The Oklahoma Water Conundrum

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What is a Conundrum?

- A confusing and difficult problem or question that evades resolution

Oklahoma's Water Conundrum

- What sources of fresh water can be used for drilling and completion operations?
- What are the disposal options for flowback and produced water?
- Primary Salt Water Disposal (SWD) may be shut in due to seismic activity

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Questions to Consider

- How much water is being used to drill and complete a well?
- Where can the water be found to drill and complete a well?
- How much produced water will be disposed of in Oklahoma?
- What is the best way to dispose of produced water?
- How many injection wells are there in Oklahoma?
- Is disposal of produced water into Arbuckle SWD wells causing earthquakes?
- What are the alternatives to using Arbuckle SWD wells?

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Water's Importance

- Water is the most common and most heavily used fluid in the petroleum industry.
- Water is produced along with oil and gas from nearly every well.
- Water is used as a base fluid in drilling, completion, and production operations.
- Water will be produced, recycled, injected, mixed, cleaned, and reinjected.
- **Water's use, protection, and disposal are emotionally charged subjects in many communities.**

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Significance of Water to the Oil and Gas Business

More than ever, water is an integral part of the success of oil and gas operations. Consider this:

No Water

No Hydraulic Fracturing

No Oil and Gas Resource Plays

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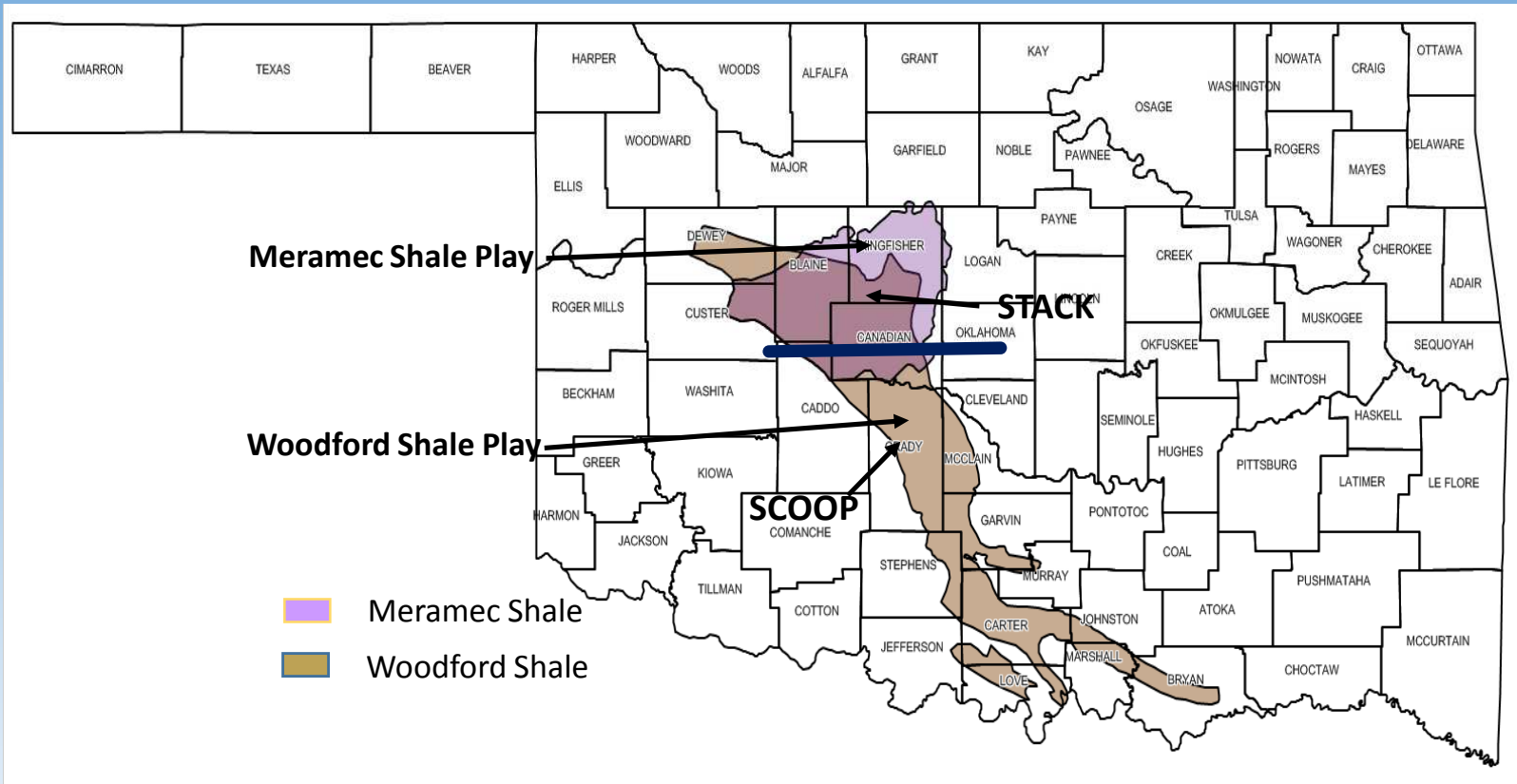
Where is water found?

OK Cana Woodford & Meramec Shale Plays



STACK = Sooner Trend Anadarko Canadian Kingfisher

SCOOP = South-Central Oklahoma Oil Province

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Oklahoma's Primary Water Sources

- Subsurface aquifers using water wells

- Surface water from naturally occurring or man made ponds and streams

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Fresh Water Sources in the Cana Woodford

- STACK Water Sources
  - Kingfisher Creek
  - Uncle John Creek
  - Landowner Ponds
  - Loyal Aquifer Water Wells
  - Cimarron River
  - Canadian River
- SCOOP Water Sources
  - Crescent Pipeline from Washita River
  - Rush Creek
  - Landowner Ponds
  - Select Pipeline from Washita River
  - Lake Fuqua (no longer available until drought breaks)

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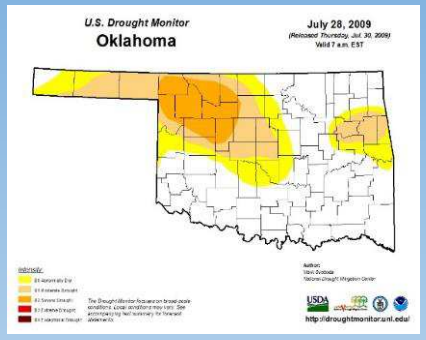
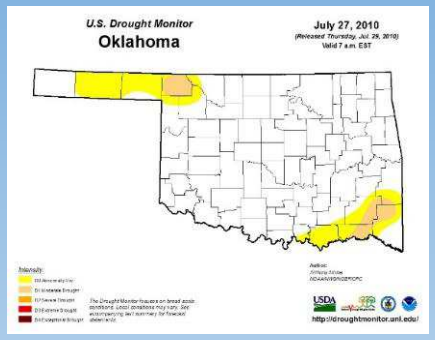
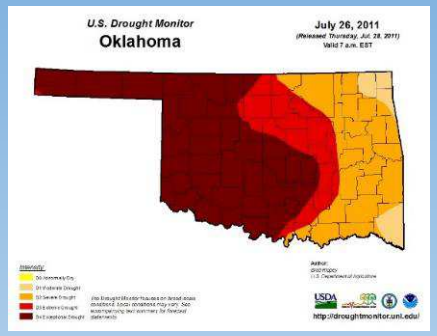
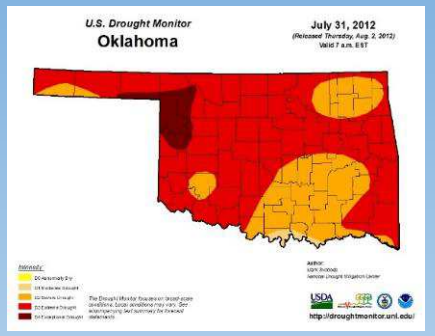
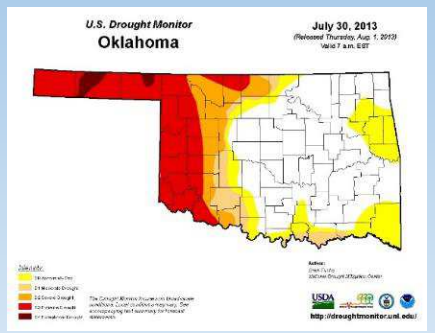
Oklahoma Drought Monitor

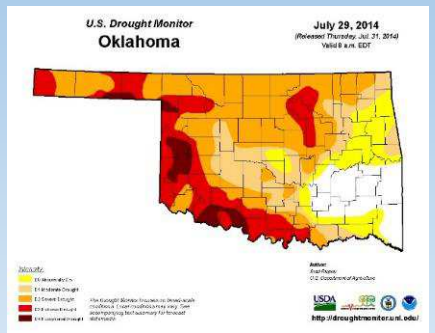


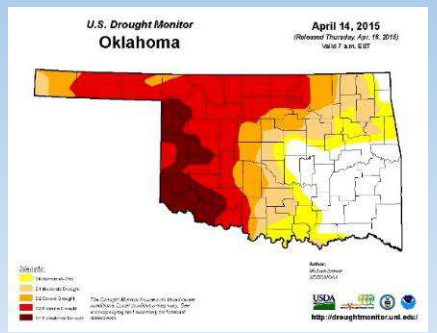


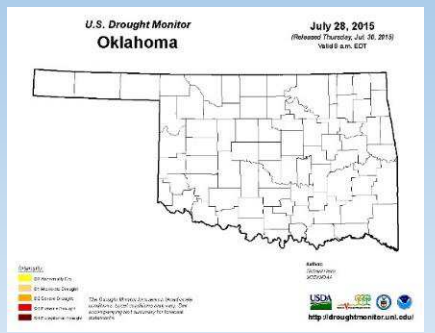












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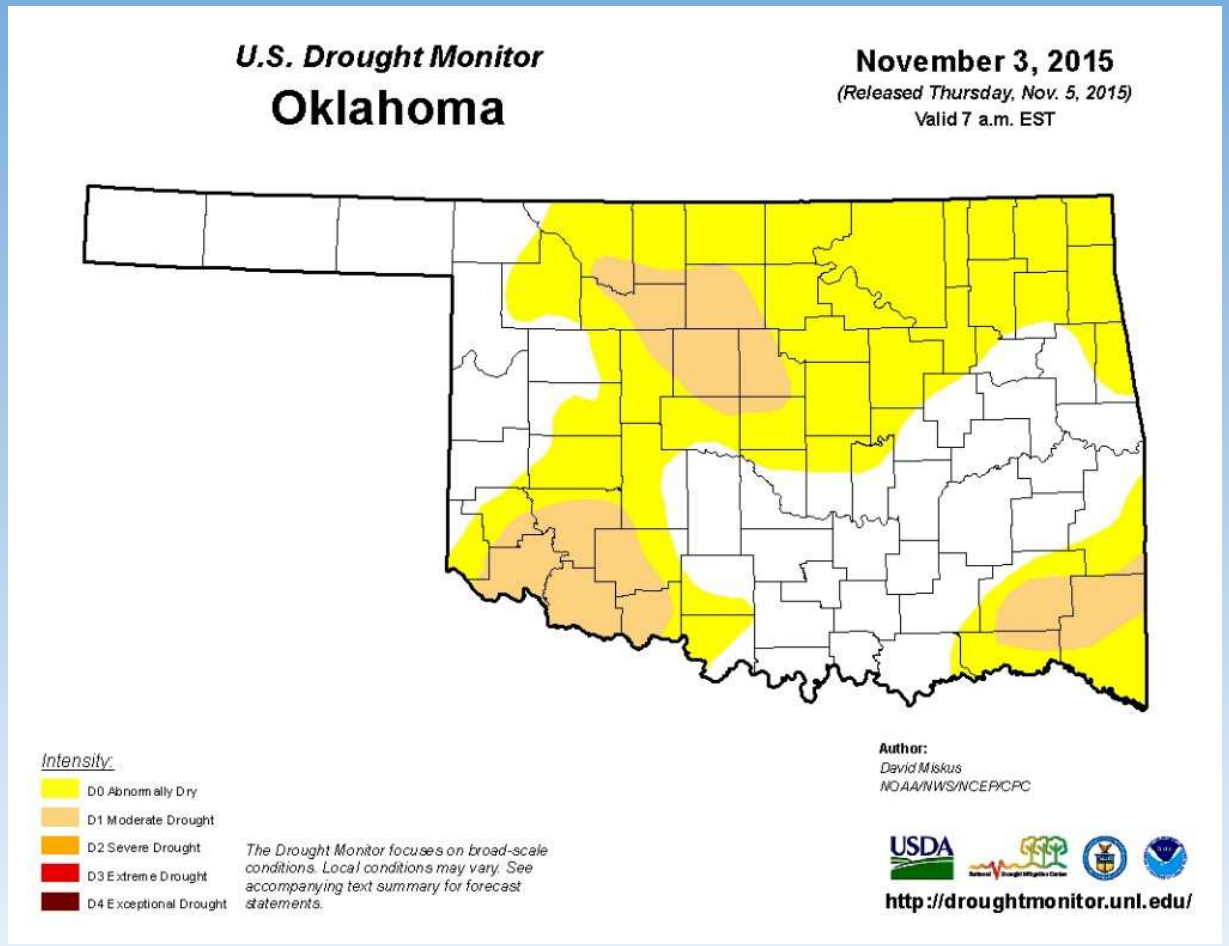
Oklahoma Drought Monitor as 11/03/15



Source: US Drought Monitor

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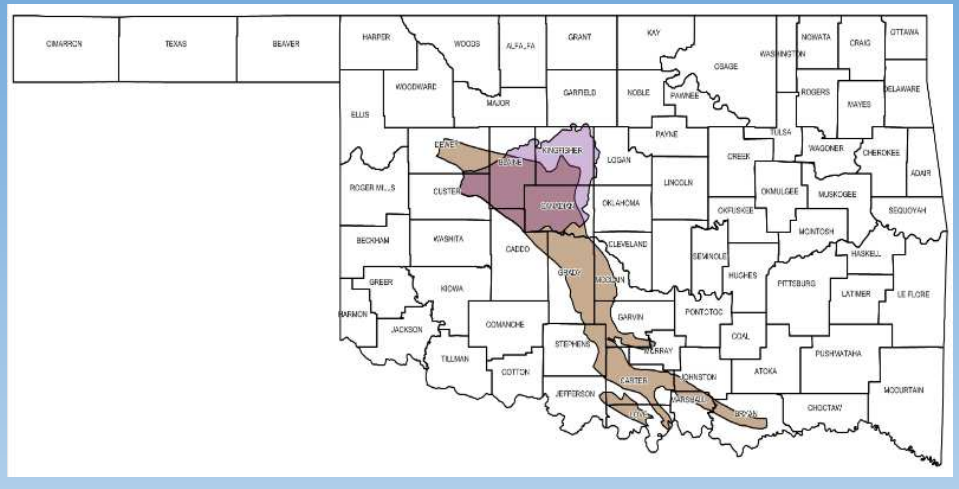
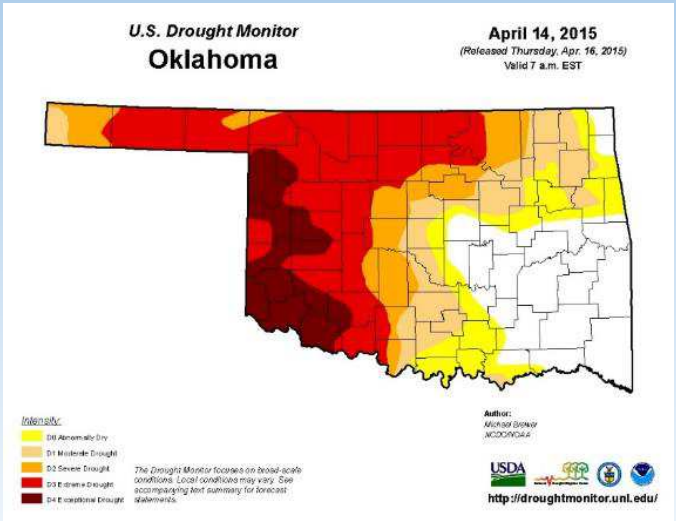
Drought Limits Fresh Water Sources in the Cana Woodford

- Effects of Drought on Water Supply
  - Streams flow intermittently
  - Communities limit purchase of fresh water
  - Aquifers dry up
  - Landowner ponds dry up
  - OWRB limits water use
  - Have to transport water longer distances





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What are the Alternatives to Fresh Water?

- Use water from non-potable or saline aquifers
- Use grey water from municipal treatment plants
- Use recycled produced water

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How Much Water Is Used in the Cana Woodford?

- How much water is used for each type of fracturing fluid?
  - Slickwater – 10 to 25,000 barrels per stage
  - Linear gel – 4 to 8,000 barrels per stage
  - Cross linked gel – 4 to 6,000 barrels per stage
- How much load water is recovered?
  - STACK – 10 – 180% - Most wells are in the 15 to 45% range.
  - SCOOP – 25 to 180% - Most wells are in the 25 to 75% range.

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What is done with produced water?

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Produced Water Disposal Options

- Salt water disposal wells
- Recycle produced water
- Treat produced water for beneficial reuse

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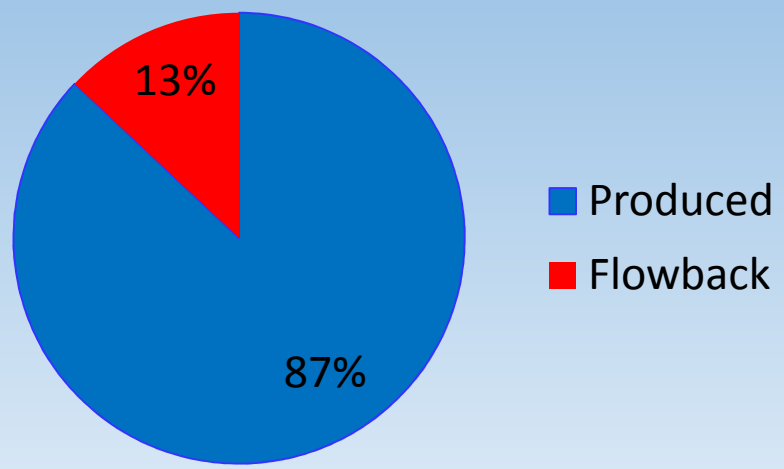
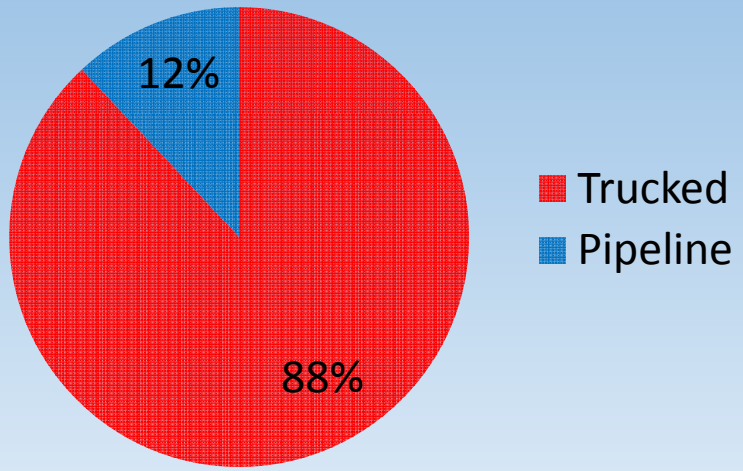
Water Disposal

Saltwater Disposal Water Type %



Transportation Method For Delivery to Disposal %



Source: Bosque Systems, LLC

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Transporting Water for Disposal

- Salt Water Disposal Well
  - Water delivered by truck
  - Water delivered through a pipeline

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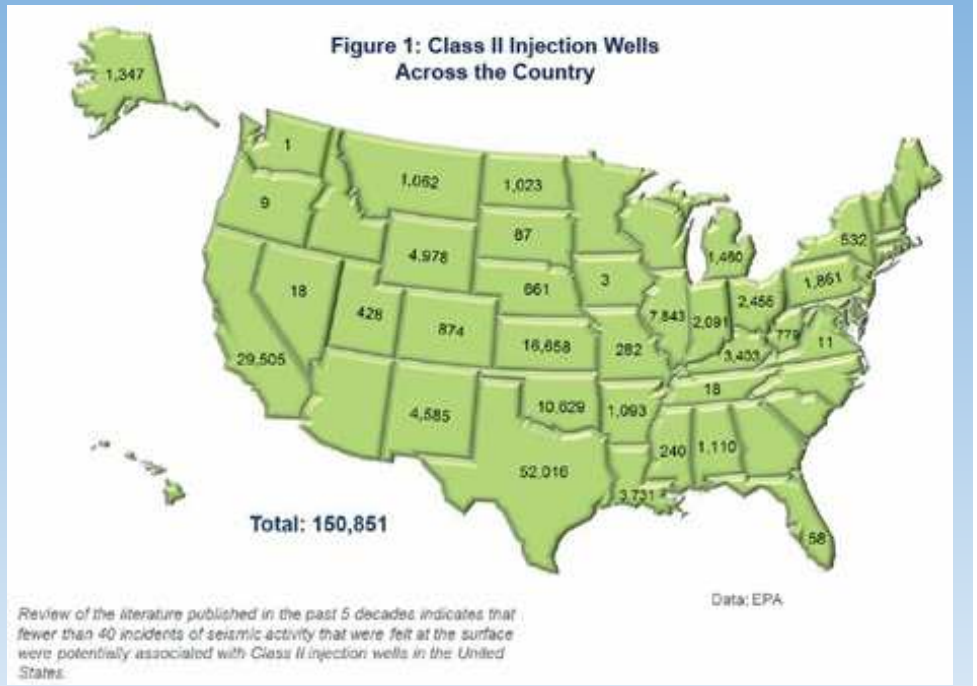
Class II Injection Wells

- There are approximately 151,000 Class II wells in the U.S.
- About 20% or 30,000 of these wells are Class II disposal wells.
- Oklahoma has 10,629 Class II wells.
- In Oklahoma, approximately 900 Class II wells inject produced water into the Arbuckle.



Source: www.energytomorrow.org

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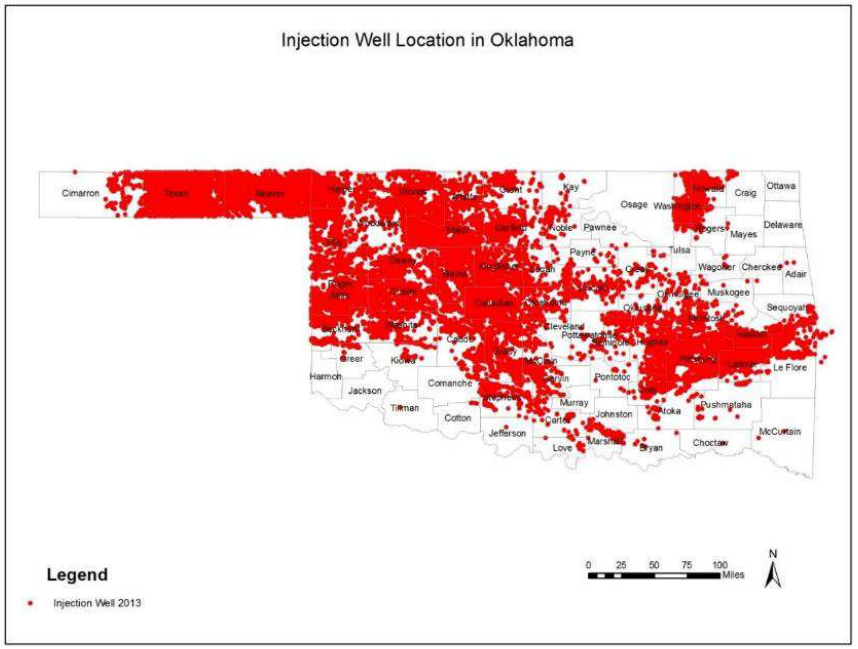
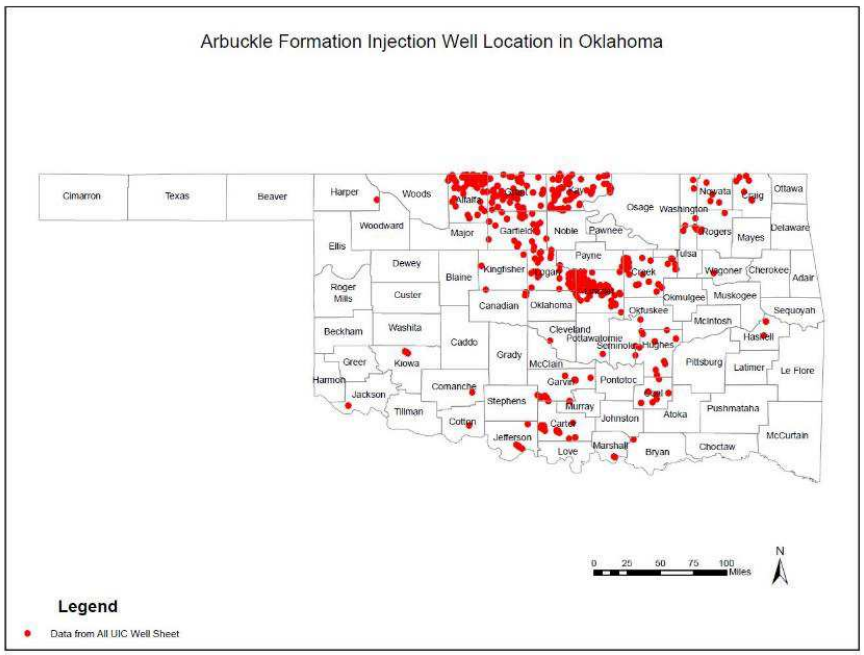
Oklahoma Injection Wells vs Arbuckle Injection Wells





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Alternatives to Using SWD Wells

- Enhanced Evaporation

- Process Water
  - Process to recycle for future completions
  - Process water for other beneficial use

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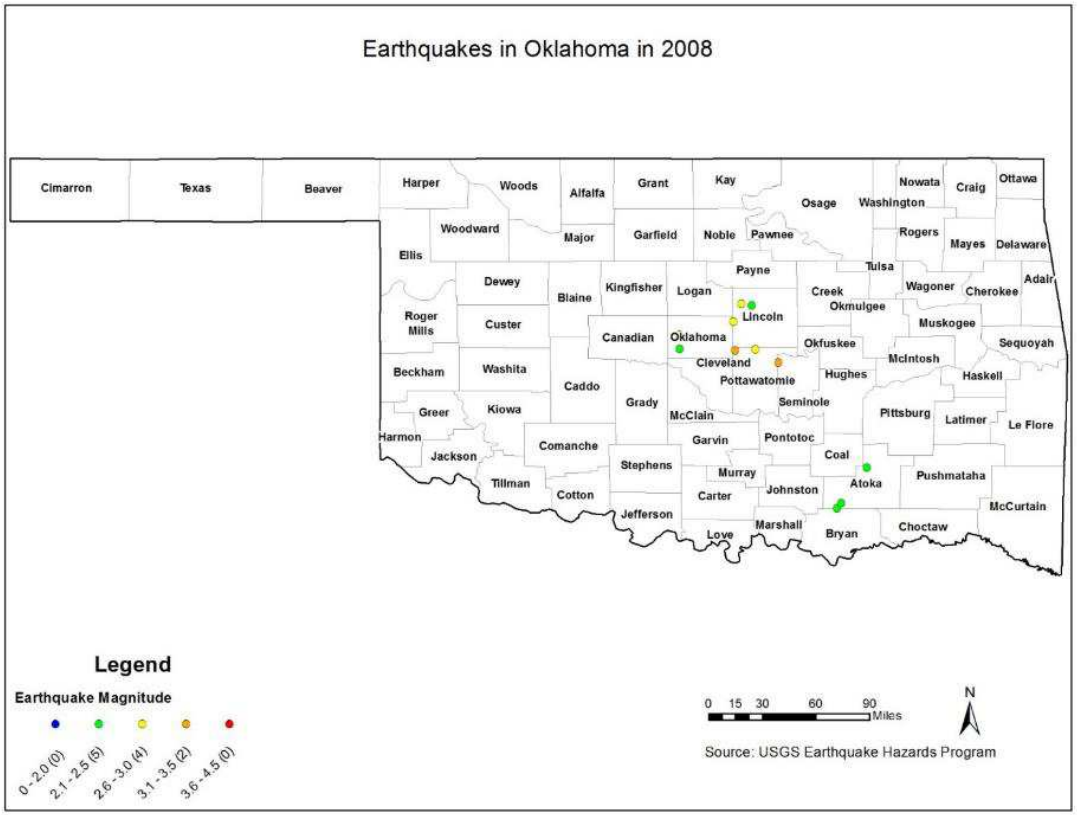
Oklahoma Seismic Activity

Oklahoma Earthquakes in 2008



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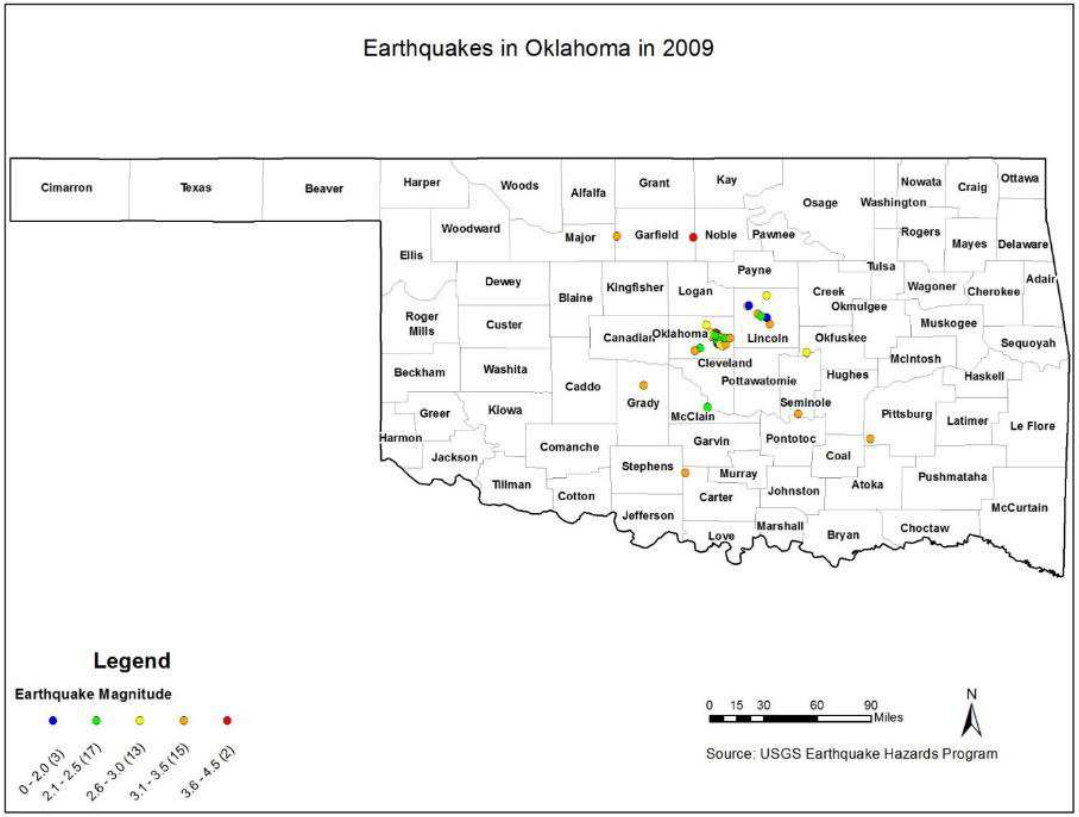
Oklahoma Earthquakes in 2009



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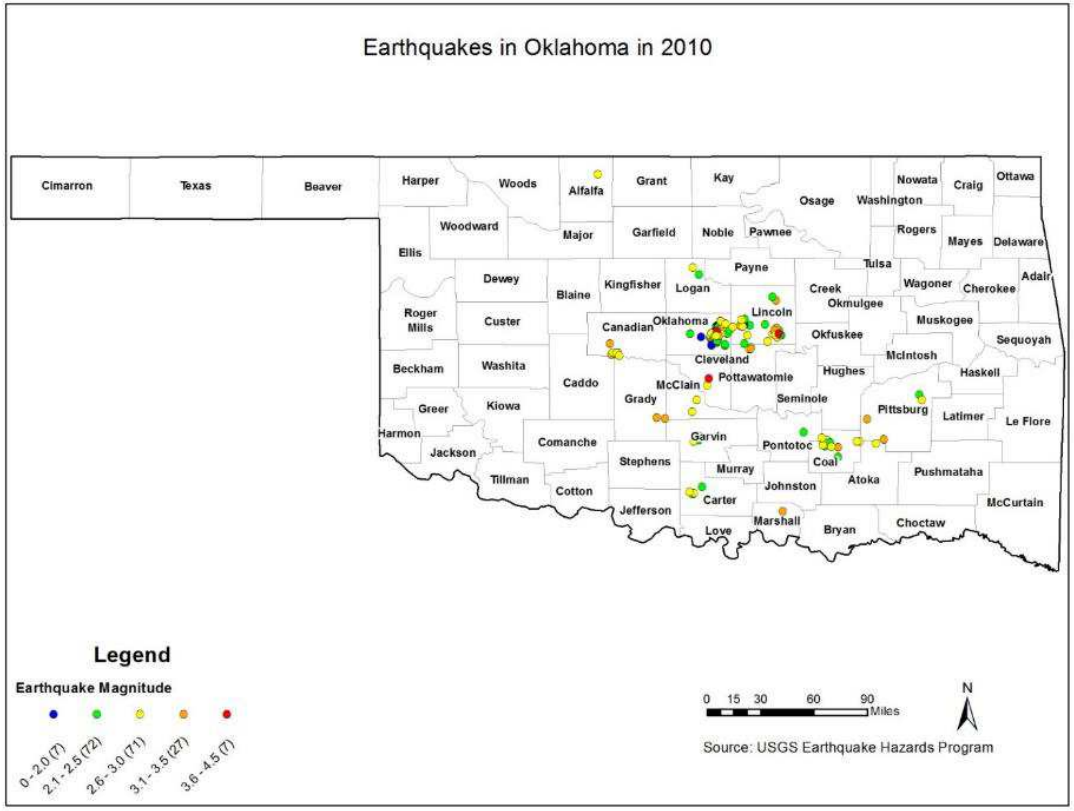
Oklahoma Earthquakes in 2010



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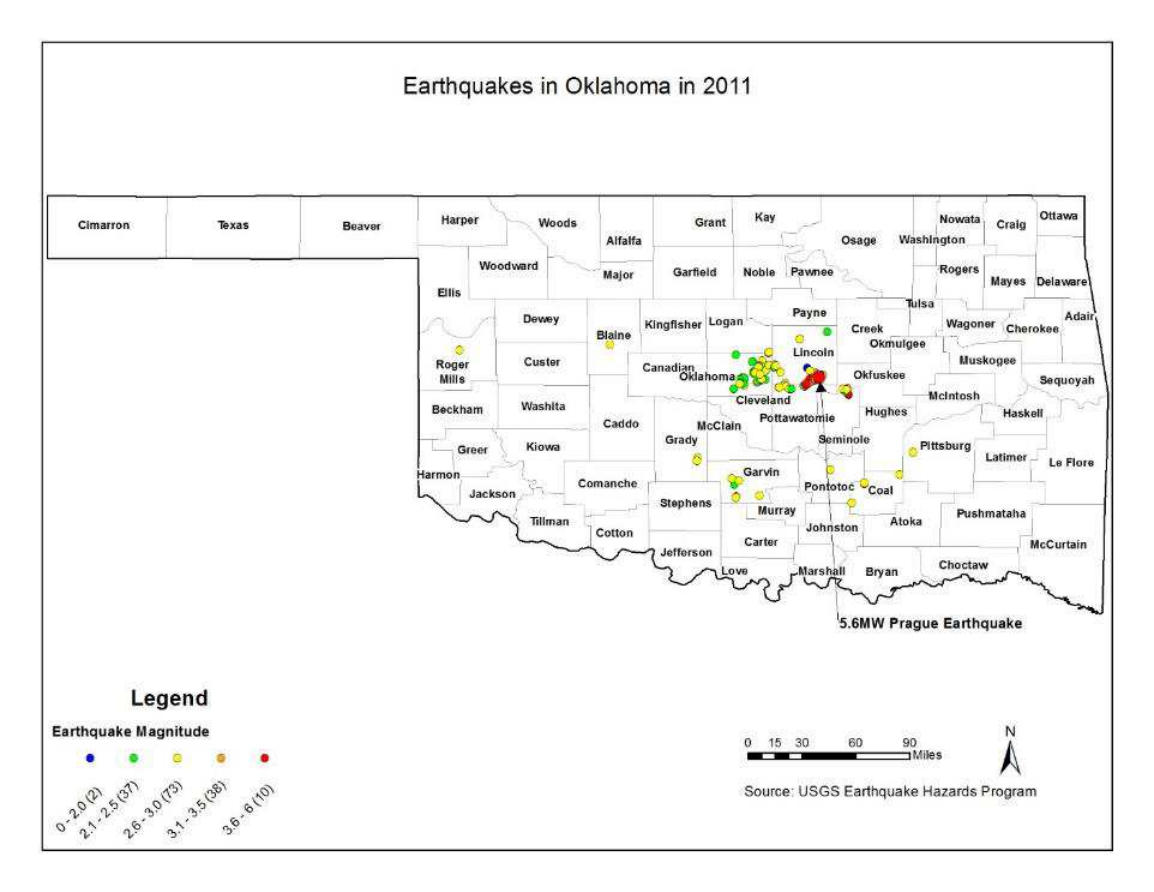
Oklahoma Earthquakes in 2011



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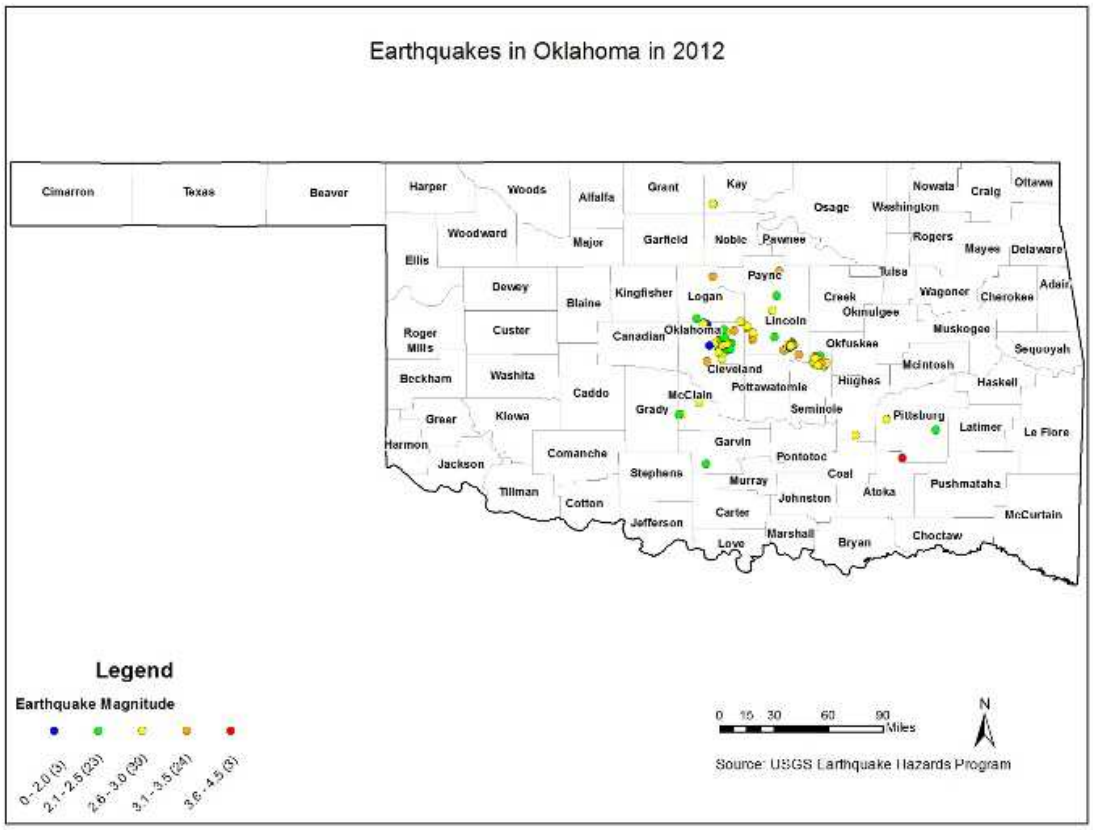
Oklahoma Earthquakes in 2012



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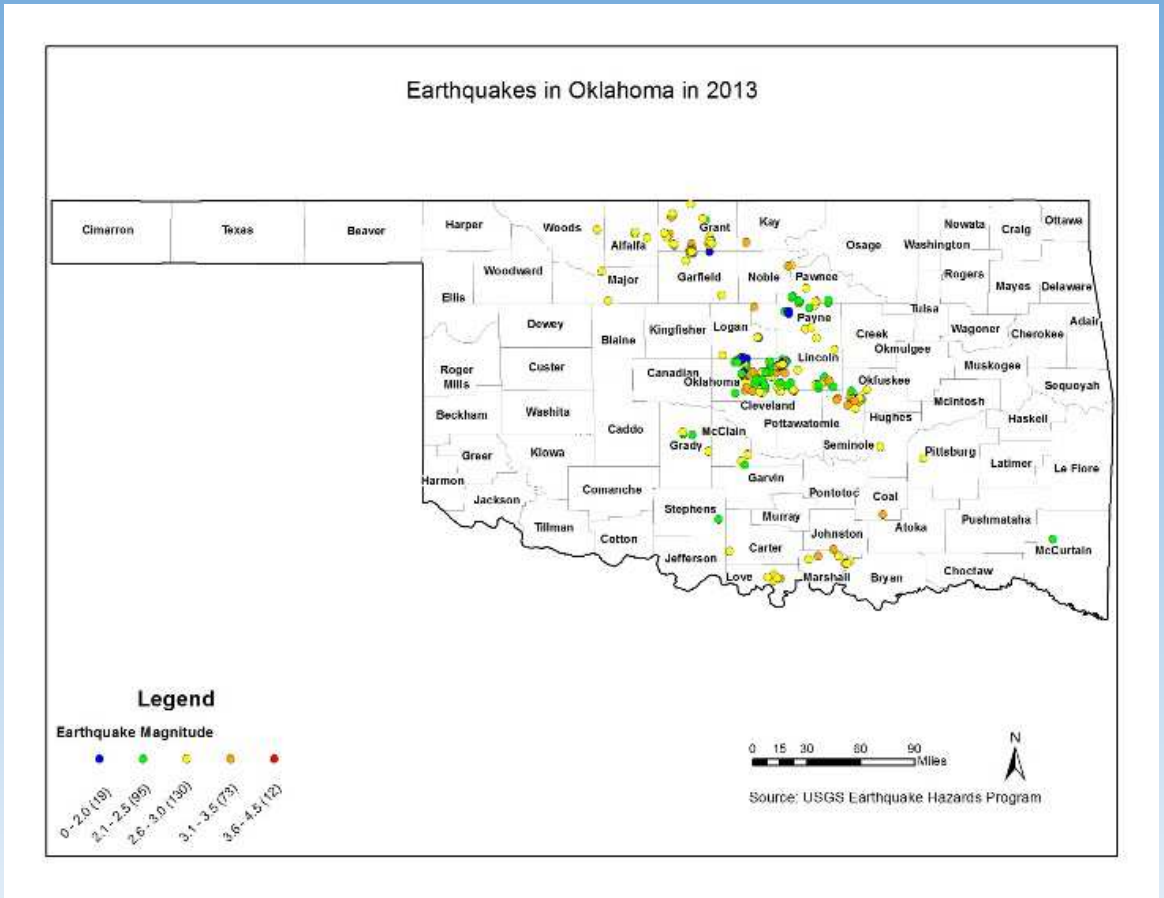
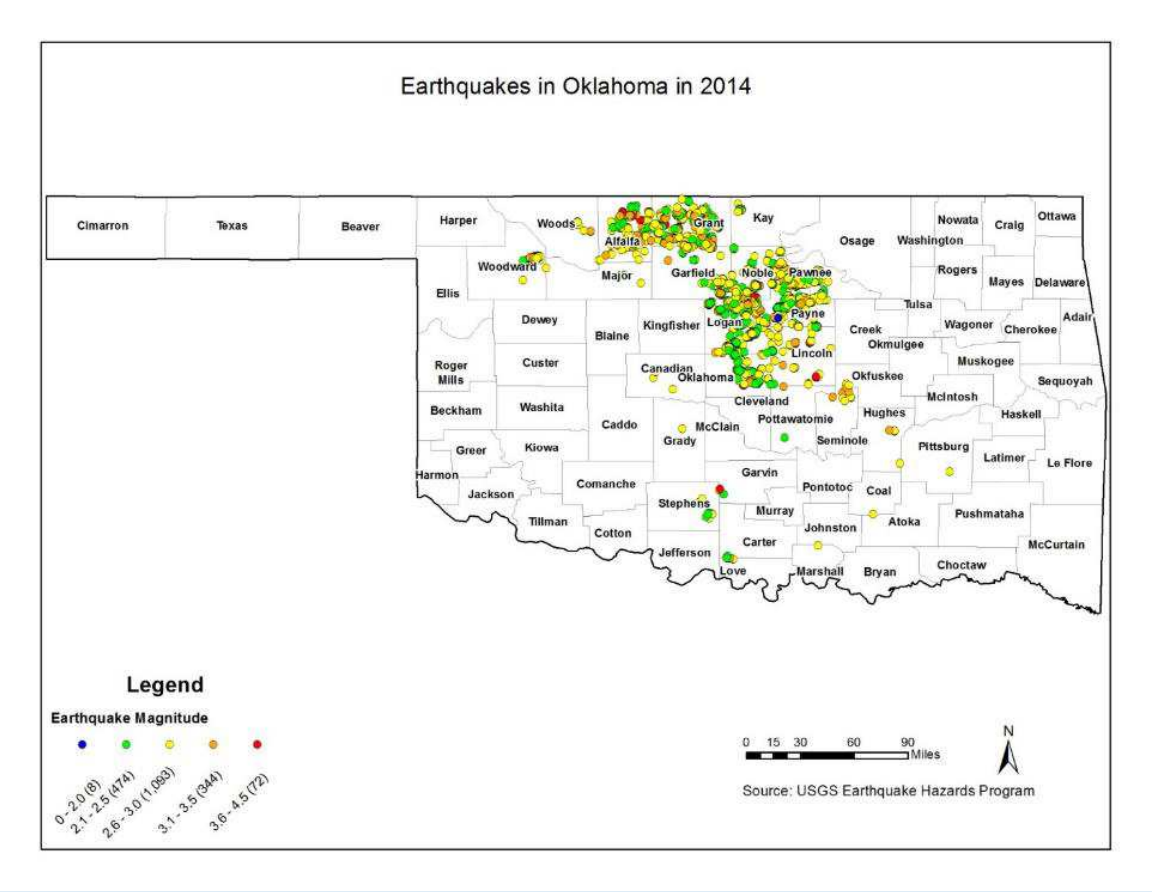
Oklahoma Earthquakes in 2013



Oklahoma Earthquakes in 2014



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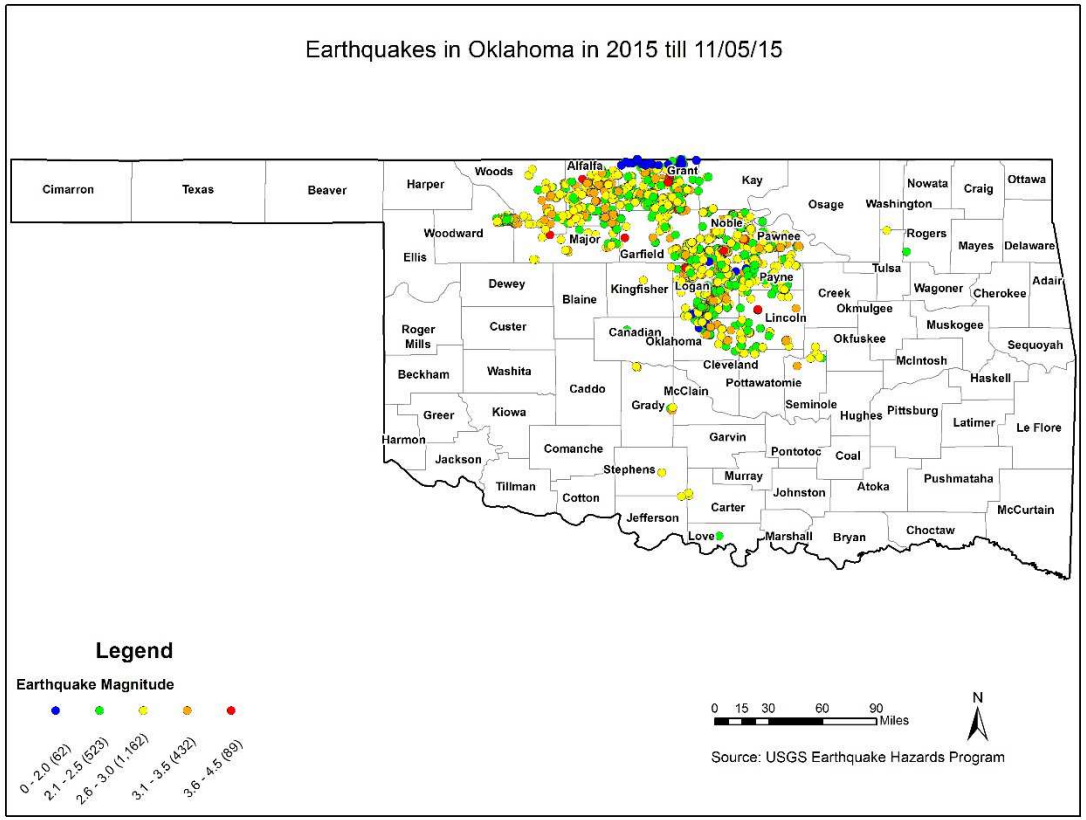
Oklahoma Earthquakes during 2015 to 11/05/15



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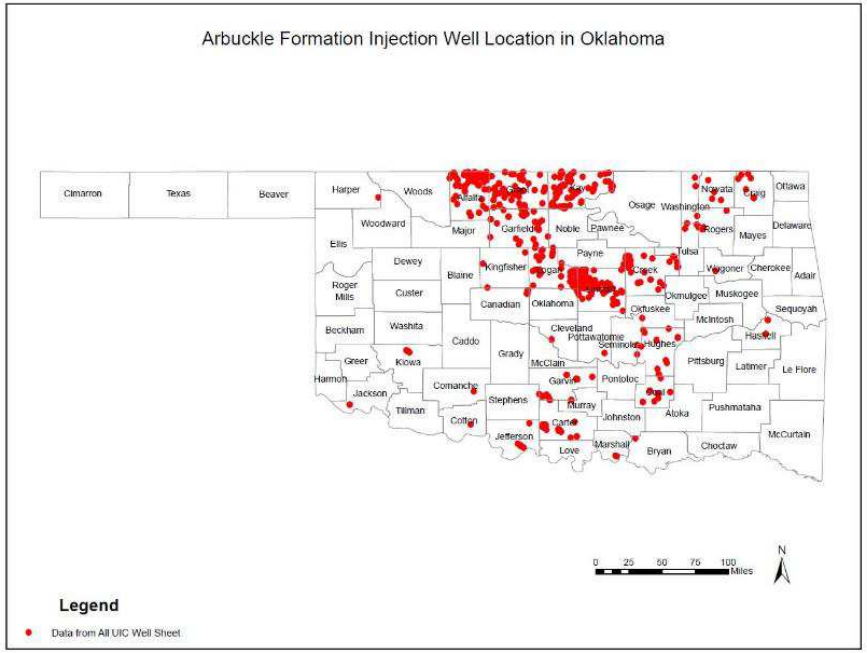
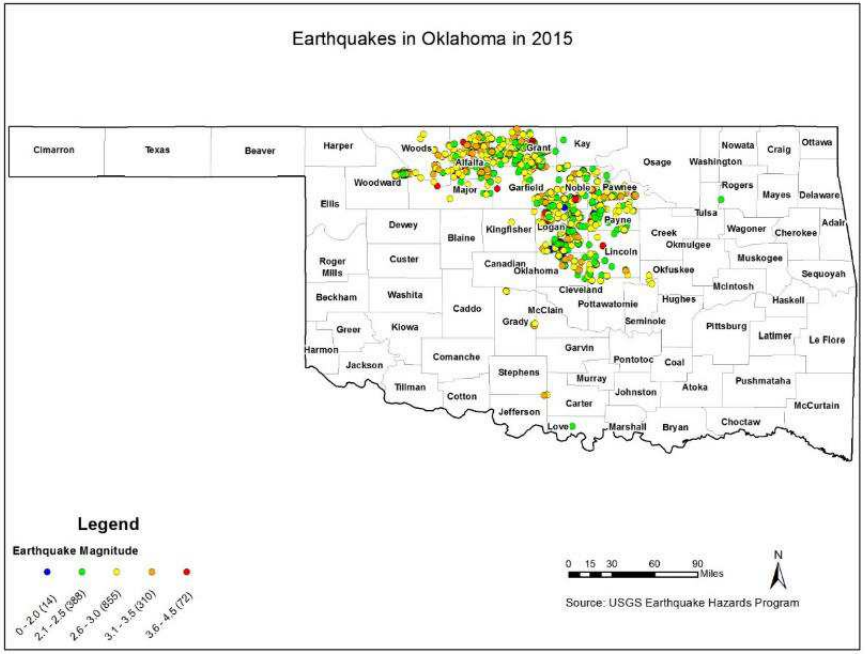
Oklahoma Earthquakes in Relation to Arbuckle SWD Wells





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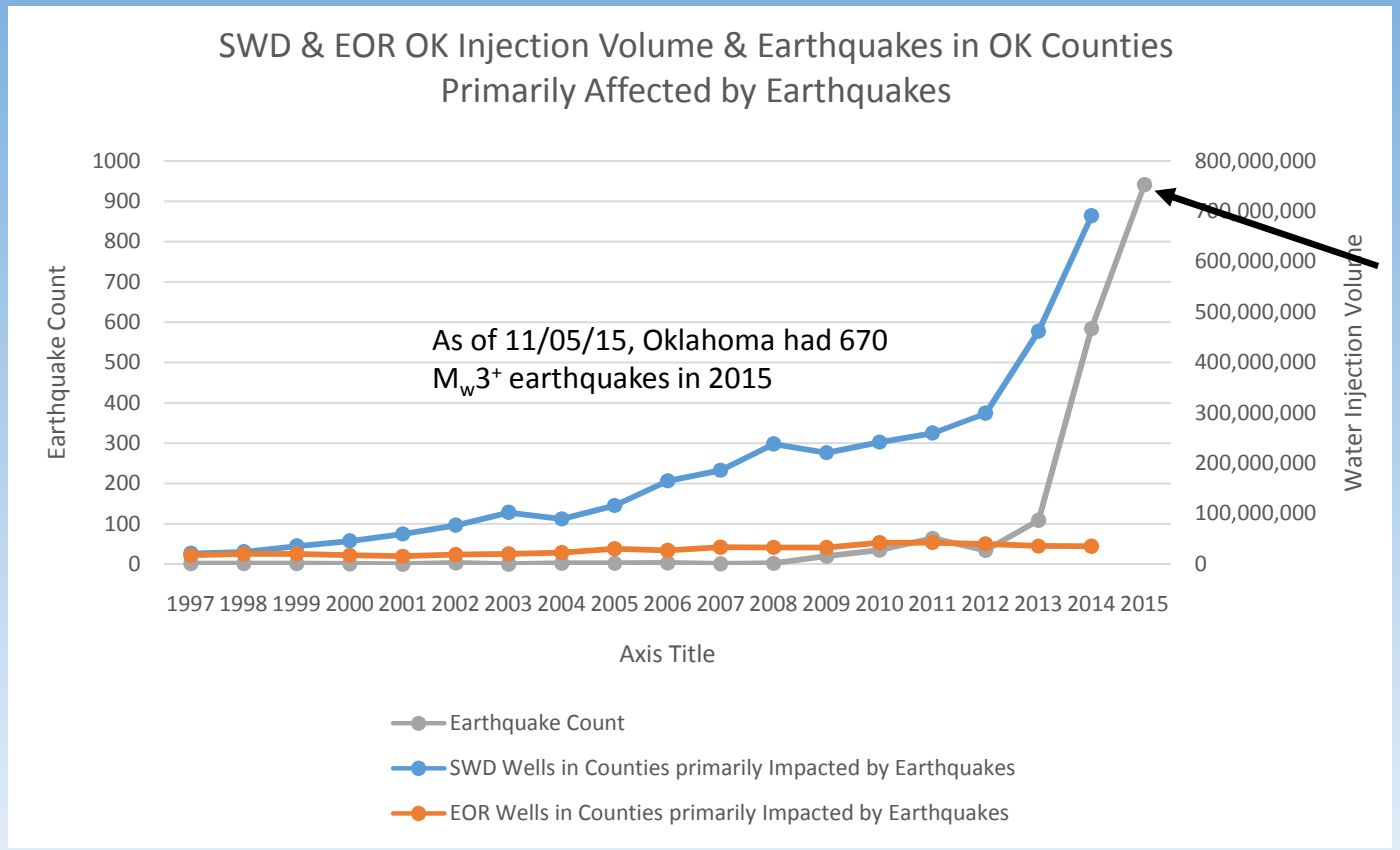
Comparison of M_w3^+ Earthquakes to Annual Water Injection in Select OK Counties

OK Counties Primarily Affected by Earthquakes
Alfalfa
Garfield
Grant
Kay
Lincoln
Logan
Noble
Pawnee
Payne



Earthquake projection for 2015

Sources: OCC UIC data base and USGS Earthquake Hazard Program

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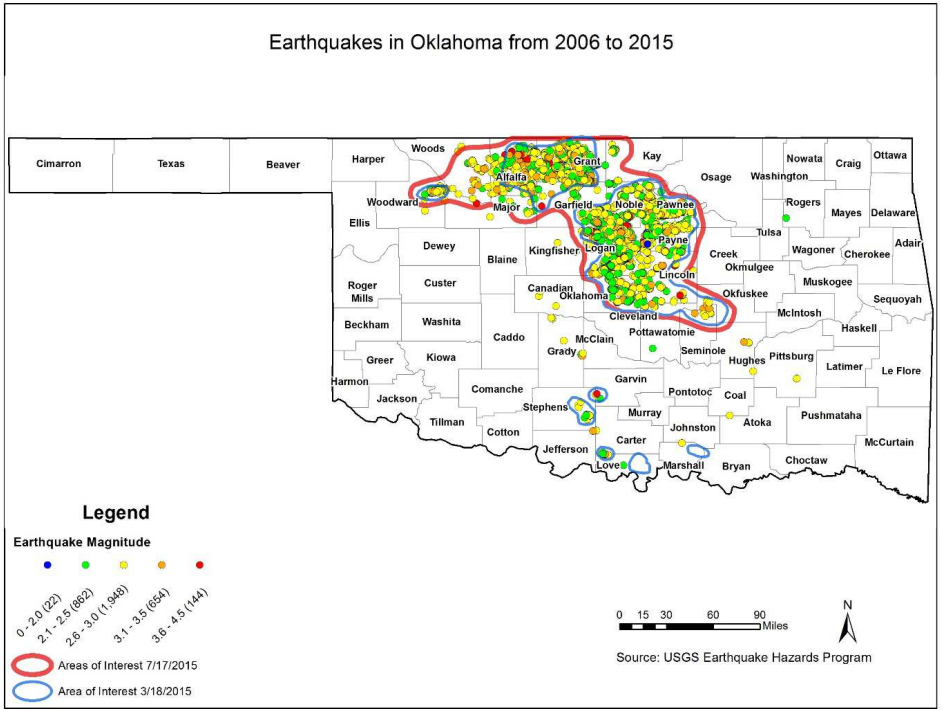
OCC Areas of Interest for Induced Seismicity

- July 17, 2015 – The OCC increased the size of the Area of Interest (AOI) to 21 counties and added 211 wells that inject into the Arbuckle to be monitored.
- March 18, 2015 – The OCC issued a directive covering 300 wells that inject into the Arbuckle and created the AOI. All wells drilled into the basement had to be plugged back to 100 feet above basement or curtail injection 50%.
- September 12, 2014 – OCC changed rules for Arbuckle injection wells from monthly to daily volume and pressure reporting. Any well injecting 20,000 BWPD or more is required to have an annual MIT.
- 2013 – "Traffic Light" system for disposal wells was instituted as recommended by National Academy of Sciences, which requires the review of permits for SWD wells for proximity to faults, seismicity and other factors.



Sources: Oklahoma Corporation Commission and USGS Earthquake Hazard Program

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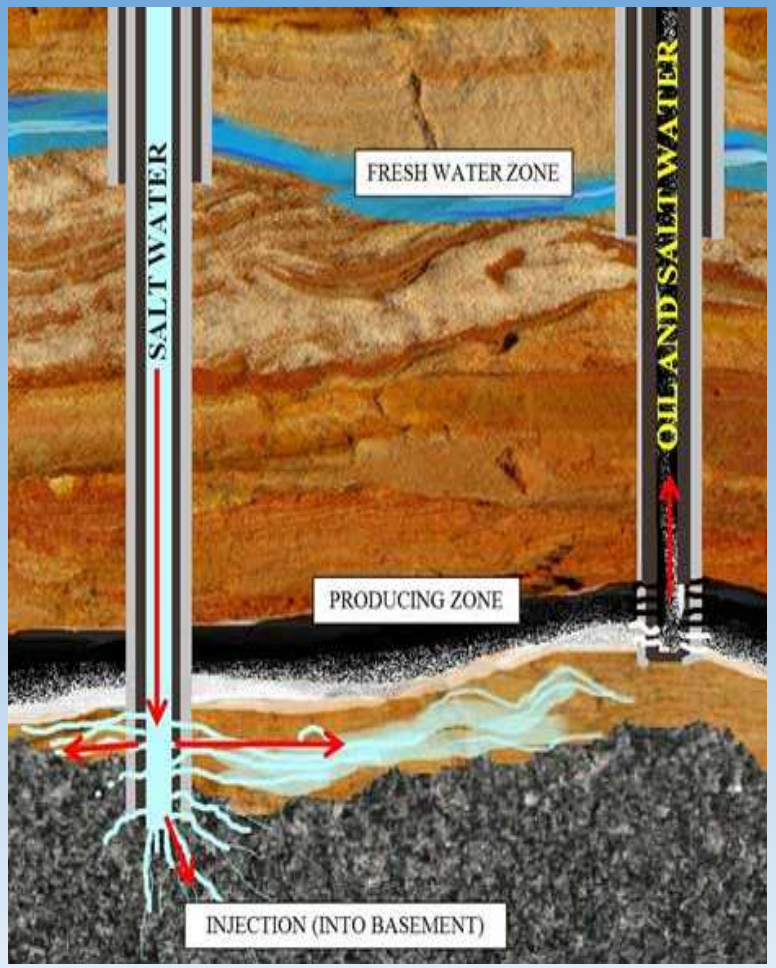
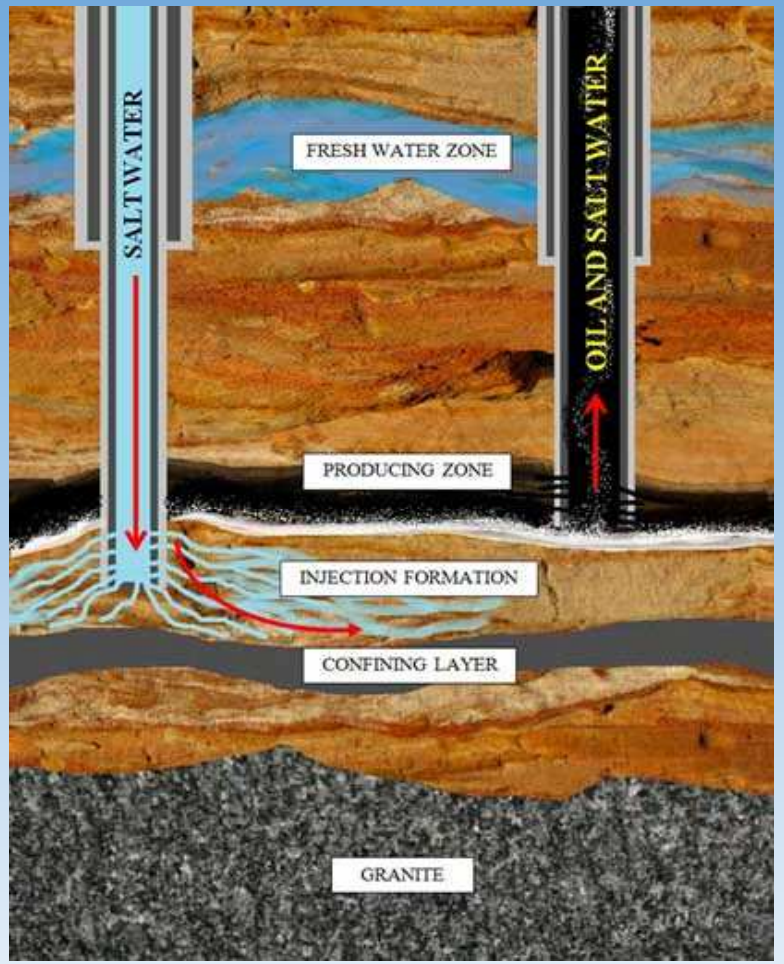
Injection Into and Above Basement





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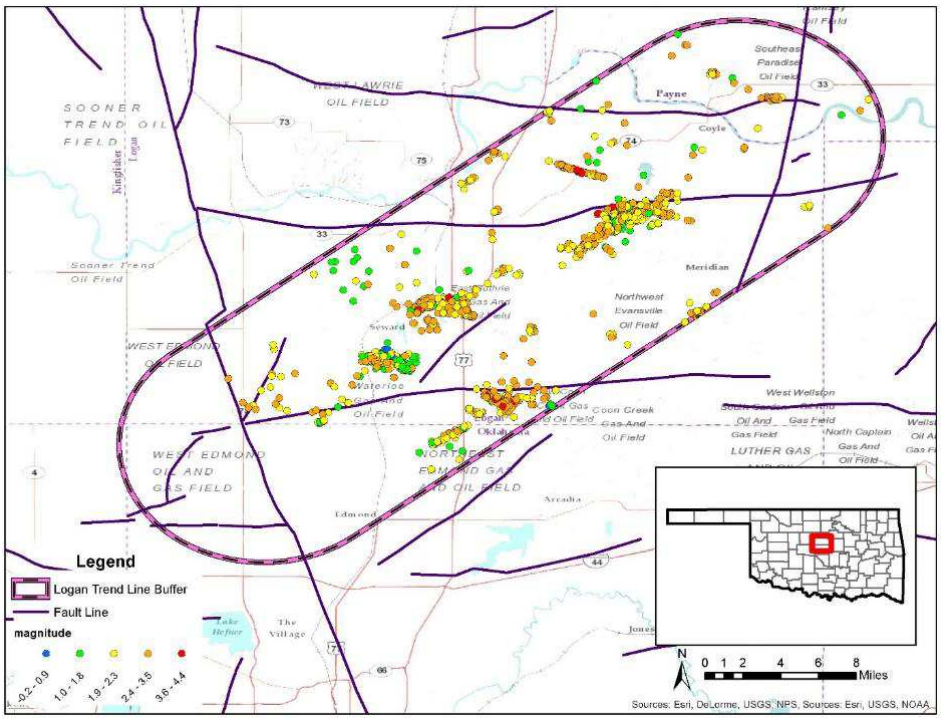
Logan County Earthquake Trend

- August 3, 2015 – OCC instituted a plan to reduce injection into Arbuckle SWD wells in proscribed areas of northern Oklahoma County and southern Logan County by 38%.
- July 28, 2015 – After 3 earthquakes above 4 M_w near Crescent, OK, the OCC contacted 3 operators of the SWD wells in Logan County – 2 voluntarily shut in their wells and the third curtailed injection 50%.



Sources: Oklahoma Corporation Commission

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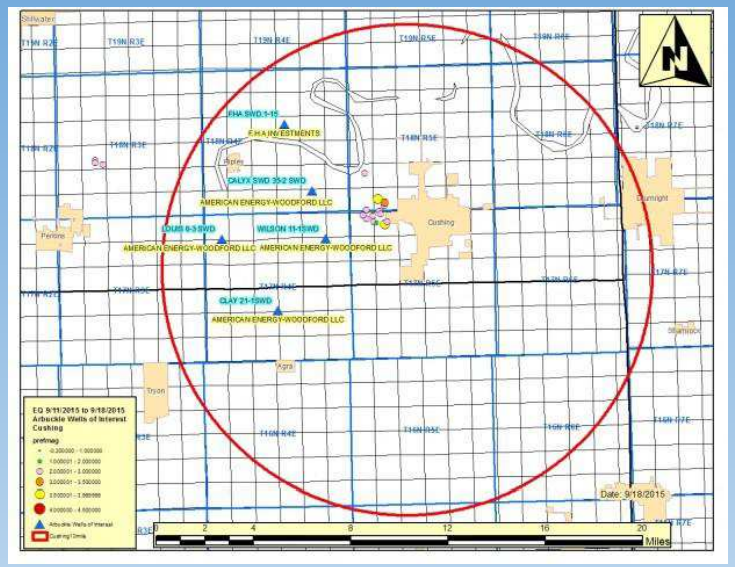
Cushing Earthquakes



OCC actions to reduce earthquakes:

- Operational changes to 13 wells
  - 4 wells SI by OCC
  - 1 well SI by Operator
  - 9 wells have reduced injection volume
- Operators put on notice that changes may be coming on 13 additional wells

Source: Oklahoma Corporation Commission, 10/19/15

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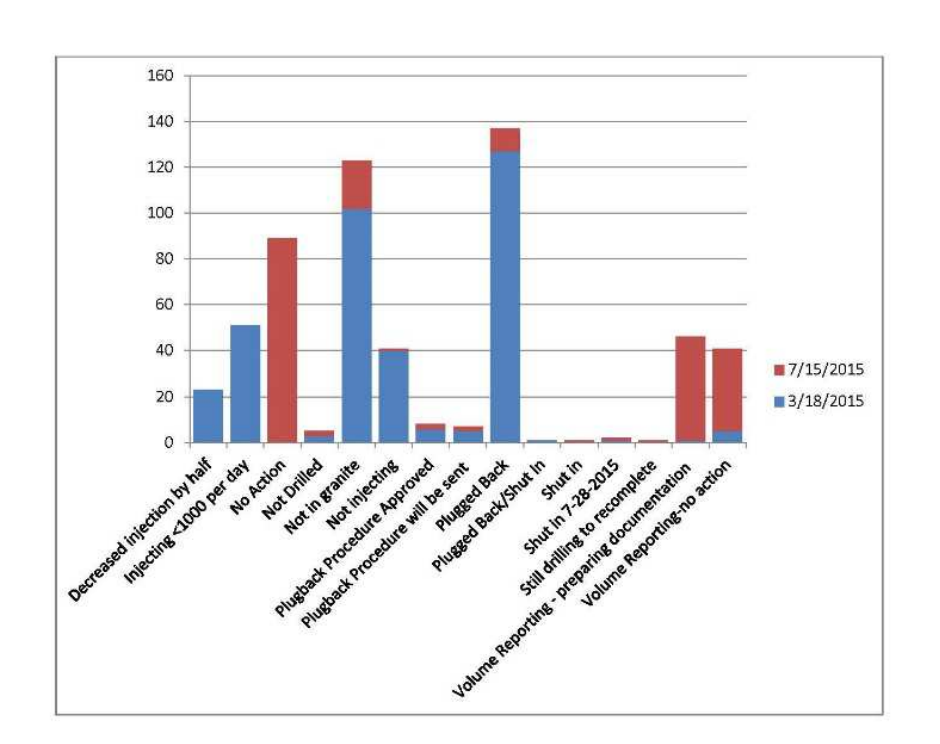
Actions taken by OCC to Reduce Earthquakes

OCC's Plan to Reduce Seismic Activity

- All operators must prove that their disposal well is not drilled into basement.
- Any well drilled into basement must be plugged back or the injection volume curtailed 50%.
- To obtain a permit for a proposed SWD well, the operator:
  - Must have a public review,
  - Must have temporary permit (6 months),
  - Must install Seismometers,
  - Must shut down if there is an increase in seismicity,
  - Must perform a reservoir pressure test every 60 days.
- Daily recording of injected volume and pressure are required by the OCC.
- Weekly volume and pressure must be reported to the OCC.
- For wells injecting 20,000 BWPD or more, an MIT is required every year.



Source: Oklahoma Corporation Commission

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Factors Affecting Seismicity from Injection

- Time between Injection and Seismicity
- Location of a potentially active fault with respect to an injection well
- Rate of injection
- Permeability of relevant strata
- Proximity of a fault that may fail
  - Only a subset of faults found in crystalline basement are potentially active
  - Significant earthquakes occurred in Oklahoma prior to 2009
  - Potentially active faults in crystalline basement have much higher permeability than in the surrounding basement rock
  - Earthquake scaling laws demonstrate large earthquakes such as Prague (M_w5.6) require slip faults tens of kilometers in extent

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Managing Injection Related Seismic Issues

In Oklahoma injection of large volumes of produced water into the Arbuckle appears to be triggering seismic activity in the crystalline basement.

- Potential Solutions
  - Reduce the total volume being injected into the Arbuckle (according to Walsh and Zoback "establishing an arbitrary upper limit to injection rates of any single well may not reduce the probability of triggering" earthquakes)
  - Inject produced water back into zones depleted by previous production
  - Inject produced water into zones which have impermeable barriers
  - Treat and reuse the water for a beneficial purpose
  - Treat and return the water to the environment

Reference – Walsh and Zoback, Science Adv. June 18, 2015

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Overview

- Water is scarce and is getting harder to acquire
- Seismicity may reduce or eliminate use of SWDs
- Pointing toward a need for:
  - Increased recycling
  - Treatment for discharge

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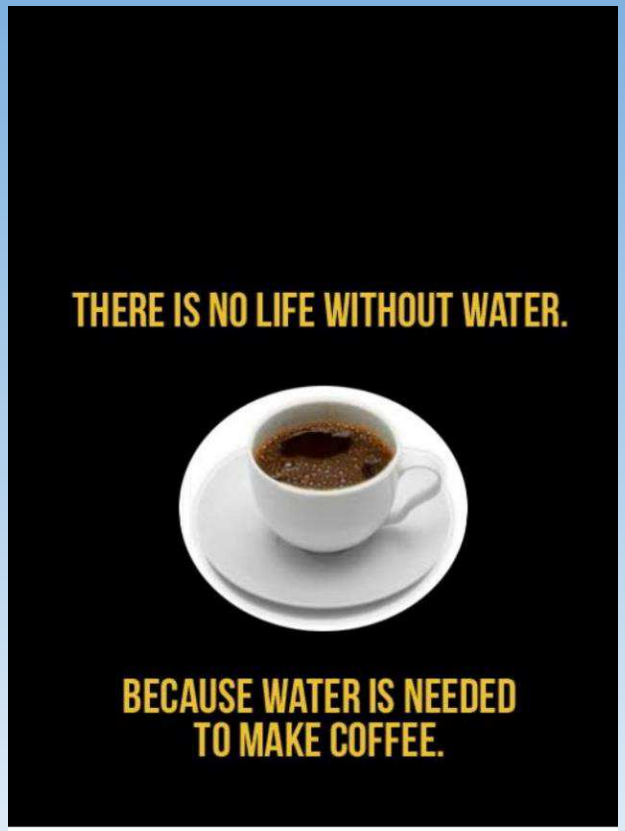
Questions?



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International Petroleum Environmental Conference 22ND IPEC

Please reference as:

Tipton, D. Steven, PE (ALL Consulting). “The Oklahoma Water Conundrum.” Presented at the Ground Water Protection Council Annual Forum, September 28-30, 2015, Oklahoma City, OK.

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