A new short-term forecast of earthquake hazard in the Central and Eastern U.S.

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Speaking of Science

7 million Americans at risk of man-made earthquakes, USGS says
2014 USGS Map of Earthquake Hazard in the Conterminous U.S.

National Seismic Hazard Model and Maps

- probabilities of damaging ground motion
- designed to provide stable long-term estimates (50 yr. or more)
- basis for seismic provisions of building codes
- updated every six years
Earthquakes in unexpected places...
Earthquake Counts, $M \geq 2.7$
Oklahoma vs. California

Number of M3+ Earthquakes in CA and OK

- Oklahoma
- California

Number of M3+ Earthquakes over time from 1990 to 2015.
Not fracking, primarily wastewater disposal

mostly “Produced Water” — not spent frack fluid
2014 USGS Map of Earthquake Hazard in the Conterminous U.S.

Ten-percent probability of exceedance in 50 years map of peak ground acceleration
Locations of oil and gas plays and sedimentary basins in relation to wells that have been associated with induced seismicity. Black text identifies zones of induced seismicity that had magnitude (M) 2.7 and greater earthquake activity in years 2014–2015, gray text identifies zones that did not have M2.7 and greater earthquake activity in years 2014–2015, and red text identifies unresolved zones.
New Publication: One-Year Seismic Hazard Forecast for the Central and Eastern U.S. from Induced & Natural Earthquakes

KEY POINTS:

• The USGS has produced a 1-year earthquake hazard forecast for 2016 for the Central and Eastern United States that includes contributions from both induced and natural earthquakes. The model assumes that earthquake rates calculated will remain relatively stationary and can be used to forecast earthquake hazard and damage intensity for the year 2016.

• Near some areas of active induced earthquakes, hazard is higher than in the 2014 USGS National Seismic Hazard Model by more than a factor of 3; the 2014 NHSM did not consider induced quakes.

• In some areas, previously observed induced earthquakes have stopped, so the seismic hazard reverts back to the 2014 NSHM. Increased seismic activity, whether defined as induced or natural, produces high hazard.

• Some places in Oklahoma, Kansas, Colorado, New Mexico, Texas, and Arkansas may experience damage if the induced seismicity continues unabated.

• The chance of having damaging earthquake shaking is 5–12 percent per year in north-central Oklahoma and southern Kansas, similar to the chance of damage caused by natural earthquakes at sites in parts of California.

• This assessment is the first step in developing short-term earthquake forecasts for any area, as the analysis could be revised with various seismicity and model parameters.
### Probabilistic Analysis

#### Level 1. Catalog, Fault Sources, and Area Sources
Declustered catalog with b-value equal to 1 and a minimum of adjusted moment magnitude 2.7; Central and Eastern United States faults and area sources are from the 2014 National Seismic Hazard Model Peterson and others, 2014.

#### Level 2. Classification of Earthquakes
- **Informed Model:**
  - The zones of induced seismicity have special treatment for Mmax and GMMs.
  - Rate Model (levels 2 through 5)
    - 1-year (0.8)
    - 2-year (0.2)

- **Adaptive Model:**
  - Earthquakes are treated uniformly inside and outside of the zones; the maximum earthquake rate is used.
  - Rate Model (levels 2 through 5)
    - 1-year
    - 2-year (see level 4 for weight)
    - 36-year
    - NSHM time frame (variable lengths)
    - NSHM treatment (variable lengths)
    - max value gets full weight (1.0)

#### Level 3. Catalog Duration
- 10-km fixed (0.5)
- 20-km fixed (0.5)

#### Level 4. Smoothing Distance
- 10-km fixed (0.5)
- 20-km fixed (0.5)
- 50-km fixed (0.5)
- NSHM treatment (variable lengths)

#### Level 5. Maximum Magnitude (Mmax)
- M6 (0.9)
- M7.1 with distribution (0.1)

#### Level 6. Ground Motion Model (GMM)
- Atkinson (2015) (0.25)
- 2014 NSHM 8 CEUS GMMs (0.75)
- 2014 NSHM 8 CEUS GMMs (1.0)
- 2014 NSHM 8 CEUS GMMs (1.0)
- 2-km hypo depth (0.5)
- 5-km (0.5)
- 5-km (1.0)
- 5-km (1.0)
Comparison of 1-year model with 2014 National Seismic Hazard Map

MAP 1

Final model

MAP 2

2014 NSHM

PGA expressed as a fraction of standard gravity (g) for 1% probability of exceedance in 1 year

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Comparison of Adaptive and Informed Models

Adaptive model (map 1)

Informed model (map 2)

PGA expressed as a fraction of standard gravity (g) for 1% probability of exceedance in 1 year

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Comparison of Damage Probabilities

Based on results from the 2014 National Seismic Hazard Model

Based on results from this study

Chance of damage from an earthquake in 2016

- <1%
- 1% – 2%
- 2% – 5%
- 5% – 10%
- 10% – 12%
Summary Points

• Recent high rates of seismicity in the CEUS have significantly increased earthquake hazard and risk in a few areas.

• USGS identified 21 areas in several states with higher seismicity in recent years, most of which are suspected induced seismicity due to oil and gas activities.

• Near some areas of active induced earthquakes, hazard is higher than in the 2014 USGS National Seismic Hazard Model by more than a factor of 3, notably in Central Oklahoma and Southern Kansas.

• Whether the recent earthquake swarms are assessed as induced or not does not greatly affect the hazard calculations.
DFW Earthquake Scenarios (FEMA-USGS)

The impact of a 5.6 magnitude earthquake
Likely injuries and a possibility of fatalities. Some 80,000 buildings with at least slight damage. Another 700 with more serious damage.
- Moderate
- Strong
- Very strong
• 1 dot = $10,000,000

Denton $422 million
Collin $480 million
Tarrant $1 billion
Dallas $9.6 billion
All others $46 million

The impact of a 4.8 magnitude earthquake
A small possibility for minor injuries. Some 2,600 buildings would see slight damage. Another 170 would see at least moderate damage.
- Moderate
- Strong
- Very strong
• 1 dot = $10,000,000

Total loss (including contents)
Denton $37 million
Collin $44 million
Tarrant $104 million
Dallas $2.3 billion
All others $2 million

SOURCES: FEMA, ESRI

The Dallas Morning News
From Hazard to Risk: Earthquakes at Cushing, Ok.

- 10% of the nation’s crude oil storage
- Pipeline crossroads of the Central U.S.
- Terminus of the Keystone XL pipeline
Risk Communication:
Example of Cushing, Oklahoma

McNamara et al, 2016

Explanation
Earthquakes
Magnitude Range
- 0.9 - 4.6

Injection Wells

Stations

Wilzetta-Whitetail Fault Zone

Coulomb Stress Change
- 1 bar
- 0.1 bar

Oklahoma
Texas