STATE OIL & GAS REGULATORY
EXCHANGE

Induced Seismicity Primer Update

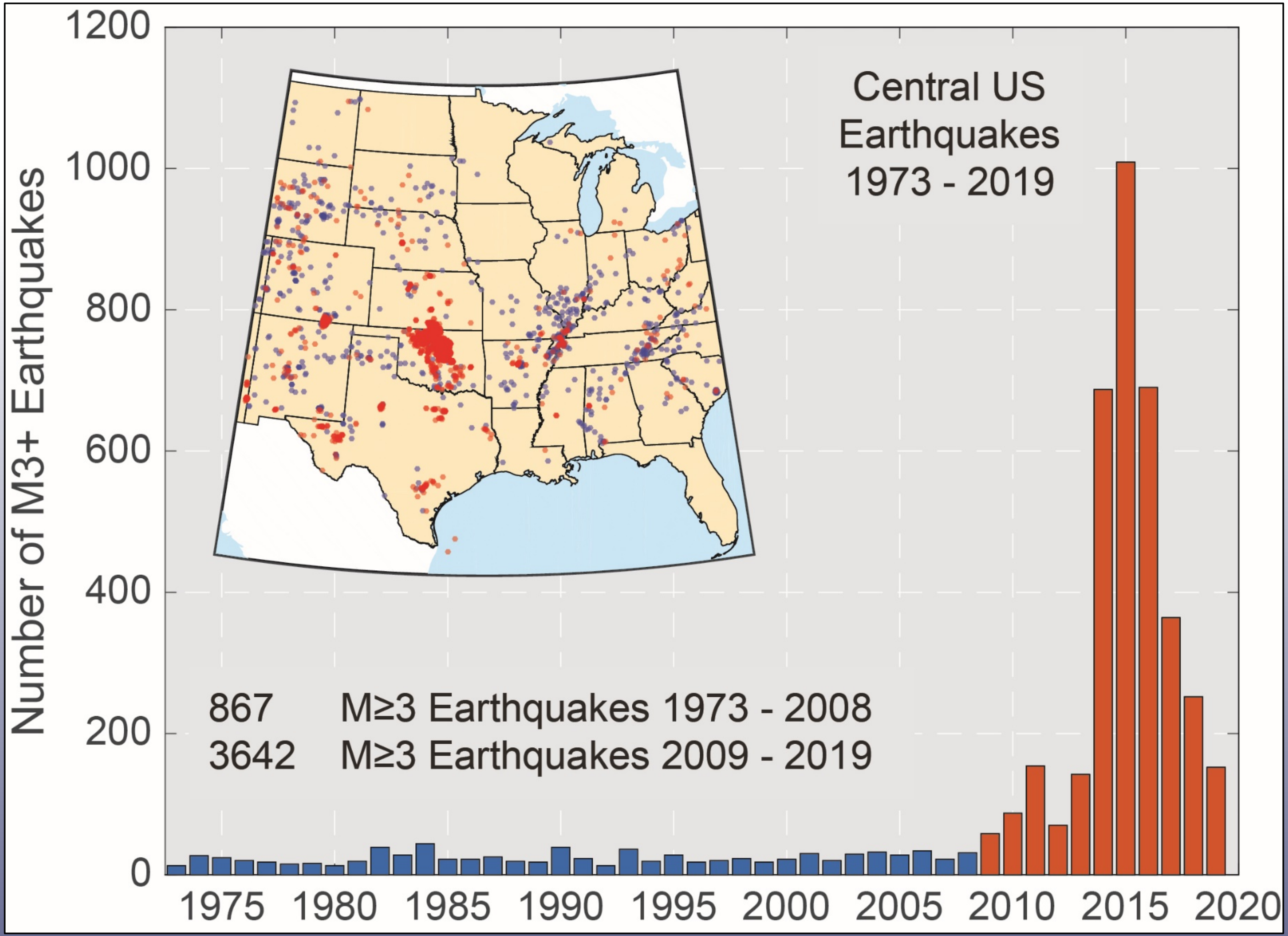
Ivan Wong

Senior Principal Seismologist
Lettis Consultants International
and
Commissioner
California Seismic Safety Commission

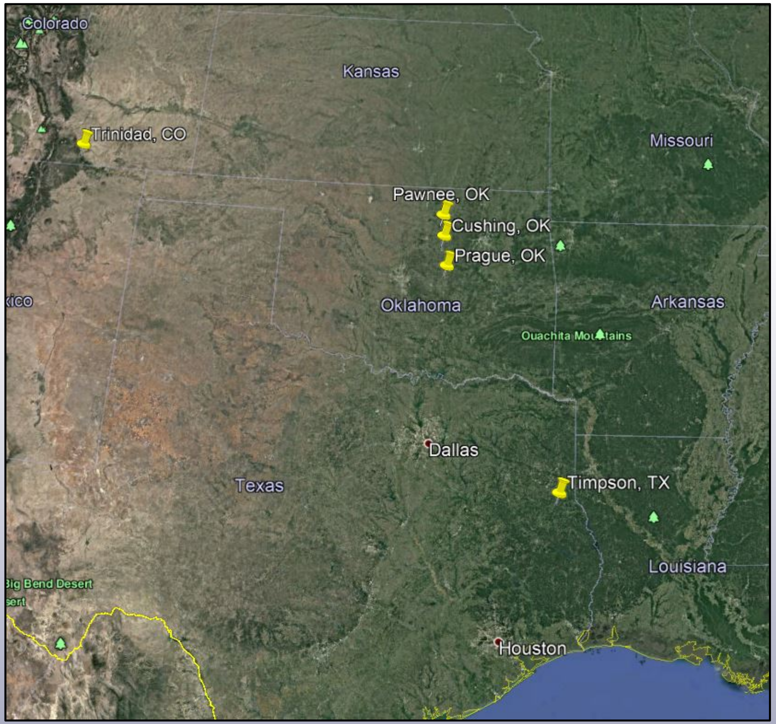
POTENTIAL INDUCED SEISMICITY GUIDE – A Resource of Technical and Regulatory Considerations Associated with Fluid Injection

- This 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
- This edition is being produced by the State Oil and Gas Regulatory Exchange, a collaboration of the IOGCC and the Ground Water Protection Council
- 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.

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

Significant Induced Earthquakes



- 2016 Pawnee, Oklahoma **M** 5.8 earthquake - damaged brickwork and cracked sheetrock at a number of structures;
- 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;
- 2016 **M** 5.0 Cushing, Oklahoma event - resulted in cracks to buildings and fallen bricks and facades on City Hall and the Lions Club; andt
- 2012 **M** 4.8 Timpson, Texas, earthquake - caused fallen chimneys and damage to masonry walls
- 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.

2011 M 5.7 Prague, Oklahoma Earthquake

2011 M 5.3 Trinidad, Colorado Earthquake

2012 M 4.8 Timpson, Texas Earthquake

Contributors – Induced Seismicity Working Group (ISWG)

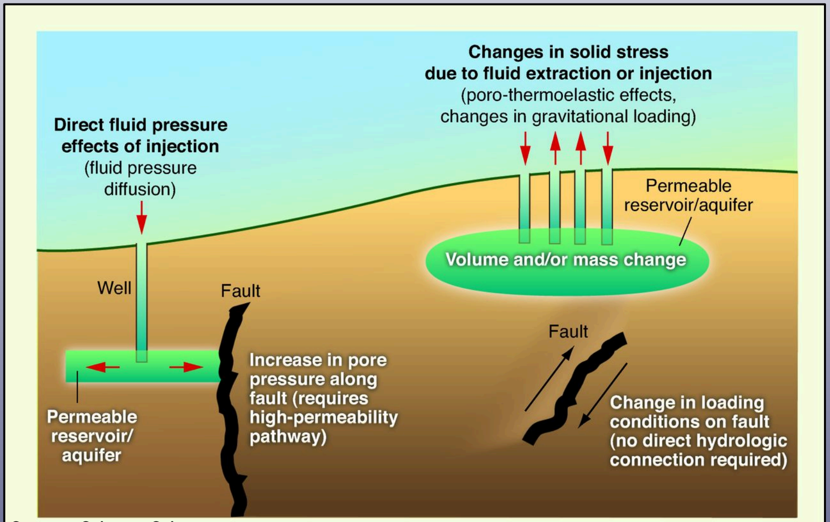
Tara Gross - GWPC
Amy Childers - 10GCC
Mike Nickolaus - GWPC
Todd Shipman - Alberta Geological Survey
Ed Steele - Ambinet
Kris Nygaard - Exxon Mobil
Kurt Hildebrandt - USEPA
Leslie Savage - Texas Railroad Commission
Tom Tomastik - ALL Consulting
Michael Young - TBEG
Cody Comiskey - Chevron
Scott Anderson - Environmental Defense Fund
Carrie Ridley - Kansas Dept Health & Environment
Jim Gonsiewski - Ohio Dept Natural Resources
Colin Brooks - Oklahoma Corporation Commission
Jake Walter - Oklahoma Geological Survey
Kurt Schrantz - Schrantz Consulting
Ivan Wong - Lettis Consultants

Purpose

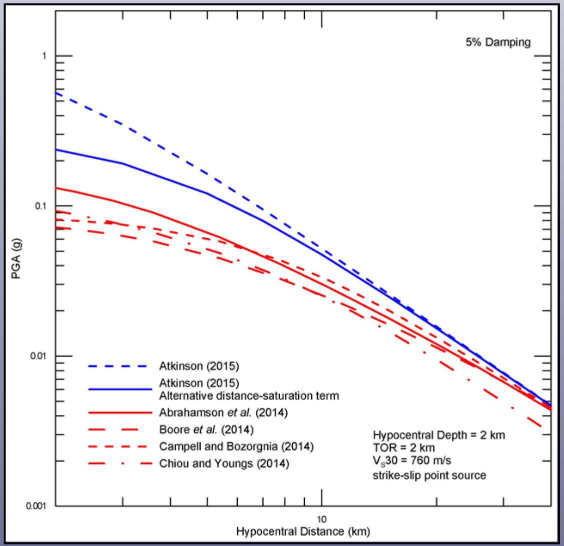
- The Guide is designed to provide state and provincial regulatory agencies with an overview of current technical and scientific information, along with considerations associated with evaluating fluid-induced seismicity, managing the associated hazard and risk, and developing response strategies.
- It 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.
- Unlike earlier versions of this Primer, 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.

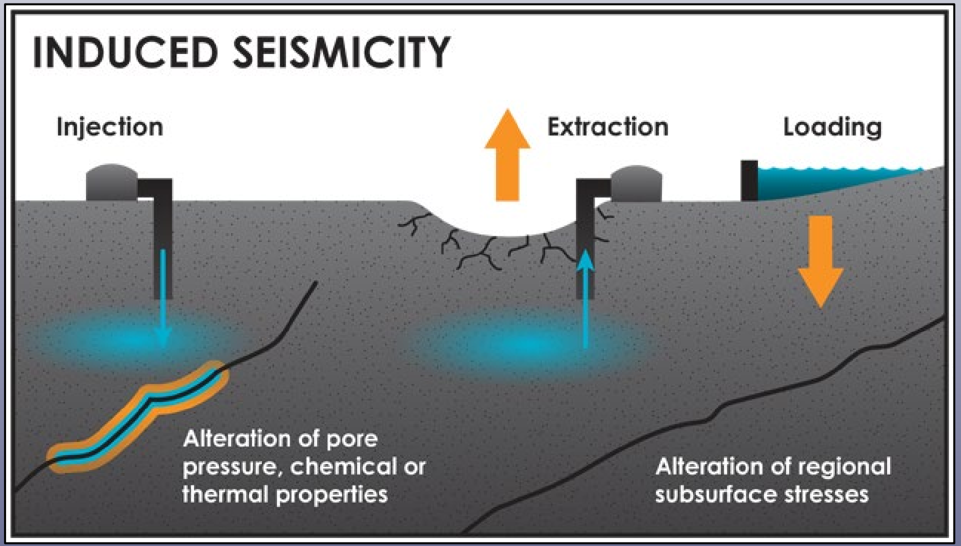
Chapter 1 Understanding Induced Seismicity

- Key concepts of earthquake science, such as magnitude, ground motion, and hazard.
- The hazards and risks related to induced seismicity and the difference between hazard and 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 pressue 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





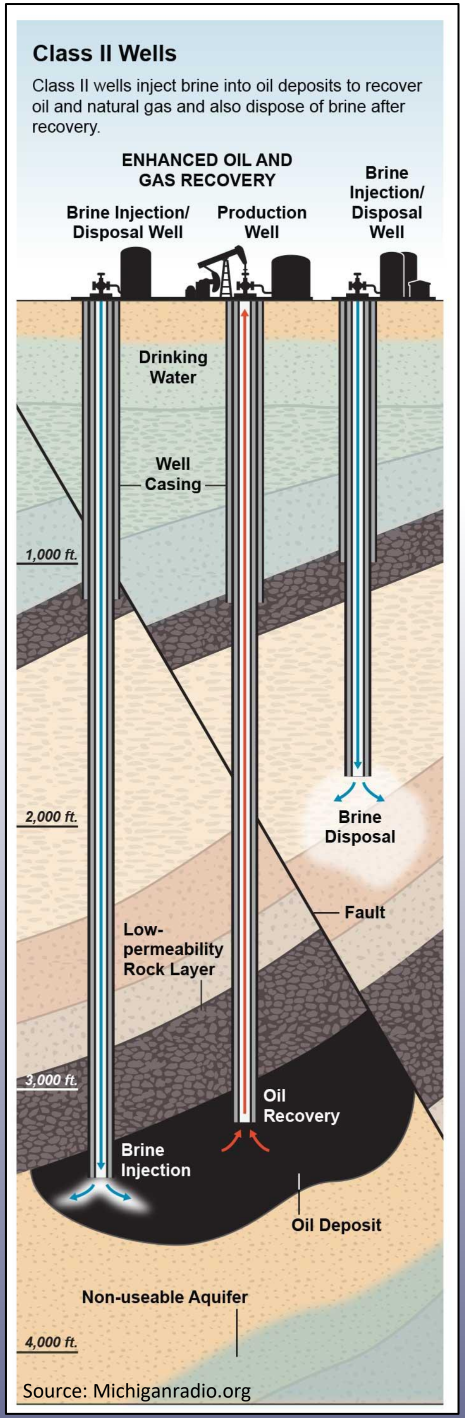
Chapter 1 (continued)

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 stress drops of injection-induced earthquakes smaller than those of natural earthquakes?
- 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
- 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
- Evaluating causation by hydraulic fracturing
  - Well Design
  - Completion Details
- Understanding differences between hydraulic fracturing and waste water disposal



Class II Wells

Class II wells inject brine into oil deposits to recover oil and natural gas and also dispose of brine after recovery.

Source: Michiganradio.org

Chapter 2 (continued)

Key Data to Understand Subsurface Conditions

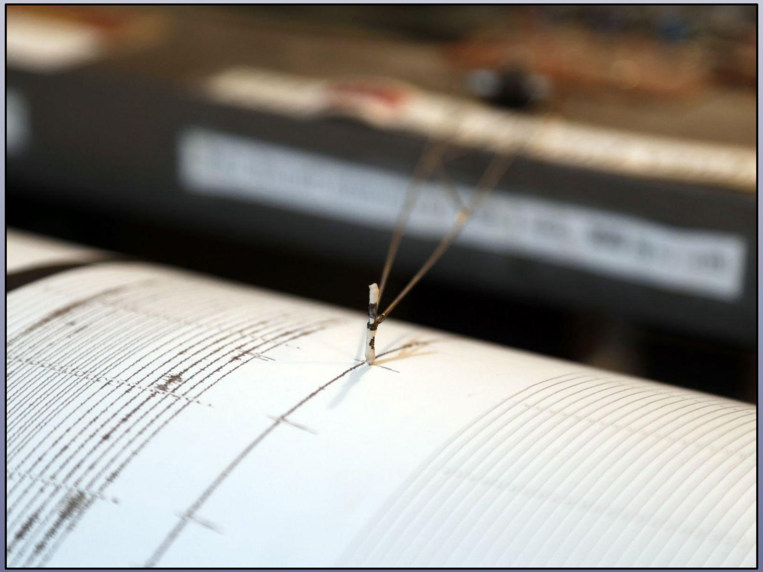
- Fluid data:
  - Volumes, rates, pressures (downhole – averaged and maximum)
  - Physical properties: fluid density and temperature, compressibility, viscosity
  - Fluid chemistry
  - In-situ fluid properties: physical and chemical, phases present (gas or liquid)
- Geological data:
  - Reservoir thickness 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 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
  - Estimating maximum magnitudes
  - Predicting hazards from ground motion
- Mitigation and response strategies:
  - Siting and permitting of new wells
  - Responding to an event

Source: sciencemagazinedigital.org

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

Appendices

- A: Relevant Earthquake Science
- B: Class I and II Injection Wells
- C: Induced Seismicity Case Studies
- D: Design and Installation of Seismic Monitoring Networks
- E: Methods for Estimating Reservoir Pressure Changes Associated with Injection
- F: Data Collection and Interpretation

Appendices (continued)

- G: State Summaries
- H: Carbon Dioxide Geologic Storage and Induced Seismicity
- I: Understanding Hydraulic Fracturing
- J: Glossary
- K: References

Appendix C Induced Seismicity Case Studies

- Love Disposal, Carter County, Oklahoma
- Youngstown, Ohio
- Geysers Geothermal, California
- Decatur CCS
- Greeley, Colorado
- TexNet
- Pawnee, Oklahoma
- Harrison County, Ohio

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.
- This, 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.