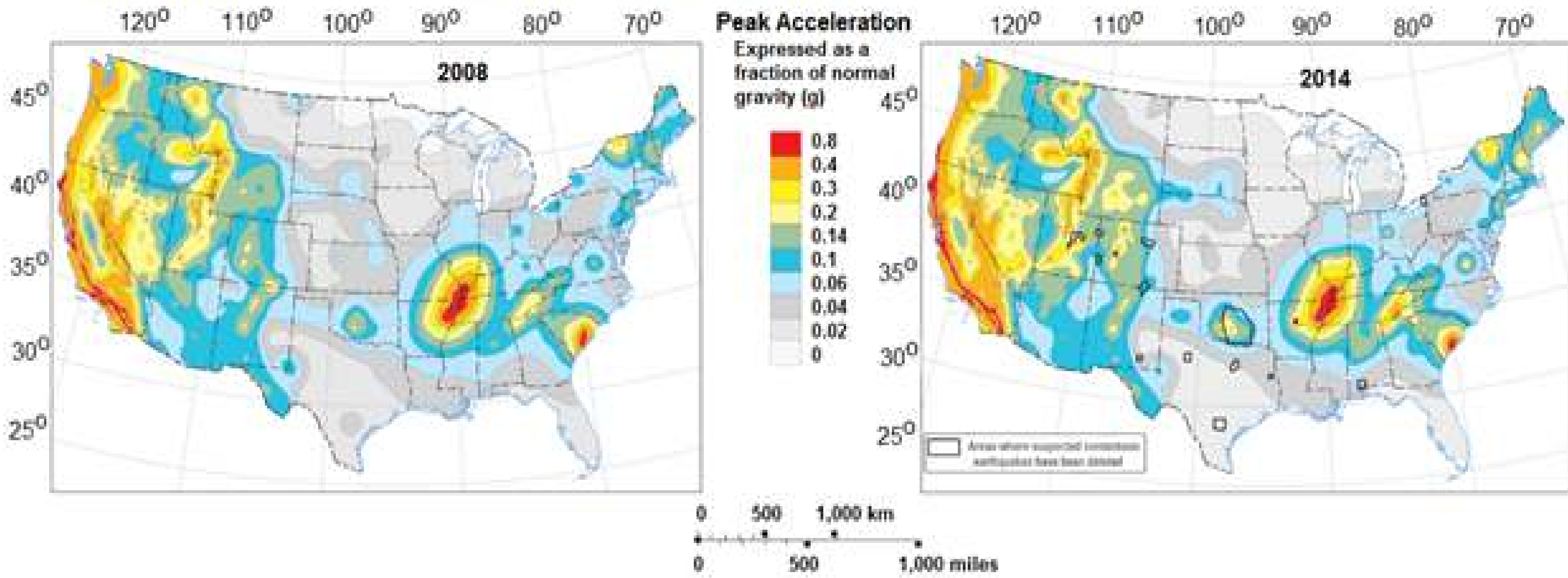
Water Disposal: Disposal Wells, Recycling and Seismic Risks

George E. King

Seismic Risk – How has it changed?

Maps showing peak ground acceleration for 2% probability of exceedance in 50 years and VS30 site condition of 760 m/sec



Reproduced from USGS Earthquake Hazards Program. 2014. Lower 48 Maps and Data. http://earthquake.usgs.gov/hazards/products/conterminous/. (accessed 29 July 2015).

Era of Construction – Technology in practice
We are Not the Past, But We Are the Future

Potential for Pollution and Risk is a Function of Technology in Practice at a Given Time

1905 vs. 2015

9 hp., 25 mph and every safety device known to man in 1905.

640 hp., 200 mph and every safety device known to man in 2015.

Pollution Potential - Changes with Time. Technology is the Driver.

Pollution Potential Changes With Time - US Oil Industry

1800's to 1920
- Cable tool Drilling
- Age of Gushers
- Inadequate or no Cement Technology
- Limited or no effective Regulation

1920 to 1940
- Rotary Drilling
- Blow Out Preventers
- Well Control
- IOGCC & effective regulations
- Logging vastly Improved

1940 to 1945
- War Years
- Steel removed from many wells
- Hard push for oil

1945 to 1960
- Fracturing starting development
- Steel pipe alloys and threads improving
- State Regulation Enforcement Improving
- Offshore Industry Started

1960 to 1980
- Cement Improvements
- Fracture Design progressing
- Unconventional resources tapped
- Offshore industry growing
- Natural gas markets created

1980 to 2000
- Multi-Frac Horizontal Wells
- Pad Well Development
- Continued cement advances
- The Fires & Oil Spills in Kuwait

2000 to Present
- Well Integrity Advances
- Chemical Toxicity Reductions
- Macondo Lessons
- Produced Water Recycling
- State laws strengthened
- Methane Leak Awareness

Earthquakes

Risk Challenges

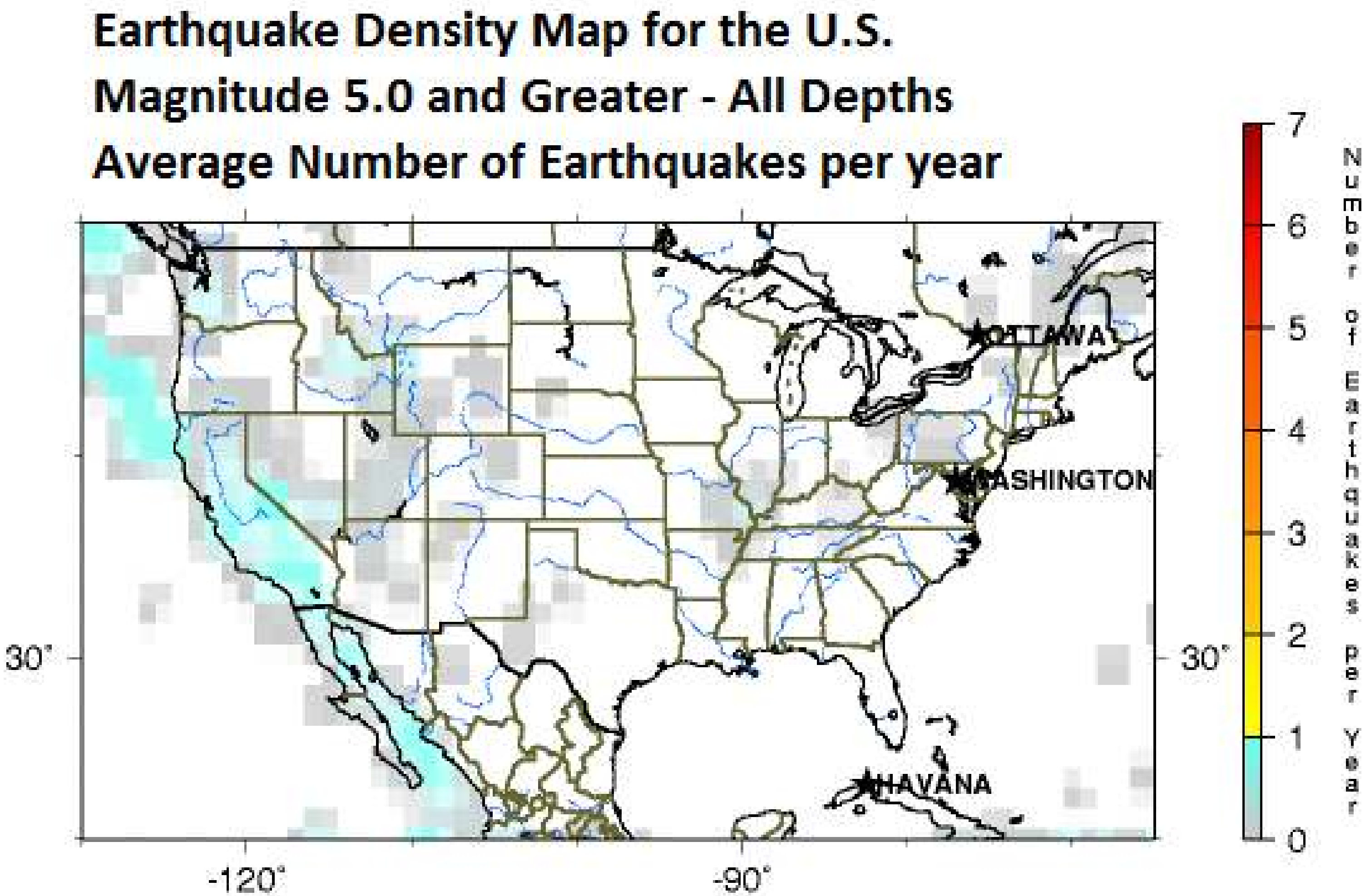
- Man-made earthquakes
  - Earthquakes associated with fracturing
  - Earthquakes associated with water injection
- Random Earthquakes

Risk Reduction

- 3-D Seismic prior to leasing
- Identification of active seismic areas & hazards
- Microseismic monitoring
- Risk mitigation decision flow-path.

Regional Variance – Very High

Earthquake Density Map



USGS

Earthquakes

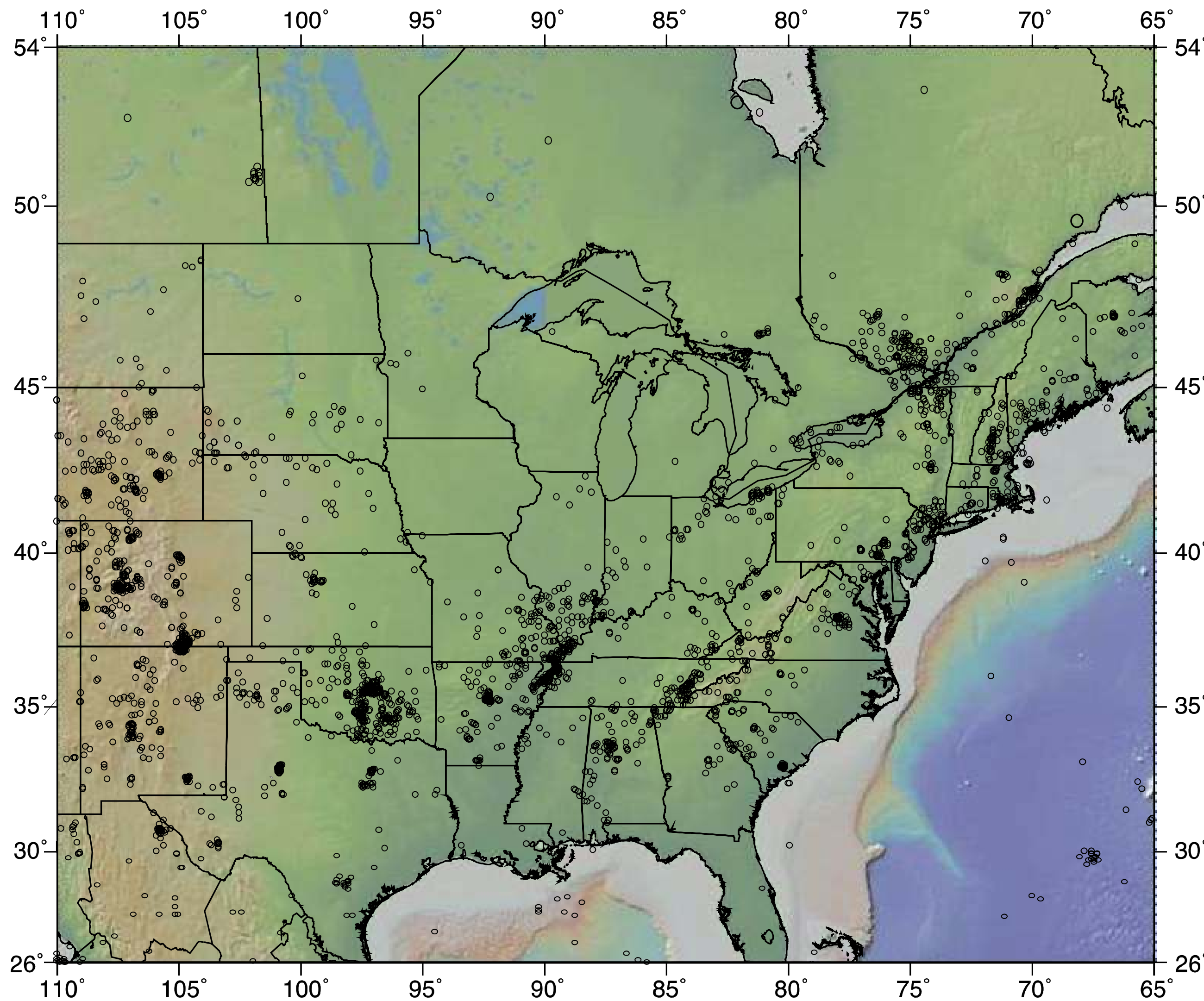
About 7 earthquakes per day are felt in the U.S. Hundreds to thousands more small quakes are common in the U.S., with earthquake swarms of 20,000 or more occurring in the span of a few months when major fault movement is triggered by plate movements.

Most of the highest magnitude quakes in these producing states predate shale developments and many predate the invention of fracturing.

To generate a major damaging producing quake (6.0 or higher), earth stresses must rip loose hundreds of miles of major faults. This is just not possible when fracturing shallow (<10,000 ft) formations.

Depths of quakes are at >2 to 7 miles beneath the surface.

State	Magnitude	Date
Alaska	9.2	1964 03 28
Arkansas	7.7	1811 12 16
California	7.9	1857 01 09
California	7.8	1906 04 18
Colorado	6.6	1882 04 18
Louisiana	4.2	1930 10 19
Montana	7.3	1959 08 18
New Mexico	7	1906 11 15
New York	5.8	1944 09 05
N. Dakota	5.5	1909 05 16
Ohio	5.4	1937 03 09
Oklahoma	5.5	2011 11 06
Pennsylvania	5.2	1998 09 25
Texas	5.8	1931 08 16
Virginia	5.9	1897 05 31
W. Virginia	4.5	1969 11 20
Wyoming	6.5	1959 08 18



110° 105° 100° 95° 90° 85° 80° 75° 70° 65°
54° 50° 45° 40° 35° 30° 26°

Risk Mitigation

- **If, <u>and only if,</u>** induced seismicity suspected
- **<u>And</u>** if surface motions exceed thresholds: amber/red traffic light
- Goal is to manage and continue operations safely

<u>Investigation - steps</u>

1. Characterize event – magnitude, location, depth
2. Assess surface effects – motion, impact (distress, damage)
3. Calibrate seismicity to operations
4. Re-visit subsurface data – faults?
5. Improve monitoring

<u>Action</u>

1. Take steps defined in Risk Management Plan ("Traffic Lights")
2. Expand data gathering, monitoring, and analysis
3. Implement outreach plan
4. As necessary modify injection parameters

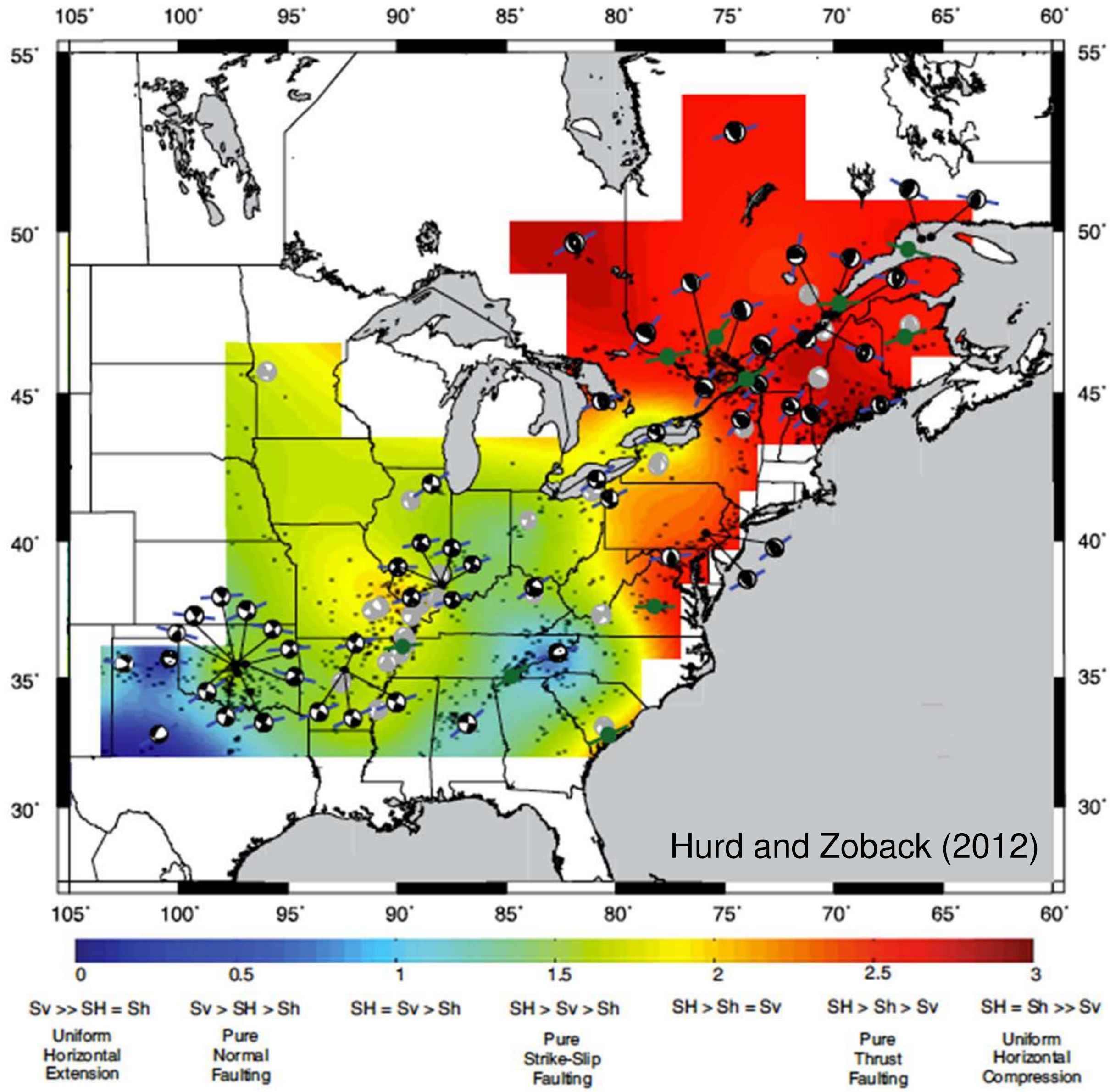
<u>Re-evaluation - steps</u>

1. Refresh evaluation – re-analyze
2. Analyze impact – ground motion studies, damage
3. Perform geomechanical and hydrologic analysis & modeling
    - Fault, stress, connection route of fluids
    - Pore pressure analysis
4. Explore all possible causes – e.g. geothermal, meteorological, production, volcanic
5. Catalog findings to inform mitigation actions

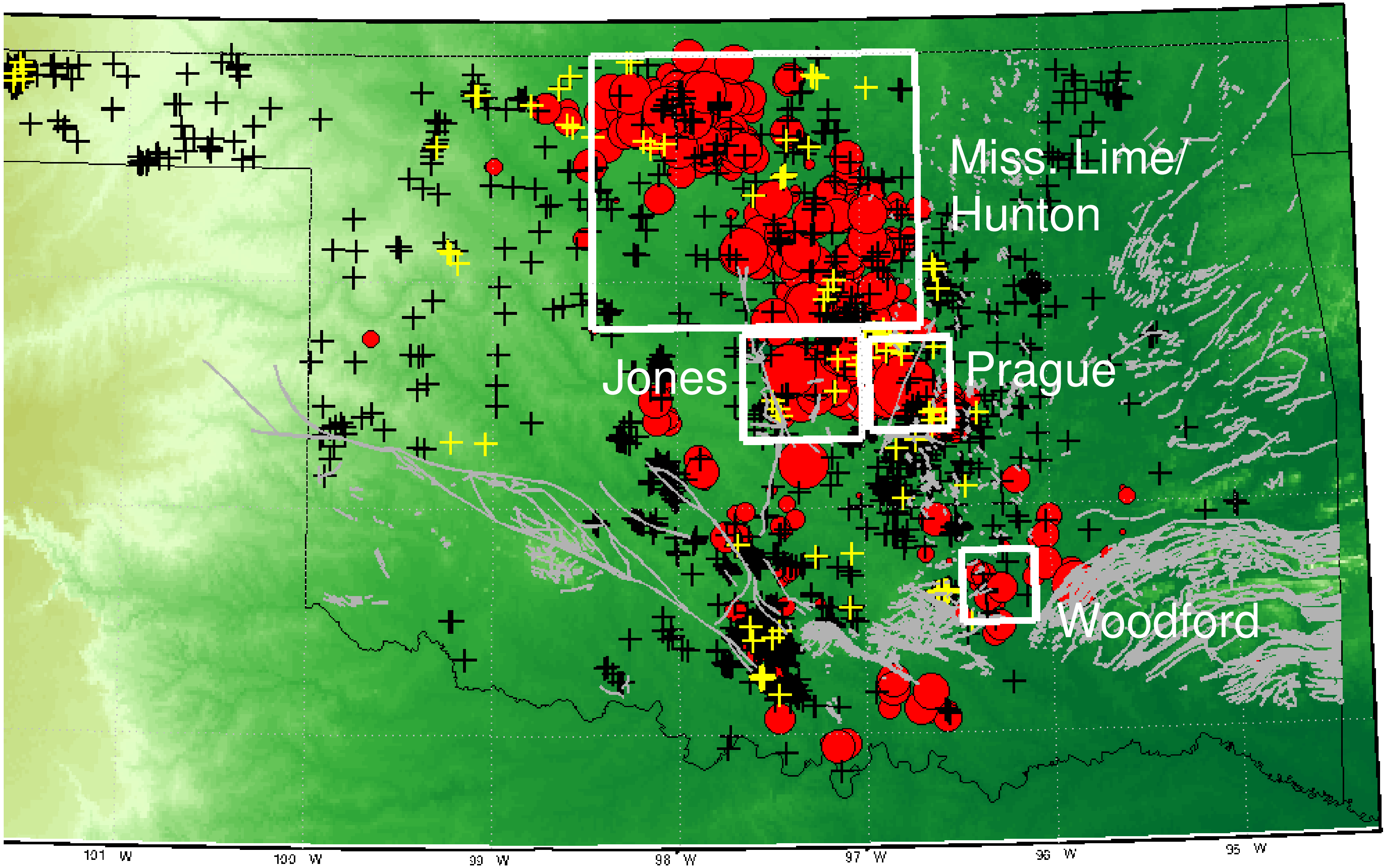
As necessary, utilize evaluation tool boxes

AXPC / Industry induced seismicity SME presentation

Intraplate Seismicity and In Situ Stress

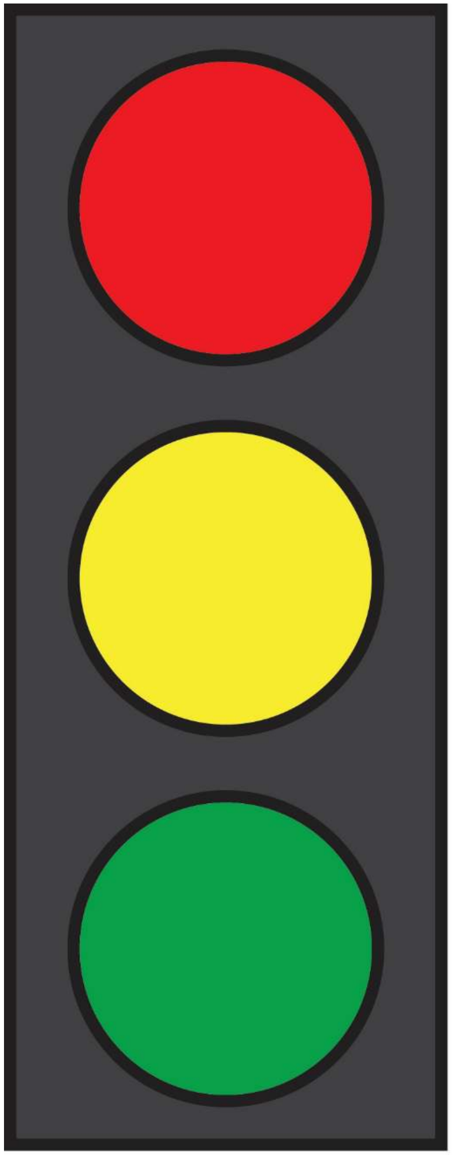


Study Areas



Miss. Lime/
Hunton
Jones
Prague
Woodford
101 W
100 W
99 W
98 W
97 W
96 W
95 W

Responding to Unexpected Events



Observations:
- Unacceptable levels of ground motions and/or magnitudes
- Events define a fault capable of producing a potentially damaging earthquake
- Microseismic events migrate into basement rock

Actions:
- Limit injection and consider well abandonment
- Continue earthquake monitoring and analysis
- Report observations and actions to area regulators and neighboring operators

Wastewater Injection

Observations:
- Unexpected event are occurring (you know the rest)

Possible Actions:
- Increase real-time earthquake monitoring and analysis
- Decrease injection rates and volume

Observations:
- No seismic events detected

Actions:
- Operations and monitoring continue as planned

Hydraulic Fracturing

Observations:
- Events have larger magnitudes than expected
- Events occur further from injection location and migrate more quickly than expected

Possible Actions:
- Avoid pre-existing faults during fracture stages
- Increase real-time earthquake monitoring and analysis
- Utilize 3D seismic data

Observations:
- No anomolous seismic events detected

Actions:
- Operations and monitoring continue as planned

Seismic Event Magnitude / Intensity / Damage Comparison (Data Source USGS)	
Magnitude	Event description
-0.3 to -0.1	[Typical Range of Hydraulic Fracturing event – not felt at surface, measurable only with sensitive instruments close to the fracture growth area. Similar energy release to dropping a jug of water on the kitchen floor – this quote added by the author]
1.0 to 3.0	Not felt except by a very few under especially favorable conditions.
3.0 to 3.9	Felt by many. Vibration similar to passing of a heavy truck.
4.0 to 4.9	Generally felt – Dishes and windows broken. Unstable objects overturned.
5.0 to 5.9	Felt by all. Brick veneer damage. Damage to poorly build buildings and chimneys
6.0 to 6.9	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
7.0 and higher	Major earthquake. Widespread damage. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations.