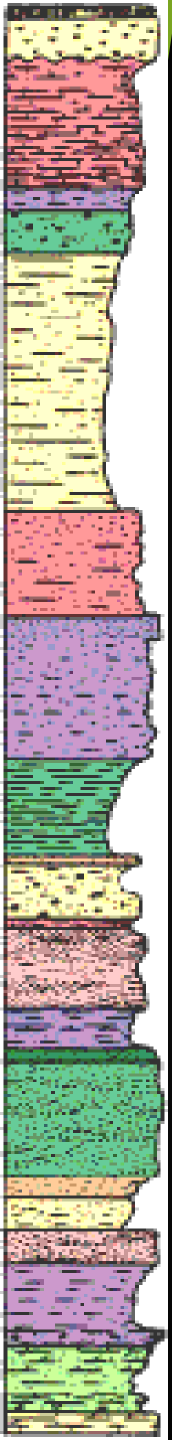

RECENT DEVELOPMENTS AND OPPORTUNITIES FOR RE-USE OF PRODUCED WATER

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Co-Authors and Acknowledgements

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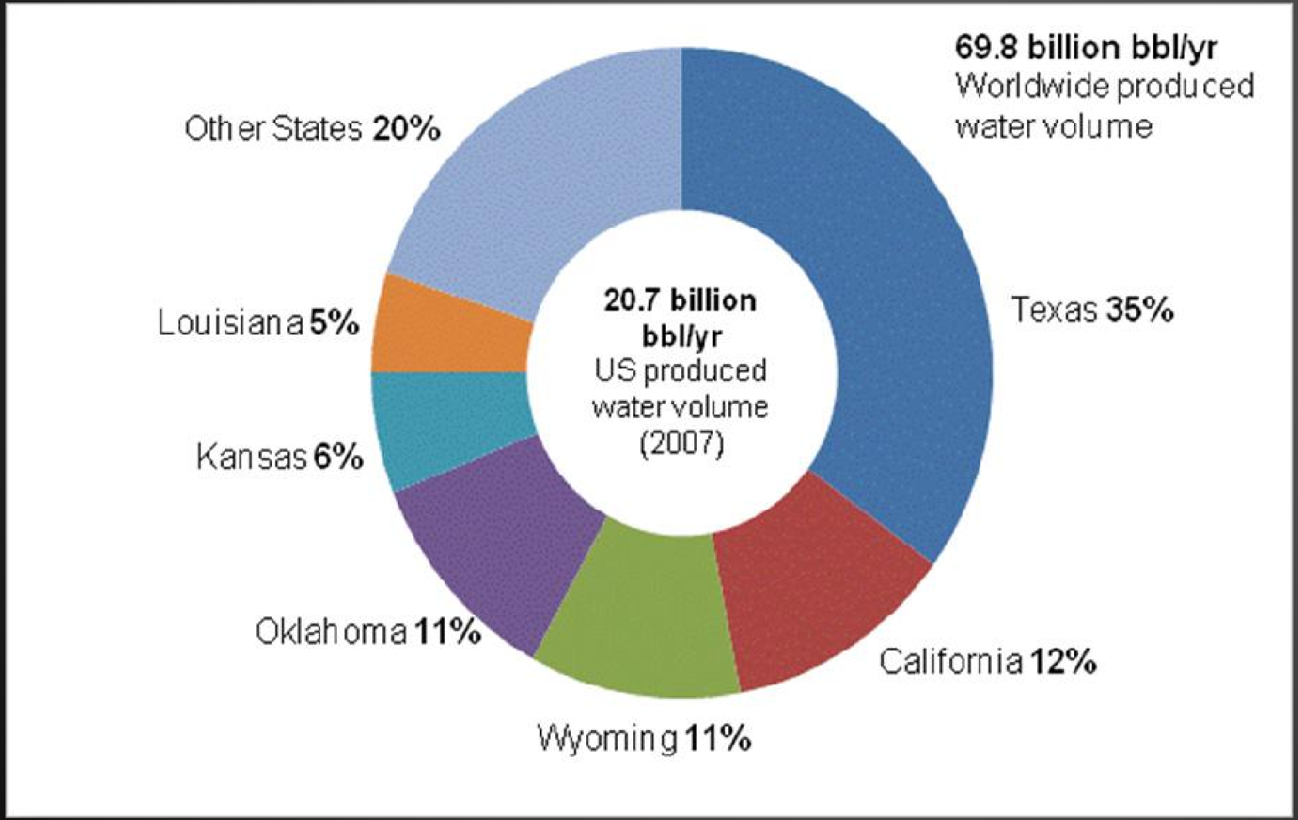
Produced Water is a New Source of Water Depending on Locale

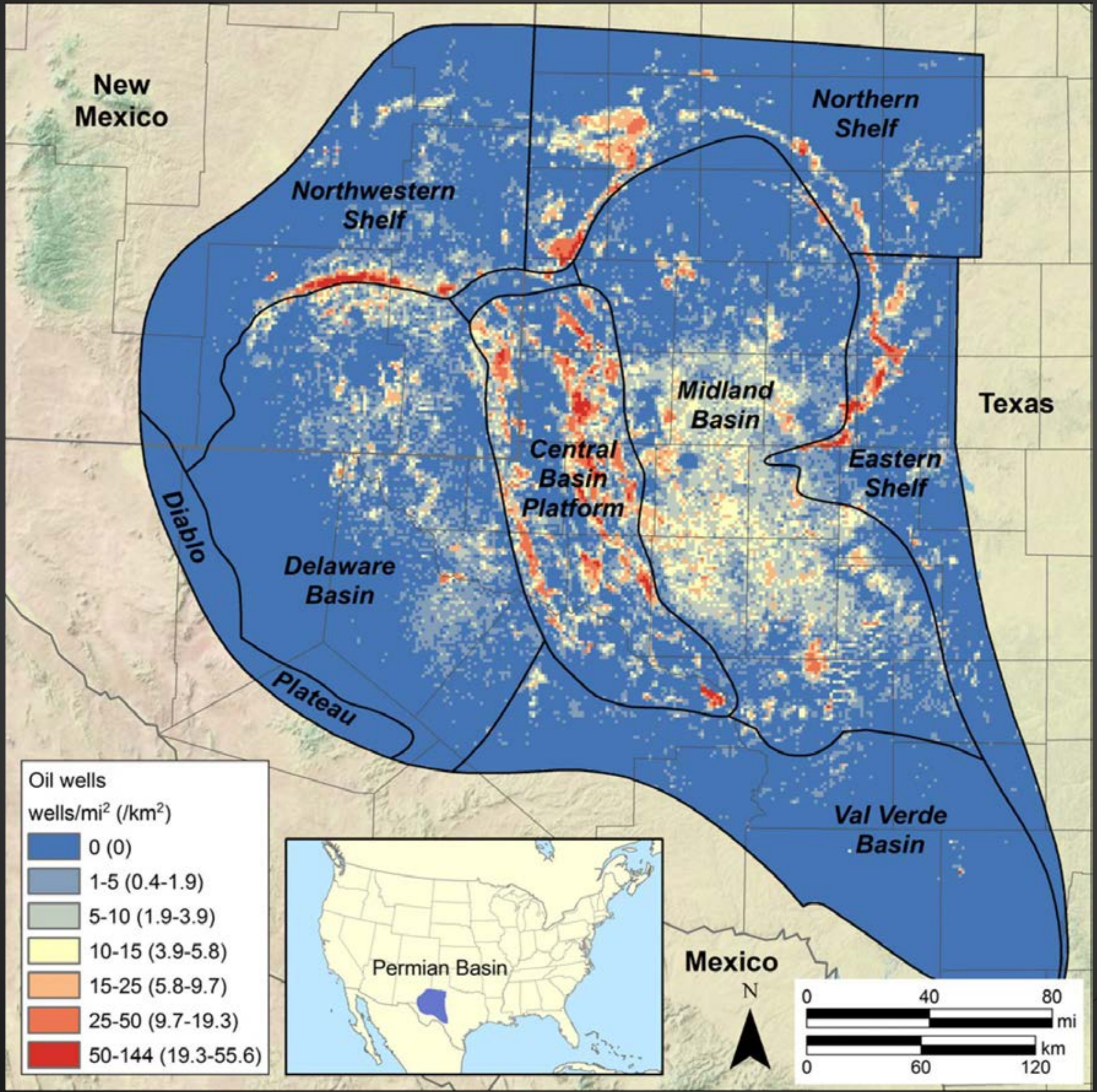


Several States and Regions Have Produced Water Reuse Initiatives That Have Borne Fruit

Pennsylvania Case Study

- Pennsylvania continues to set the pace for recycling produced water for fracking in the Marcellus shale versus other states in the play, with
- More than 60% of the 25 million barrels produced are being stored and treated for multiple applications.
- At the close of 2016, reported wastewater production from Pennsylvania's 6,538 permitted wells declined 54% to 11.8 million barrels from a historical high of 25 million barrels in the second half of 2014.
- Data based on information for over 6,500 horizontal wells

Texas BEG Study



Produced Water Re-Use: Technological Developments Help Sustain Shale Oil & Gas Well Drilling & Production Increases

- Overview of Opportunities
- Factors Affecting Water Reuse
- Generation of Produced Water by Play
- Produced Water Chemistry Issues
- Produced Water Management Options
  - Direct Filtration and Reuse
  - Deep Well Disposal
  - Advanced Treatment for Reuse
- Experience with Water Reuse/Recycling
- Criticisms of Shale Gas Water Use
- Conclusions

Water Use: Hydro-fracturing and Shale Well Production

- Barnet Shale:
  - 4 Million Gallons per Well
- Haynesville Shale:
  - 5.6 Million Gallons per Well
- Eagle Ford Shale:
  - 6.1 Million Gallons per Well
- Fayetteville Shale:
  - 4.9 Million Gallons per Well
- Marcellus Shale:
  - 5.6 Million Gallons per Well

Texas BEG Study

- The average volume of water needed to frac a new horizontal well has increased by about 10 times during the past decade from 2005-2014
  - with a median value of 250,000 barrels or 10 million gallons of water used per well in the Midland Basin in 2015.
  - Unconventional wells produce much less water than conventional wells do
    - Unconventional wells average about 3 barrels of water per barrel of oil
    - Conventional wells average about 13 barrels of water per barrel of oil produced

Produced Water

- Produced Water is water that is returned to the surface through a well borehole
- Made up of water injected during fracture stimulation process as well as natural formation water
- Typically is produced for the lifespan of a well (quantities vary significantly)
- Produced water is chemically analyzed prior to reuse / recycling or disposal
  - Analyzed for hydrocarbons, metals, and naturally occurring elements
- Water quality varies:
    - "Brackish" (5,000 to 35,000 ppm TDS)
    - "Saline" (35,000 to 50,000 ppm TDS)
    - "Brine" (50,000 to 150,000+ ppm TDS)

Produced Water vs. Slick Water Volumes

- Feasibility of Produced Water Reuse is dependent on 3 factors:
  - quantity, duration, and quality
- Produced Water Generation by Shale Play Varies Widely:
  - Initial Produced Water vs. Quantities and Rates of Water Production and Demand
- Important for Reuse: Need large volume of water over short time period
  - "Initial" defined here as first 10 days of Flowback and Production Process
- Barnett, Fayetteville, and Marcellus Shales
  - 500,000 to 600,000 gallons per well in first 10 days
  - ~ 10% to 15% of total water needed to frac a new well
- Haynesville Shale
  - 250,000 gallons per well in first 10 days
  - ~ 5% of total water needed to frac a new well

Produced Water Production Rates Vary

- High "Long Term" Produced Water Generating Play (> 1,000 Gallons Per MMCF)
  - Barnett Shale: Formation characteristics result in high produced water generation
  - Higher volumes of natural formation water present in / near shale

- Moderate "Long Term" Produced Water Generating Plays (200 – 1,000 Gallons Per MMCF)
  - Eagle Ford Shale, Haynesville Shale, Fayetteville Shale
  - Less fluid production per MMCF; Relatively desiccated formations (dry)

- Low "Long Term" Produced Water Generating Play (< 200 Gallons Per MMCF)
  - Marcellus Shale
  - Higher water production in South (West Virginia), lower in North (Pennsylvania)
  - Shale formation characteristics tend to "trap" fluids; Highly desiccated formations (very dry)
  - Capillary pressure difference "binds" water to formation (known as imbibition)

Chemistry/Treatment of Produced Water

- Dissolved Parameters : Blending for Reuse
  - Chlorides and Total Dissolved Solids (TDS)
  - Generally not looking at removal, determines freshwater blending ratios
  - Very high TDS increases friction in hydraulic fracturing process (bad)
  - Counter: Freshwater can damage a formation
- Suspended Parameters : Filtering Prior to Reuse
  - Turbidity and Total Suspended Solids (TSS)
  - Can determine filtration rates, size of filter, performance
  - High solids can plug well and decrease biocide effectiveness
- Other Parameters of Concern
  - Water “hardness” compounds (e.g. Calcium and Magnesium)
  - Sulfates can be used by bacteria to create hydrogen sulfide
  - Barium can combine with sulfates to create scale
  - High iron can drop out creating emulsions and plugging
  - Bacteria is always a concern

Comparison of Two Plays

- Barnett Shale
  - Significant increase over time in TDS (50,000 140,000 ppm) and Chlorides (25,000 - 80,000 ppm);
  - Initial produced water is relatively low in TDS and Chlorides
  - Relatively low TSS, no problem for filtration
  - Iron values are relatively low compared to other plays, but still pose concern
- Fayetteville Shale
  - “Good Quality Water” on both initial and long-term:
  - Very low Chlorides (~ 10,000 ppm), low TDS (~15,000 ppm)
  - Lower scaling tendency (low Calcium, low Magnesium)
  - Excellent potential for reuse of both initial and long term produced water

Comparison of Plays

- Haynesville Shale
  - Immediately after frac, very poor quality water
  - High TDS, high Chlorides, high TSS (~350 ppm)
  - High scaling tendency:
    - high calcium (~8,000 ppm) and
    - high magnesium (~500 ppm)
  - Relatively unattractive reuse potential
- Oklahoma proximate fields
- Mississippi Lime produces high volumes of water relative to the oil production.
  - Highest salinity of the producing areas in OK
  - The Granite Wash and Tonkawa areas produce less water and the water has a lower salinity.
  - The STACK and SCOOP areas are relatively new developments that have the most current exploration and production activity and have the highest potential for future development.
  - Can transfer water from Mississippi Lime to New areas

Example Filtration Process for Reuse

- Filtration Process:
  - Produced water during “ flowback” process collected and stored in holding tanks onsite.
  - Produced water pumped from tanks through a 100-micron filter followed by a 20-micron filter
  - Filter is designed to remove suspended solids in fluid (not salts) .
  - Filtered fluid is pumped into a clean storage tank and transported to next well to be hydraulically fractured
  - Filters and solids collected are disposed of by a licensed contractor and sent to an approved landfill
- Reuse Process:
  - Prior to use in frac, the water is tested for remaining constituents
    - (TDS/Salts, Scaling Compounds) that were not removed in filtration process
    - Test results determine blending ratios
  - Robust scale inhibition and bacteria elimination programs implemented which require substantial management and testing prior to frac
  - Fresh or brackish “make-up” water is blended in to meet quality and quantity requirements

Advanced Technologies: Thermal Distillation

- Thermal Distillation
  - Ability to treat produced water and recapture distilled water
  - Beneficial in times of drought or in arid areas
  - Very energy intensive (and costly)
  - Most distillation systems are designed for treatment of large volumes of water
  - Centralized treatment facilities
  - Long transportation distances
  - In Use in West Texas

Advanced Technology; Reverse Osmosis and Chemical Treatments

- Membrane Systems (Reverse Osmosis)
  - Historically prone to scaling without comprehensive pretreatment
  - Need very experienced operators
  - Technology much improved with advanced multi-membrane systems and membrane washing
  - Advanced coatings
  - Energy requirements have decreased with membrane advances
  - Increased use in Texas
- Chemical Precipitation and Electro-Coagulation
  - Less expensive
  - Still requires relatively experienced operators
  - Used more with alternative sources of water such as municipal waste water

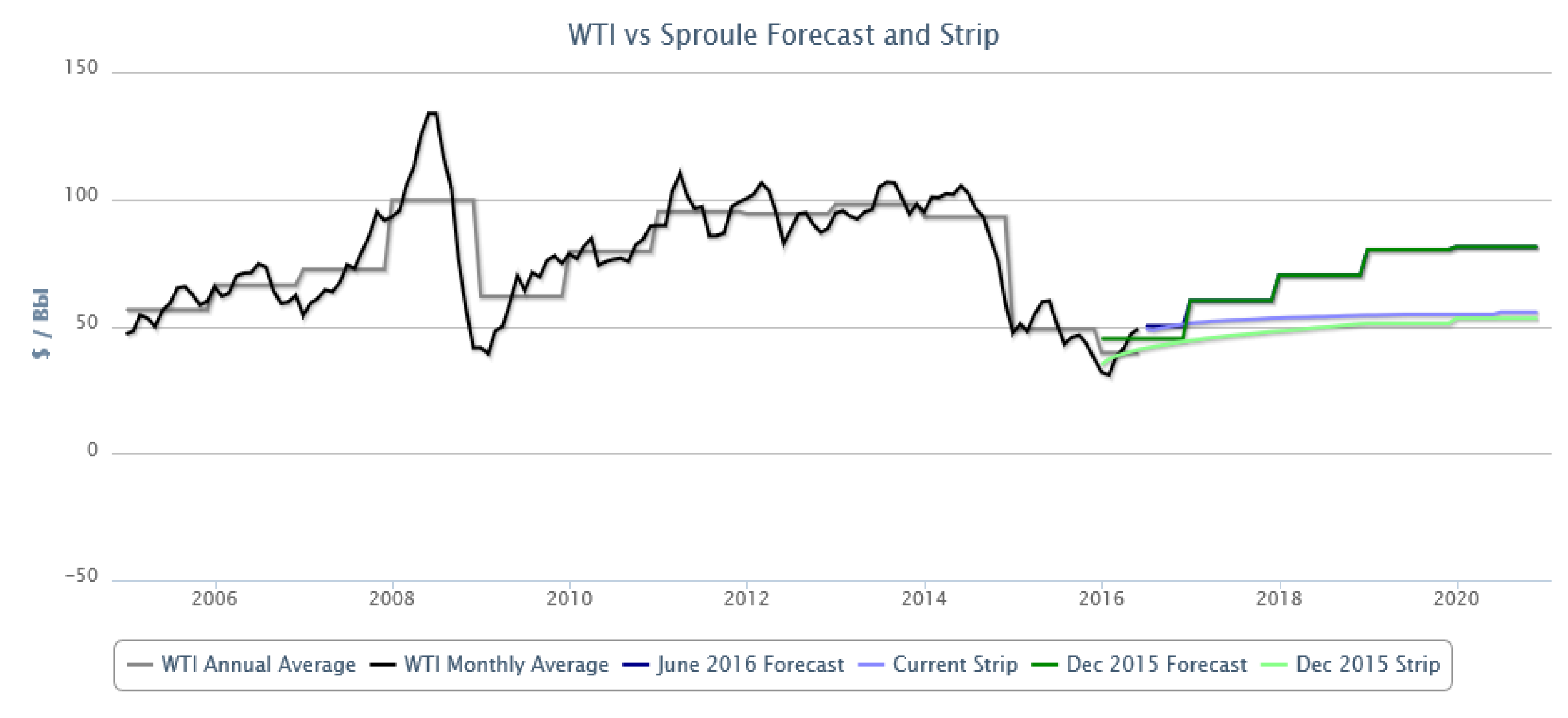
Economic and Social Contract Drivers

- Reduction in the volume of wastewater
  - Less sent offsite for disposal
  - Less risk of seismic activity
  - Less fresh water needed for hydraulic fracturing operations
  - Reduced impact on local supplies
  - Reduced truck traffic on public roads (less fresh water hauled)
  - Less impact on public roads, noise, air quality
- Filtration process used is inexpensive and does not require substantial amounts of energy
- Process that remove salts (i.e. reverse osmosis membranes, distillation)
- Helps reduce the cost of operations
  - Reduces wastewater disposal costs, water supply costs, and transportation costs

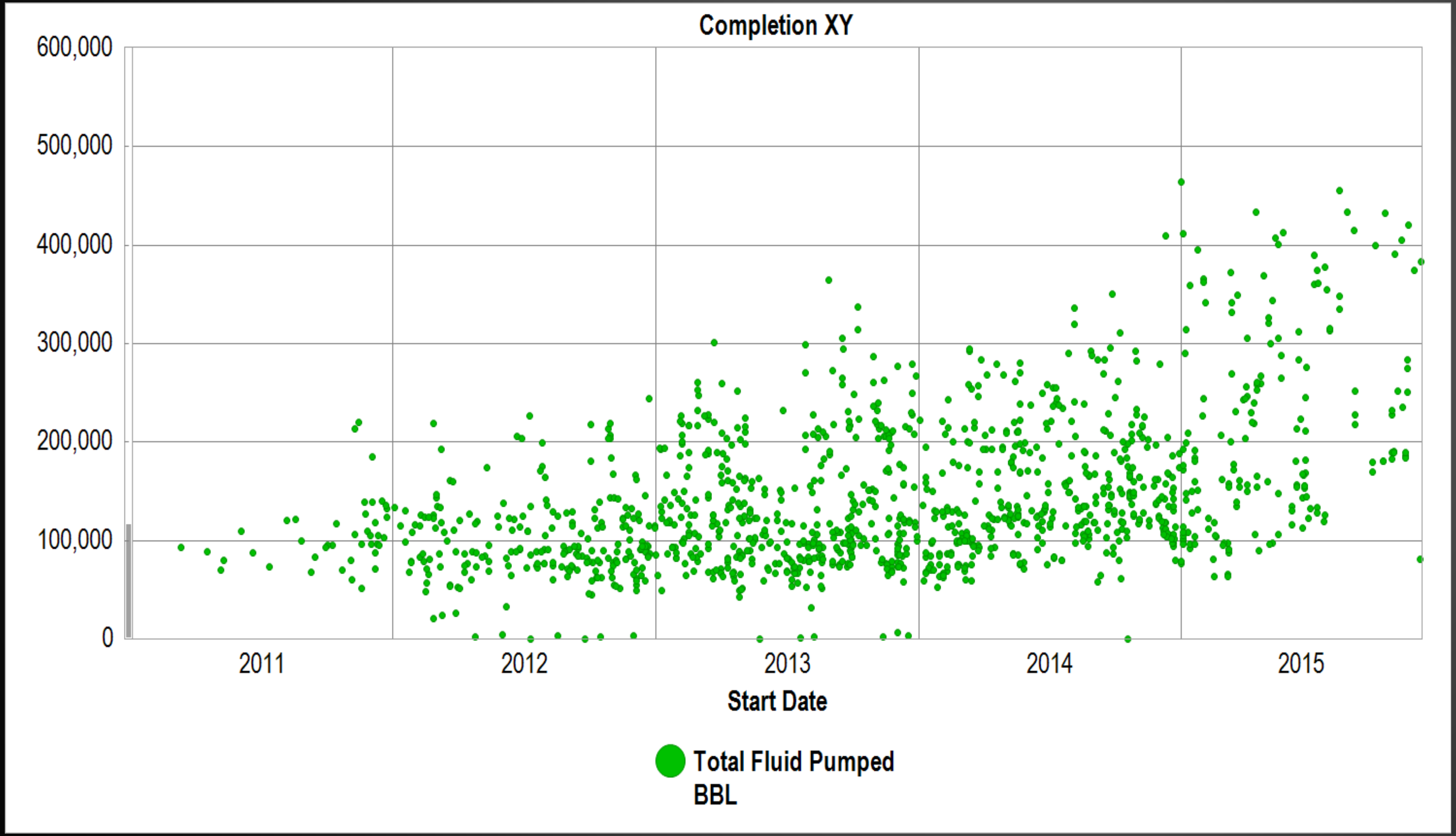
Extreme Environmentalists Are Fighting Reuse

- Concerns of the so called permanent removal of water from the effective hydrologic cycle
- Concerns will reduce water available for human consumption
  - Most water used in shale gas development either remains in the formation or returns as produced water
  - Environmentalists oppose both water used in fracturing as well as water reuse
  - Concerns with “re”use of treated municipal waste water
  - All water use is reuse; many river flows are nearly all treated waste water
- The conventional method for disposal of produced water is through permitted Class II Salt Water Disposal Wells which have been associated with increased seismicity
- Argument that this is a different type of “consumption” than the evaporation of water from a power plant and other types of “consumption”
  - Agricultural production is by far largest consumer of water
  - Oil and gas very small in comparison

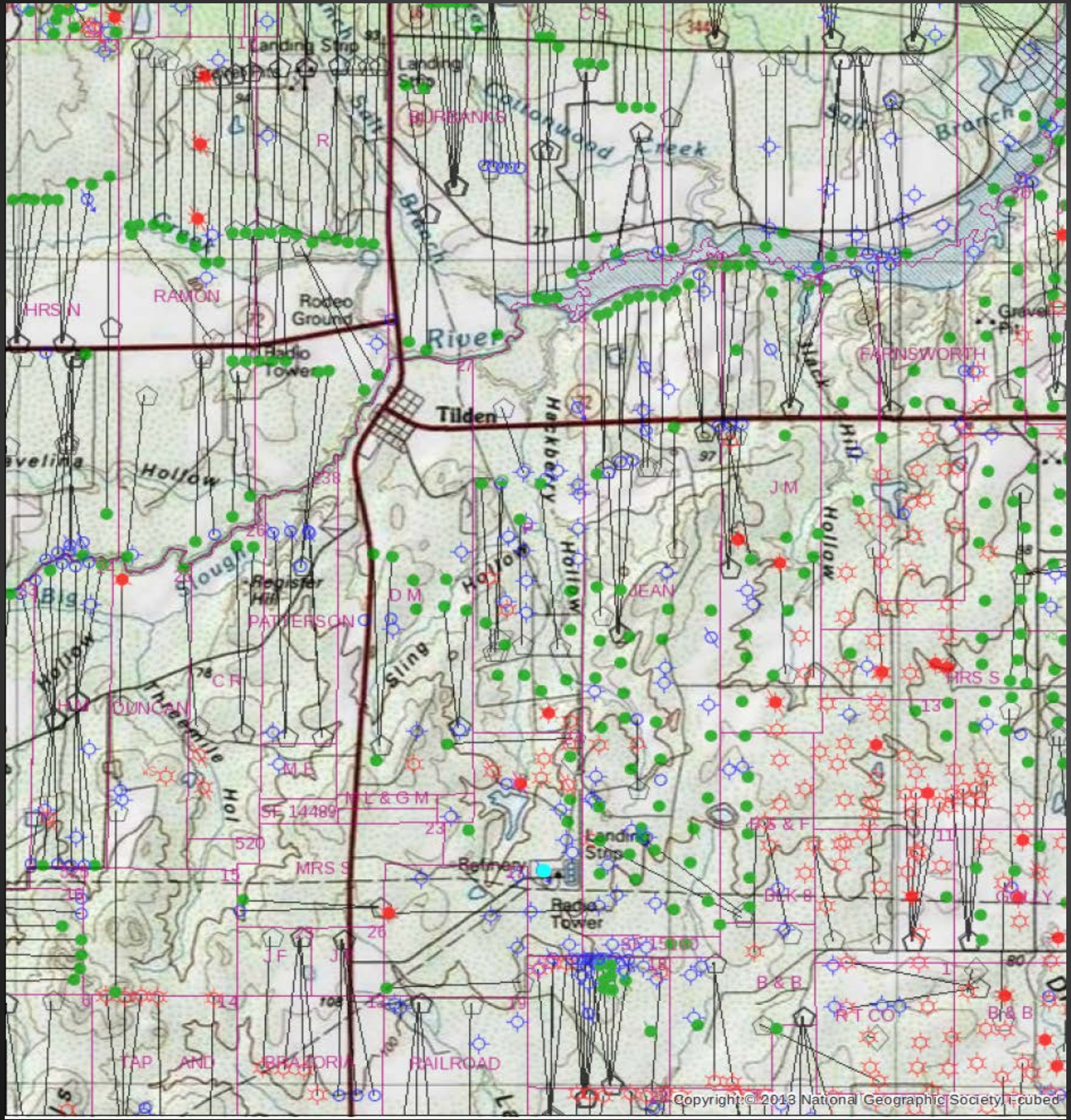
Future Price Forecasts Encourage Future Production Increases



Trends Toward Larger Hydro-fracturing Water Volumes



Closer Well Spacing: Example in South Texas Project Area



Conclusions

- Technological advances are benefiting and addressing environmental concerns and facilitating increased production and effectiveness
- No compelling data in literature yet that ground water impacted by hydro-fracturing. Only by poorly completed or plugged older, vertical wells whose completion & plugging predated current practices and standards.
- Injection for disposal has been associated with releases & seismicity.
- Economic and Social Contract Incentives for Increasing Produced Water Reuse

Questions and Answers

2016 One-Year Seismic Hazard Forecast for the Central and Eastern United States from Induced and Natural Earthquakes

By Mark D. Petersen, Charles S. Mueller, Morgan P. Moschetti, Susan M. Hoover, Andrea L. Llenos, William L. Ellsworth, Andrew J. Michael, Justin L. Rubinstein, Arthur F. McGarr, and Kenneth S. Rukstales

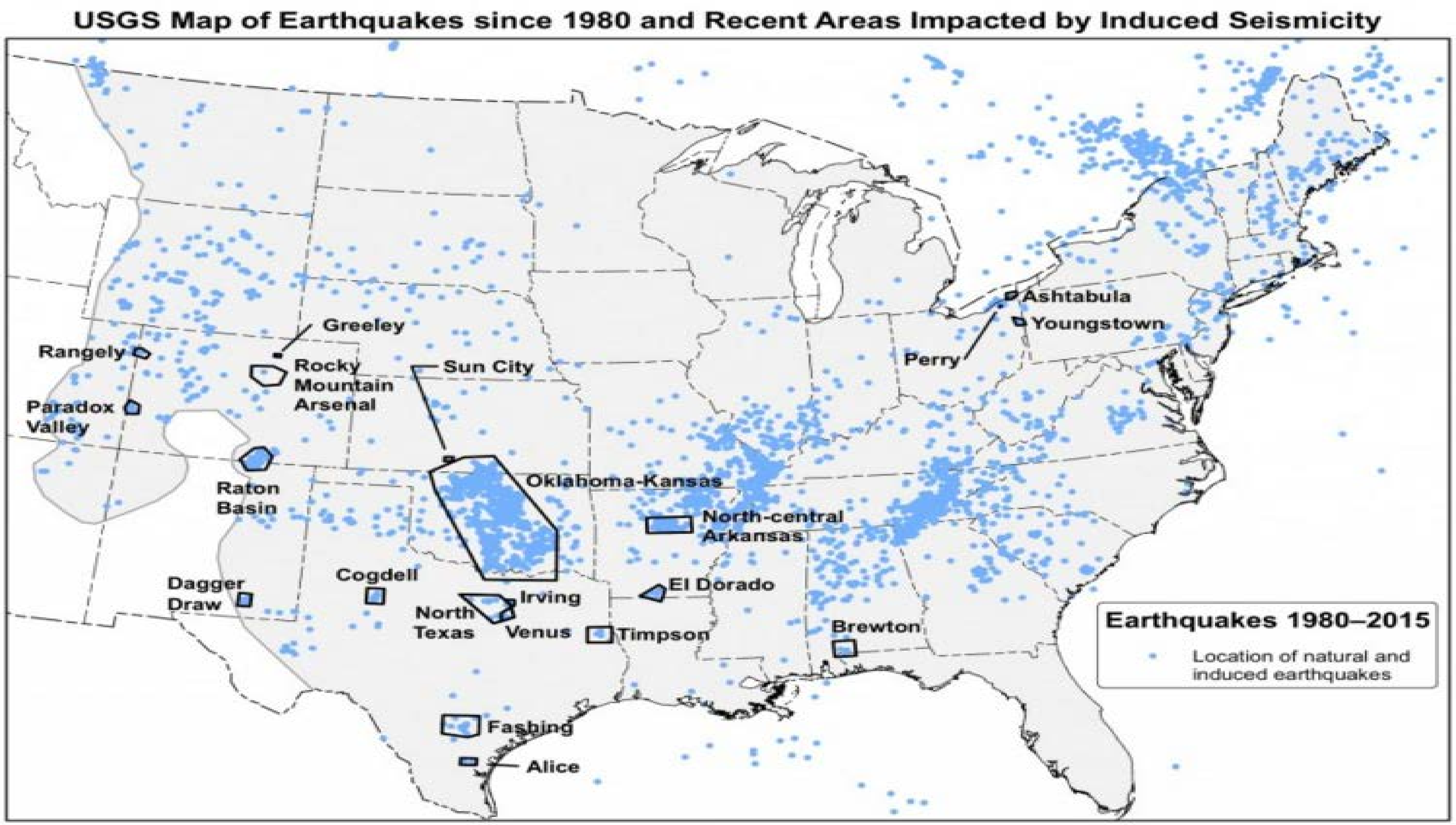
Open-File Report 2016–1035

FINDINGS OF USGS Earthquake STUDIES

1. Recent Earthquake Activity is NOT related to Hydro-fracturing(or EOR)
2. Recent Earthquake activity is related to Brine Injection
3. Triggered by Increased Salt Water Injection Rates
4. Suggests there are Safe Injection Rates

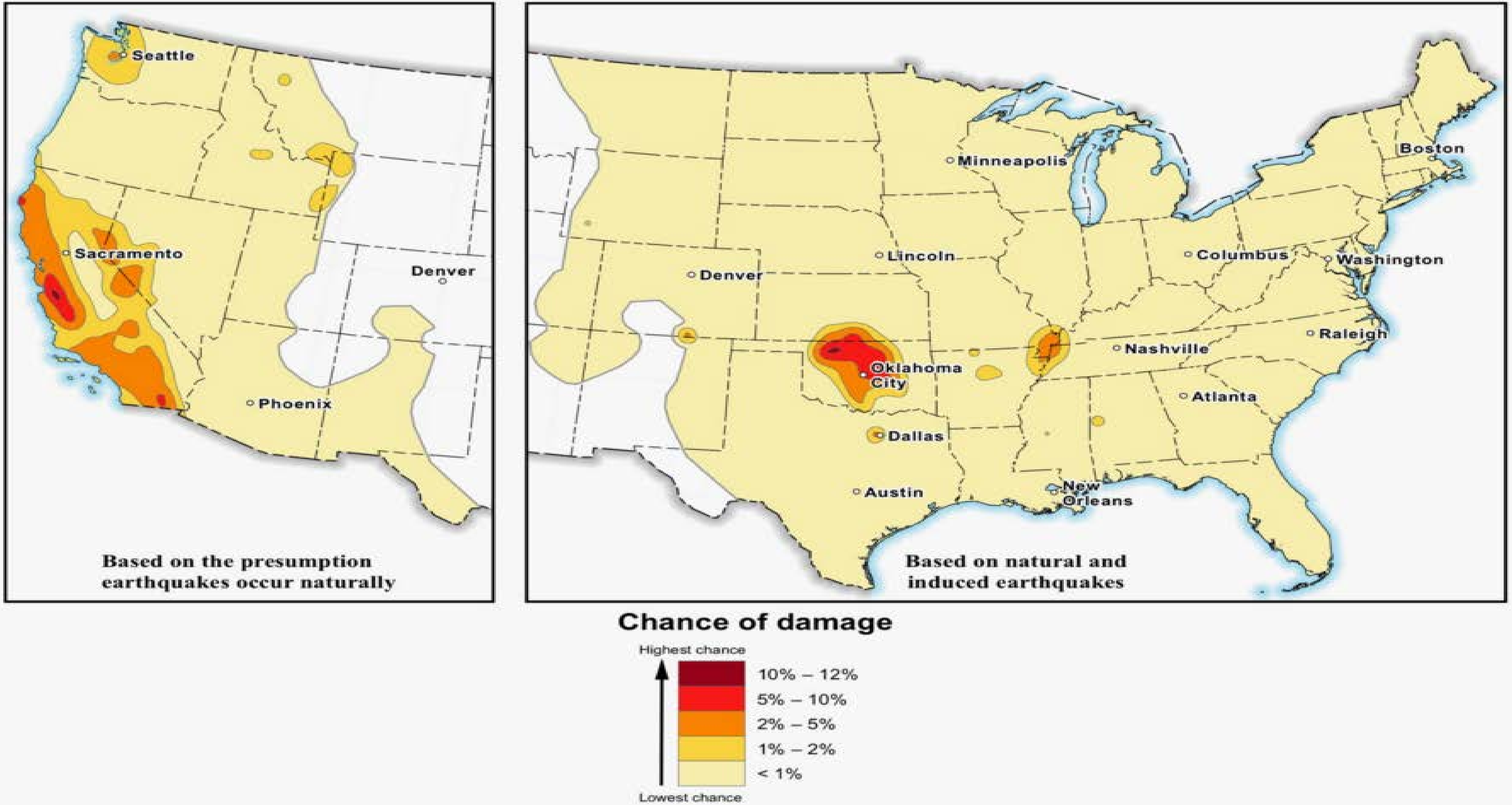
   Oklahoma quakes quelled since limits emplaced

5. USGS Predicts Future Earthquake Risks



USGS map displaying 21 areas where scientists have observed rapid changes in seismicity that have been associated with wastewater injection. The map also shows earthquakes—both natural and induced—recorded from 1980 to 2015 in the central and eastern U.S. with a magnitude greater than or equal to 2.5.

USGS Forecast for Damage from Natural and Induced Earthquakes in 2016



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.

Perspective on Water Cycle and Water ReUse Demand vs Supply

- Methane Combustion Reaction to Produce Water Vapor:
  - CH+ 2O = 2CO2+ 2H2O
- Volume of Water Vapor Produced per Million Cubic Feet of Natural Gas:
  - 10,675 gallons
- Require 525 MMCF of natural gas to produce an equivalent amount of water (as vapor) used to drill and complete a typical Shale well
- Based on current production trends, it takes an average Marcellus Well < 6 months to produce 525 MMCF of Natural Gas
- One well produces yields many times more water vapor than water required to frac a new well
- Total produced water predicted in West Texas is much greater than water required to frac new wells