad Comm.
Tom Tomastik - ALL Consulting
Michael Young – TBEG
Lori Wrontenbery – IOGCC
Rex Buchanan – KGS
Lloyd Hetrick – LHH Engineering

Cody Comiskey - Chevron
Scott Anderson - Environmental Defense Fund
Carrie Ridley – KS Dept Health & Environment
Jim Gonsiewski – ODNR
Steven Dade - ODNR
Colin Brooks - OCC
Jake Walter - OGS
Kurt Schrantz - Schrantz Consulting
Ivan Wong - Lettis Consultants
Shawn Maxwell – Ovintiv Services
Aaron Velasco – Texas Railroad Commission
Robert Voorhees – Underground Inject. Tech. Council

POTENTIAL INDUCED SEISMICITY GUIDE – A Resource of Technical and Regulatory Considerations Associated with Fluid Injection

- The guide is the third edition of a document previously called
  - *Potential Injection-Induced Seismicity Associated with Oil & Gas Development – A Primer on Technical and Regulatory Considerations Informing Risk Management and Mitigation*
    - First Edition 2015 by StatesFirst Induced Seismicity
    - Second Edition 2017 by StatesFirst Induced Seismicity
- Previous two versions focused on induced seismicity from Class II wells. This version now includes hydraulic-fracturing seismicity and includes a discussion of CCS. Also the guide covers western Canada.

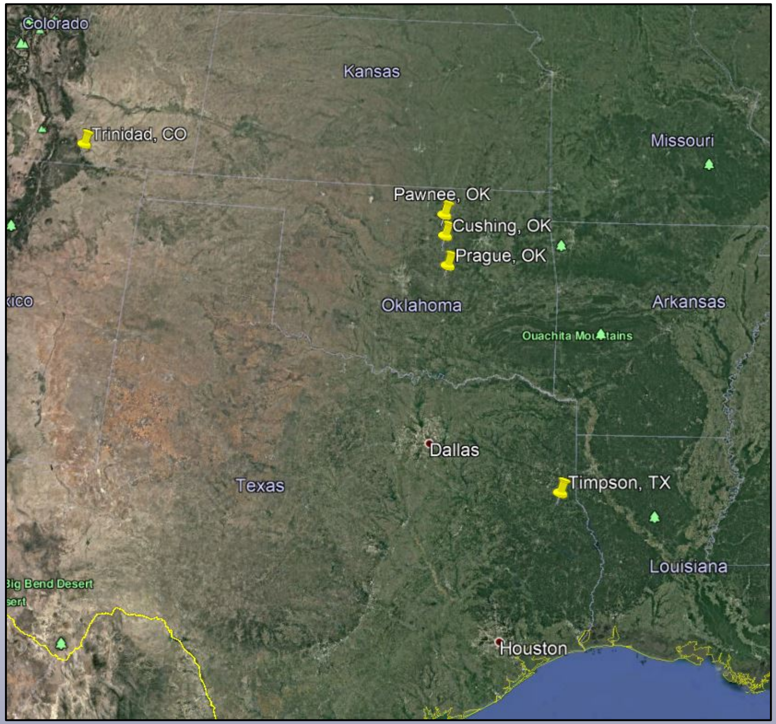
Purpose

- The Guide is designed to provide state and provincial regulatory agencies with an overview of current technical and scientific information, along with considerations associated with evaluating fluid-induced seismicity, managing the associated hazard and risk, and developing response strategies.
- It is not intended to offer specific regulatory recommendations to agencies but is intended to serve as a resource.
- Also, unlike prior studies by the National Research Council, EPA, Stanford University, and others, this document is not intended to provide a broad literature review.

Purpose

- Unlike earlier versions of this Primer which focused on Class II wells, we now give equal attention to injection-induced seismicity due to hydraulic fracturing.
- The increasing number of cases of hydraulic-fracturing induced earthquakes and the increasing magnitudes of such events requires additional research and mitigation.
- Management and mitigation of the risks associated with induced seismicity are best considered at the state level, with specific considerations at local or regional levels.
- A one-size-fits-all approach is infeasible, due to significant variability in local geology and surface conditions, including such factors as population, building conditions, infrastructure, critical facilities, and seismic monitoring capabilities.

Significant Induced Earthquakes



- 2011 **M** 5.7 Prague, Oklahoma, earthquake - damaged some local homes, broke windows, cracked masonry, and collapsed a turret at St. Gregory's University
- 2011 **M** 5.3 Trinidad, Colorado, earthquake - caused structural damage to unreinforced masonry as well as nonstructural damage, including cracked masonry, fallen chimneys, broken windows, and fallen objects
- 2012 **M** 4.8 Timpson, Texas, earthquake - caused fallen chimneys and damage to masonry walls
- 2016 **M** 5.0 Cushing, Oklahoma event - resulted in cracks to buildings and fallen bricks and facades on City Hall and the Lions Club
- 2016 **M** 5.8 Pawnee, Oklahoma earthquake - damaged brickwork and cracked sheetrock at a number of structures

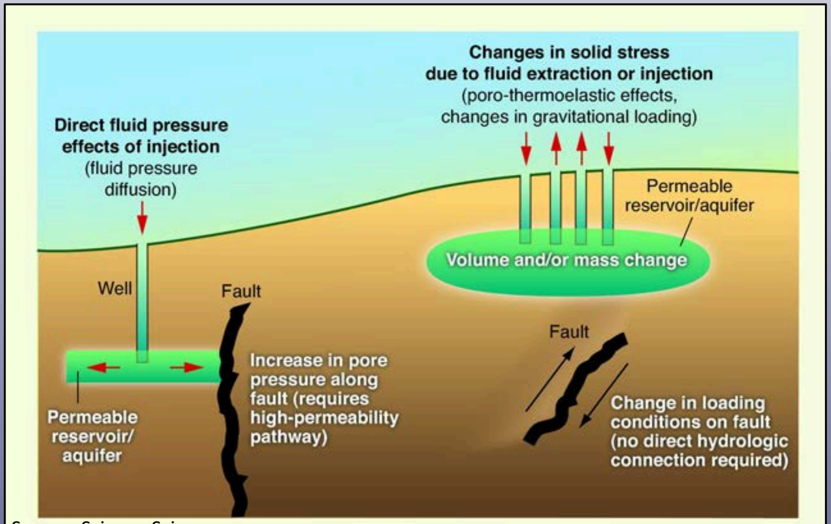
- Also **M** 4.6 event in British Columbia, **M** 4.7 and 5.7 in Sichuan, China due to hydraulic fracturing and the **M** 5.5 in Korea due to geothermal activity.

Table of Contents

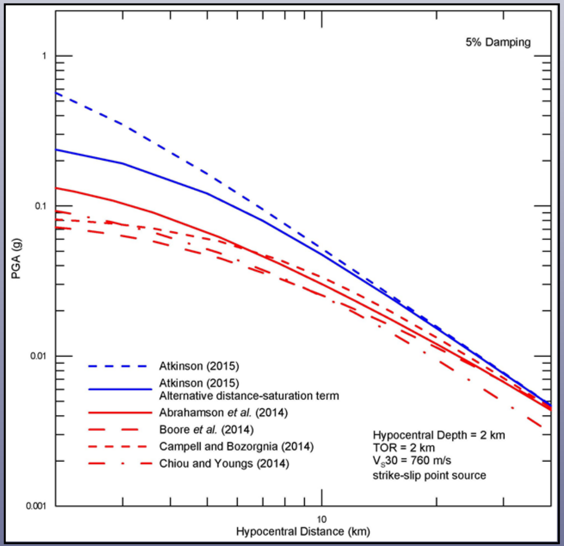
- Executive Summary
- Chapter 1: Understanding Induced Seismicity
- Chapter 2: Assessing Potentially Injection-Induced Seismicity
- Chapter 3: Risk Management and Mitigation Strategies
- Chapter 4: Considerations for External Communication and Engagement
- Appendix A: Relevant Earthquake Science
- Appendix B: Class I and II Injection Wells
- Appendix C: Induced Seismicity Case Studies
- Appendix D: Design and Installation of Seismic Monitoring Networks
- Appendix E: Methods for Estimating Reservoir Pressure Changes Associated with Injection
- Appendix F: Data Collection and Interpretation
- Appendix G: State Regulatory Summaries
- Appendix H: Carbon Dioxide Geologic Storage and Induced Seismicity
- Appendix I: Understanding Hydraulic Fracturing
- Appendix J: Glossary of Terms
- Appendix K: Glossary of Acronyms
- Appendix L: List of References

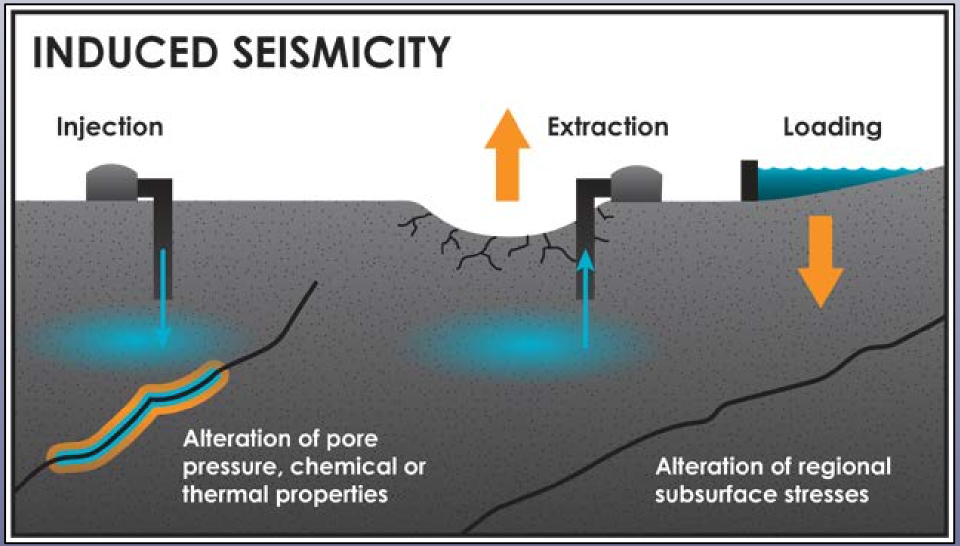
Chapter 1 Understanding Induced Seismicity

- Key concepts of earthquake science, such as magnitude, seismic monitoring, locating earthquakes, ground motion, and hazard.
- The hazards and risks related to induced seismicity and the difference between hazard and economic impacts damage, anxiety risk as they pertain to the potential effects of induced seismicity.
- The ways in which fluid injection might cause induced earthquakes, including the concept that the main physical mechanism responsible for triggering injection-induced seismicity is increased pore pressure on critically stressed faults.
- Ground motion models currently being used and the need to develop models specific to injection-induced earthquakes.



Source: Science.Sciencemag.org



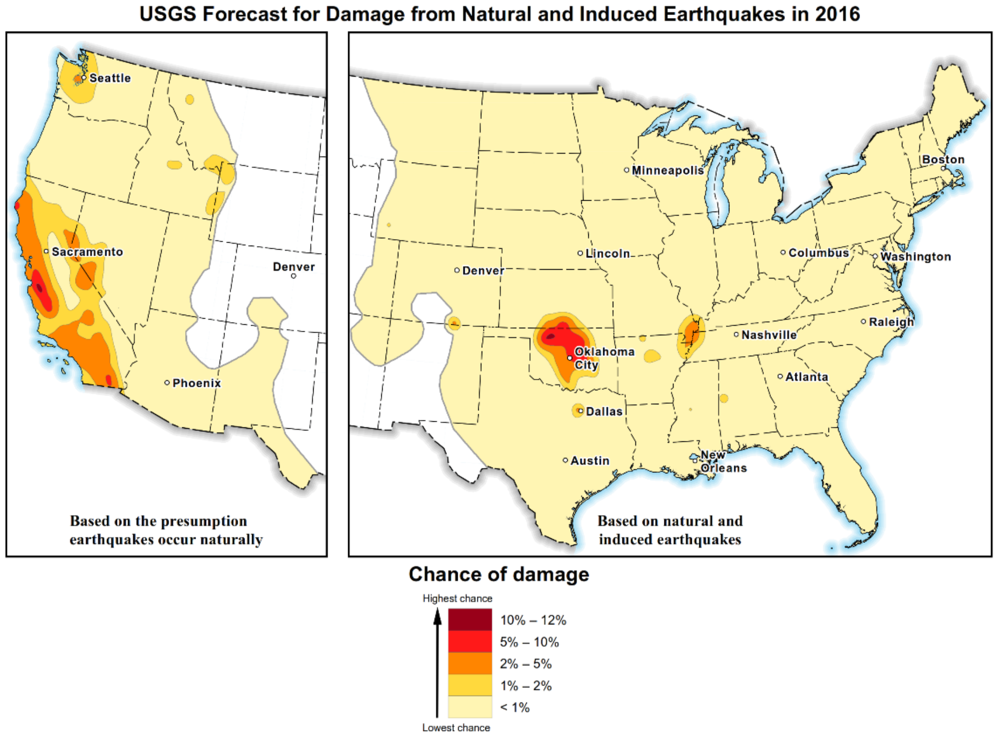


Other Chapter 1 Topics

- Development of integrated technologies i.e., “FSP” software
- Long-term and short-term USGS National Seismic Hazard Maps
- Forecasting potential induced seismicity
- Hydraulic fracturing versus Class II well injection
- Decreasing rates since 2015 in Oklahoma due to regulatory response including stopping injection at problematic wells

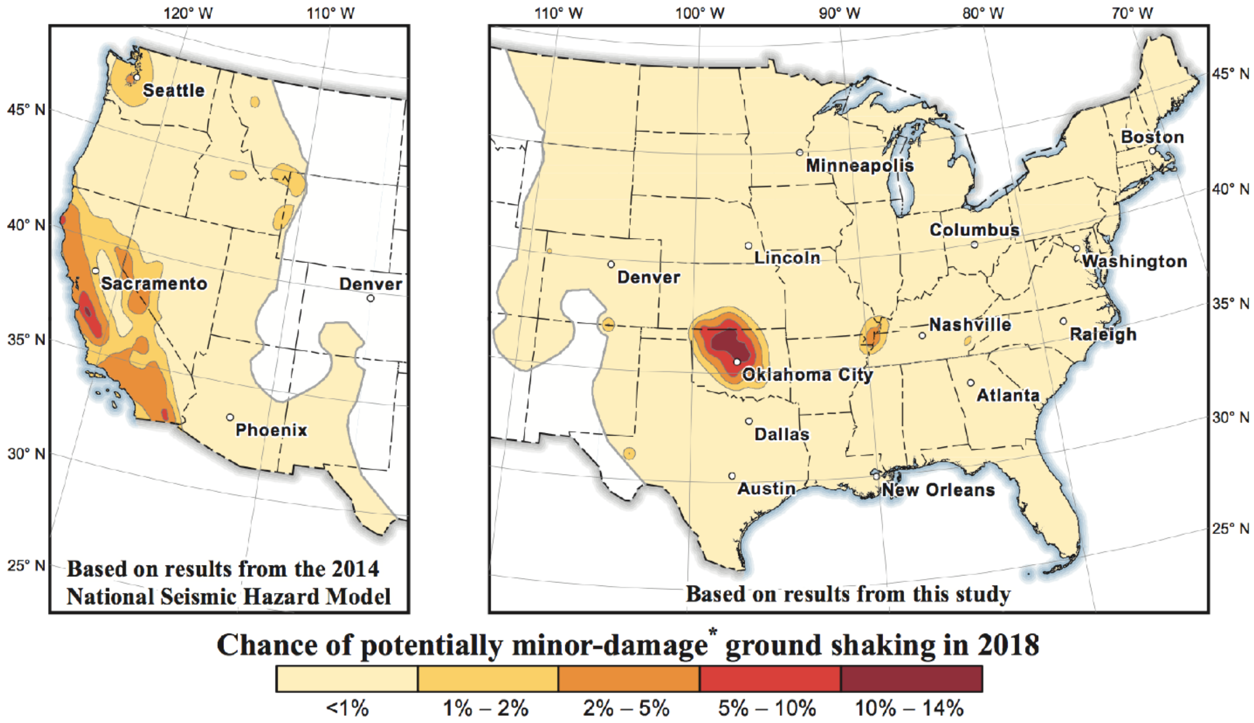
USGS Short-Term Induced Seismicity Forecast

2016 map



USGS map displaying potential to experience damage from natural or human-induced earthquakes in 2016. Chances range from less than 1 percent to 12 percent.

2018 map



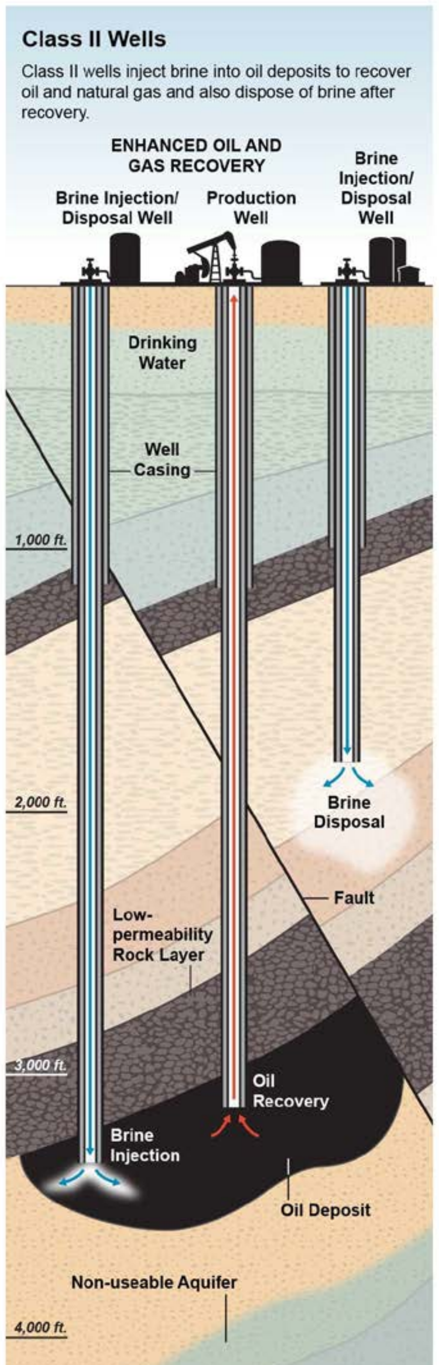
* equivalent to Modified Mercalli Intensity VI, which is defined as: "Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight."

Chapter 1
Future Research

- What new methods and techniques can be used to better identify the presence of critically-stressed faults in proximity to injection sites?
- Are ground motions of induced earthquakes different from those causes by natural earthquakes?
- Can the largest induced earthquake be estimated?
- Can we further develop induced earthquake forecasting on a regional and site-specific basis?
- Can advanced seismic waveform processing techniques be developed to offer higher sensitivity in

Chapter 2 Assessing Potential Injection – Induced Seismicity

- Assessing seismicity based on historic records and contemporary and current and ongoing seismicity
- Emphasis on national versus regional (state) versus local seismic monitoring.
- Development of seismic networks by state agencies.
- Injection well disposal zone conditions
  - Fluid data from one well, consideration of adjacent wells
  - Geologic and hydrologic data
- Evaluating causation by injection wells
- Hydraulic fracturing fluids and target zone conditions
  - Fluid data
  - Geological data
  - Geophysical data
  - Well Design
  - Completion Details
- Understanding differences between hydraulic fracturing and waste water disposal



Source: Michiganradio.org

Chapter 2 (continued)

Key Data to Understand Injection Well Disposal Zone Conditions

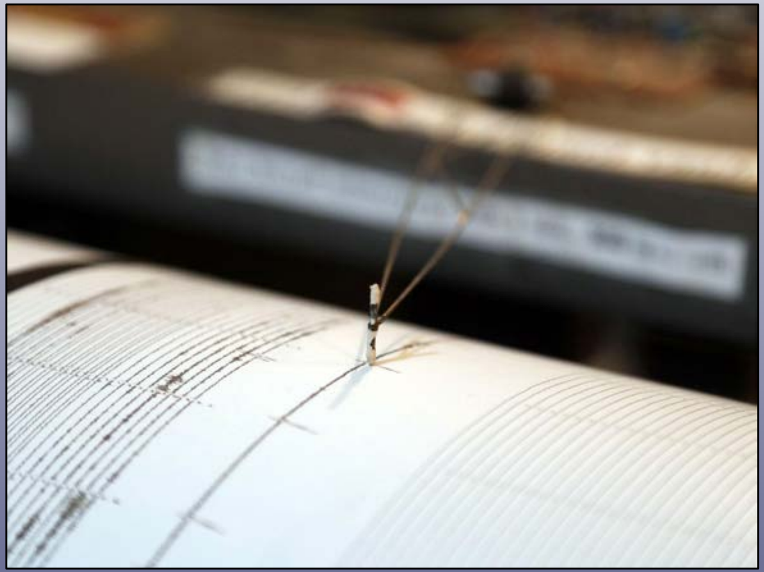
- Fluid data:
  - Volumes, rates, pressures (downhole – averaged and maximum)
  - Physical properties: fluid density and temperature, compressibility, viscosity
  - Fluid chemistry
  - In-situ fluid properties: physical and chemical, phases present (gas or liquid)
- Geological data:
  - Reservoir thickness and areal extent
  - Reservoir porosity, permeability and initial pressure
  - Mechanical properties – elasticity, ductility
  - Stratigraphy – especially presence of confining layers above and below
  - Presence and orientation of faults and fractures
  - In-situ stresses, vertically and horizontally, due to rock mass and fluids

Chapter 2 (continued)

Evaluating Causation for Injection Wells

While most injection sites do not trigger earthquakes, induced seismicity can occur under certain conditions.

- Sufficient pore pressure buildup from disposal activities
- Faults of concern
- A pathway allowing the increased pressure to communicate with the fault



Chapter 2 (continued)

Key Data to Understand Subsurface Conditions for Hydraulic Fracturing

- Fluid data:
  - Hydraulic fracturing fluid design (slickwater vs gel)
  - Fluid/slurry densities, proppant concentrations, friction reducers
  - Pumping rates, max treatment pressure, average treatment pressure
  - Total fluid by foot of perforated length, by stage, by well, by pad
- Geological data:
  - Reservoir thickness and areal extent
  - Reservoir porosity, permeability and initial pressure
  - Mechanical properties – elasticity, ductility
  - Stratigraphy – especially presence of confining layers above and below
  - Presence and orientation of faults and fractures
  - In-situ stresses, vertically and horizontally, due to rock mass and fluids
- Geophysical data:
  - 3D geophysical assessment of target formation(s) and underlying units
  - Fault mapping from geophysical outputs
  - Fault intersection characterization with target reservoir(s)

Chapter 2 (continued)

Understanding the Differences between Hydraulic Fracturing and Waste Water Disposal

- Hydraulic fracturing operations are intended to fracture the rock while injection operations are not.
- The pumping operation only lasts for a short period of time; the entire well stimulation typically lasts several days to weeks, depending on the well completion type.
- The amount of fluid pumped in a fracture completion is orders of magnitude less than in a disposal operation over time. However, high-rate fluid injection during a hydraulic fracturing stage may be several times greater than traditional disposal well rates over short periods of time (minutes to hours).
- The fluids in a fracture completion are largely stored in the fractures; and some volume of the fracturing fluids is normally recovered soon after the treatment while the remaining fluid is imbibed in the reservoir.

Chapter 2 (continued)

Understanding the Differences between Hydraulic Fracturing and Waste Water Disposal

- Fracturing is very different from injecting into a permeable disposal zone where the fluid is stored in the porous and permeable formation.
- In addition, the well will typically be produced relatively soon after the fracturing operations are completed. With flowback, the initially increased pressure associated with the hydraulic fracturing operation is relieved by the subsequent flowback. Then with longer-term production, the reservoir pressure is further reduced below original reservoir pressure due to depletion effects.
- Therefore, unlike disposal well operations, hydraulic fracturing operations followed by production operations generally results in lowering of reservoir pore pressure in proximity to the well.

Chapter 3

Risk Management and Mitigation Strategies

- The difference between hazard and a risk
- The strategies for managing and mitigating the risk of induced seismicity
- The strategies are different for Class II wells and hydraulic fracturing
- The two basic questions risk assessment from induced seismicity addresses:
  - How likely is an injection operation to pose an induced-seismicity hazard?
  - What is the risk – the probability of harm to people or property – if seismicity is induced?
- Science-based approaches to assessing and managing induced seismic risk from injection including:
  - Characterizing the site
  - Built environment
  - Estimating maximum magnitudes
  - Operational scope
  - Predicting hazards from ground motion
- Mitigation and response strategies:
  - Siting and permitting of new wells
  - Responding to an event


Source: sciencemagazinedigital.org

Risk mitigation options in siting and permitting new Class II disposal wells in areas of concern may include:

- Obtaining local stakeholder input concerning risks
- Selecting a different location for new disposal wells
- Avoiding injection into the crystalline basement or even into formations that directly overly the basement
- Locating faults in the vicinity of the proposed project area based on seismic reflection survey data or geologic mapping and placing the well outside the at-risk area where injected fluid may not significantly and adversely perturb the pore pressure/stress state
- Avoiding direct injection of fluids into optimally oriented and critically stressed faults of concern

Permits for new or existing Class II disposal wells might include some conditions, such as:

- Proactive temporary (short-term) seismic monitoring at specific sites and establishment of magnitude thresholds by incorporating baseline historic seismicity in the area
- A procedure to modify injection operations (e.g., step increases in injection rates during start up or reducing rates as needed) if a specified ground-motion/magnitude event occurs within a specified distance from the well
- An administrative order to suspend injection operations if seismicity levels increase above threshold values for minimizing a public disturbance and damage
- A mitigation plan to determine if SWD operations could be restarted and the procedure for establishing injection at safe levels

Temporary and proactive seismic monitoring

- May be considered at the sites of proposed new disposal wells in local areas where induced seismicity is of significant risk.
- A seismic monitoring requirement with specific magnitude thresholds and location accuracy may be incorporated into the permit as a mitigation plan.
- Goals of seismic monitoring may include the ability to:
- Identify any seismicity that may be attributable to injection at a site
- Indicate when any induced seismicity at a site has the potential to damage structures, be felt by the public, and/or cause serious disturbance to the public
- Use data to create appropriate site-specific actions to mitigate the risk of potential induced seismicity

Planning for and responding to an event of potentially induced seismicity

- Because the risk from induced seismicity depends on the characteristics of the disposal well locations and operations, many state regulatory agencies utilize site-specific, flexible, and adaptive response actions when an incident of seismicity occurs that may be linked to injection.
- Regulatory agencies may determine that different types of response strategies are "fit for purpose," depending on whether an event of potentially induced seismicity resulted in damage or felt levels of ground motion or was detected using seismic monitoring, with no damage or felt levels of ground motion or was detected using seismic monitoring, with no damage or felt levels of ground motion.

Response Strategy

- Generally, an initial step in developing a response strategy is to collect background and baseline information about the earthquake.
- As part of the collection of background information, all potential source or causation of seismicity should also be considered.
- Historical Tectonic Seismicity Data
- Well Data
- Geologic Data
- Local factors

Mitigation and Response Strategies for Hydraulic Fracturing

- General risk management and mitigation approaches relevant to potential injection-induced seismicity also can be applied to large volume hydraulic fracturing is extremely rare, is quickly mitigated, and when detected at the surface generally has the lowest levels of surface impact.
- Hydraulic fracturing stimulations utilize temporary injections, in contrast to longer term disposal injections such that the risk is spatially and temporarily limited to well stimulation operations.
- Therefore, evaluation and response systems should be tailored differently for hydraulic fracturing than for disposal.
- Several jurisdictions have introduced guidelines for hydraulic fracture-induced seismicity, including Ohio and Oklahoma, along with Alberta and British Columbia in western Canada.
- These guidelines often involve a traffic light system approach based on the magnitude of seismicity in the vicinity of hydraulic fracturing operations within a specific area of interest

Risk Management Systems

- Risk management systems should be designed and implemented to be responsive and mitigate potential risks independent of specific completion methodologies that are being employed.
- Whether a Traffic-Light System and/or Area of Interest are implemented as the risk mitigation approach, the approach should be implemented considering the risk exposures for the local community.
- It is desirable for the system to enable flexibility in the implementation risk mitigation elements such that protocols and procedures may be specifically tailored and adaptable for each unique situation.

Chapter 4
Considerations for External Communications

- The communication planning process, including preliminary scans, stakeholder involvement, tying communication strategies to risk, conducting mock exercises and other training
- Communication plan elements, such as scenario analysis, external and internal audience analysis, definition of key messages and communication strategies, communication team roles and responsibilities, materials and resources, and potential answers to frequently asked questions
- Guidelines for responding to an event include providing professional, clear, concise, and authoritative responses, listening, documenting, avoiding absolutions, and sharing only approved information
- Incorporating lessons learned, which includes understanding how communication takes place, documenting how decisions were made, avoiding definitive statement or promises, and improving a communications plan

Source: Medium.com

Several key aspects of communication

- Clear and direct communication with the public is an important responsibility of states that are managing the risks of induced seismicity
- Earthquakes can come with no warning and in areas that have not have previous seismicity
- Earthquakes may grow with time and activity may go on for days
- Initial official reports of locations and magnitudes can be inaccurate
- The USGS "Did You Feel It?" system and Shakemaps are good early indicators of intensity and location
- Public anxiety levels can be high and significant to deal with regardless of damage levels; and
- Determining causes of earthquakes may be difficult and jumping to conclusions should be avoided.

Based on its follow-up, the agency can improve its communication plan by considering:

- What communication strategies were effective or ineffective, and why?
- What forms of mediated communication were effective or ineffective, and why?
- What message was misunderstood, and why?
- Have stakeholder concerns changed, and if so, how?
- What worked or did not work regarding intra-agency communication and cooperation?
- What other assets can be used to improve the communication plan?

Appendix C Induced Seismicity Case Studies

- Love County, Oklahoma
- Youngstown, Ohio
- The Geysers, California
- Decatur CCS
- Greeley, Colorado
- Pawnee, Oklahoma
- Harrison County, Ohio
- Poland Township, Ohio
- Eagle Ford Shale Play, Texas
- Septimus, BC
- Tower Lake, BC
- Alberta

Appendix G State Regulatory Summaries

- Ohio
- Oklahoma
- Texas

Appendix H Carbon Dioxide Geologic Storage and Induced Seismicity

- The connection between produced water injection and induced seismicity has gained attention in recent years and similar concerns exist for CO_2 injection operations.
- Felt induced seismic events could hamper public acceptance of CCS. In a worst-case scenario, seismic fault slip could compromise the seal integrity.
- The success of CCS lies with minimizing such induced seismicity events.
- Fortunately, induced seismicity events related to geologic CO_2 storage projects to-date have been limited to small magnitude events (**M** 1.7 or less).
- Felt induced seismicity events (**M**>3) have been observed in one CO_2 Enhanced Oil Recovery (EOR) project.

Summary

- The guide discusses the potential for induced seismicity related to underground fluid injection related to oil and gas activities and identifies some strategies for evaluating and addressing the effects of such events.
- Management and mitigation of the risks associated with induced seismicity are best considered at the state level, with specific considerations at local or regional levels.
- A one-size-fits-all approach is not feasible, due to significant variability in local geology and surface conditions, including such factors as population, building conditions, infrastructure, critical facilities, and seismic monitoring capabilities
- The ISWG recognizes that the science surrounding induced seismicity is undergoing significant changes and that the guide has and will need to be updated to provide readers with the most-up-to-date information.

A Look Ahead

- Through the collaboration of regulators and the oil and gas industry, the rate of induced seismicity and significant induced earthquakes due to Class II well disposal appears to have been effective in the past few years.
- However, the scientific community are debating whether there remains a potential for future significant induced events.
- Outside the U.S., induced earthquakes such as the events in China and Korea suggest that induced seismicity is still a challenging issue.
- The Groningen gas field in the Netherlands is a good example of small magnitude induced earthquakes (< M 4) that remains a problem in areas with vulnerable buildings.
- Seismicity due to hydraulic fracturing in the U.S. and particularly in western Canada may be the next big challenge for the industry.
- We still have lots to learn about induced seismicity so we need to keep our foot on the pedal in terms of research and mitigative actions.