

The **Relationship of** Wastewater Injection to the Increase in Central and Eastern U.S. Seismicity



Damage from 2011 M5.6 Prague earthquake

- Matthew Weingarten, University of Colorado-Boulder
- Barbara Bekins and Andrea Llenos USGS
- Shemin Ge, University of Colorado-Boulder
- Katie Keranen, Cornell University



USGS Powell Center

- Funds data compilation and synthesis studies
- Induced seismicity study Oct. 2012-2014
- Next proposal deadline 1/31/16





<u>Working Group members:</u> Barbara Bekins, Nina Burkardt, James Dewey, Paul Earle, Bill Ellsworth, Shemin Ge, Jonathan Godt, Steve Hickman, , Austin Holland, Paul Hsieh, Ole Kaven, Andrea Llenos, Ernie Majer, Hal McCartney, Art McGarr, Evelyn Roeloffs, Justin Rubinstein, Anne Sheehan, Matt Weingarten



The rate of increase of M≥3 earthquakes is unprecedented





Ellsworth, 2013

Earthquake increase is limited to only a few areas where oil and gas production occur





Graphic design: Andrea Llenos, USGS

Underground Injection Control (UIC) Program

Begun by EPA in 1980's 6 types of liquid waste

- Class II are oil and gas >188,000 Class II wells in Central and Eastern U.S.
- Two types: Salt water disposal (SWD) net injection Enhanced oil recovery (EOR) recirculation





Rubinstein and Mahani (2015)

Parameters Hypothesized to Affect Seismicity





Operational:

Cumulative volume Injection Rate Injection Pressure Injection Depth



Geological and hydrological:

Stratigraphy Proximity to basement Faults Background stress Background pore pressure





Study Plan

- Compile injection well database for central and eastern US
- Find injection wells associated with earthquakes using spatial and temporal criteria
- Spatial
 Well within 15 km of epicenter
- Temporal

Well must be active at the time of the earthquake





Plan View

Injection Well Database

Built state-by-state from publicly available sources

188,570 total

106,070 active: 27,102 Salt water disposal



78,968 Enhanced oil recovery





Associated Injection Wells

18,757 associated ~ 10% of all wells 14,490 are active

Oklahoma Kansas Texas





High-rate injections (>300,000 barrels/ month) are much more likely to be associated with earthquakes





There is no increased likelihood of association for high cumulative injected volumes





Case study: Could high rate injection trigger the Oklahoma Jones swarm?

Swarm 2009-2012

Northeast migration of earthquakes

4 SW wells inject > 4M bbls/mo

15-20 km to SW wells 40 km to NE cluster



Science for a changing world

Why are injection rates so high in Oklahoma?

- In <u>dewatering</u> high volumes of water are pumped to lower reservoir pressures causing oil and gas to migrate from tight porosity
- Initial water:oil ratios 1000:1
- Production water:oil ratios
 30:1 Hunton
 40:1 Arbuckle
- National average 5:1











Dewatering production and disposal





700 m deeper

Hydrogeologic Conceptualization





The model pressure front tracks the onset of seismicity





Dozens of low rate wells to the northeast add pore pressure contribution of smaller magnitude





Conclusions and Recommendations

- The entire increase in recent U.S. midcontinent seismicity is associated with oil and gas production
- High injection rates (>300,000 bbl/month) increase the likelihood of earthquake association
- Cumulative injected volume does not affect the likelihood of association
- Need better access to data on permeabilities, downhole pressures, and stresses in target formations.

