Drop of Water by Jani Ravas

Water and Unconventional Energy: Dependent Resources

A Look at Current Issues in Water Usage, Fluid Waste Disposal, and Induced Seismicity Related to Hydraulic Fracturing

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Hydraulic Fracturing and Water Usage

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Hydraulic Fracturing

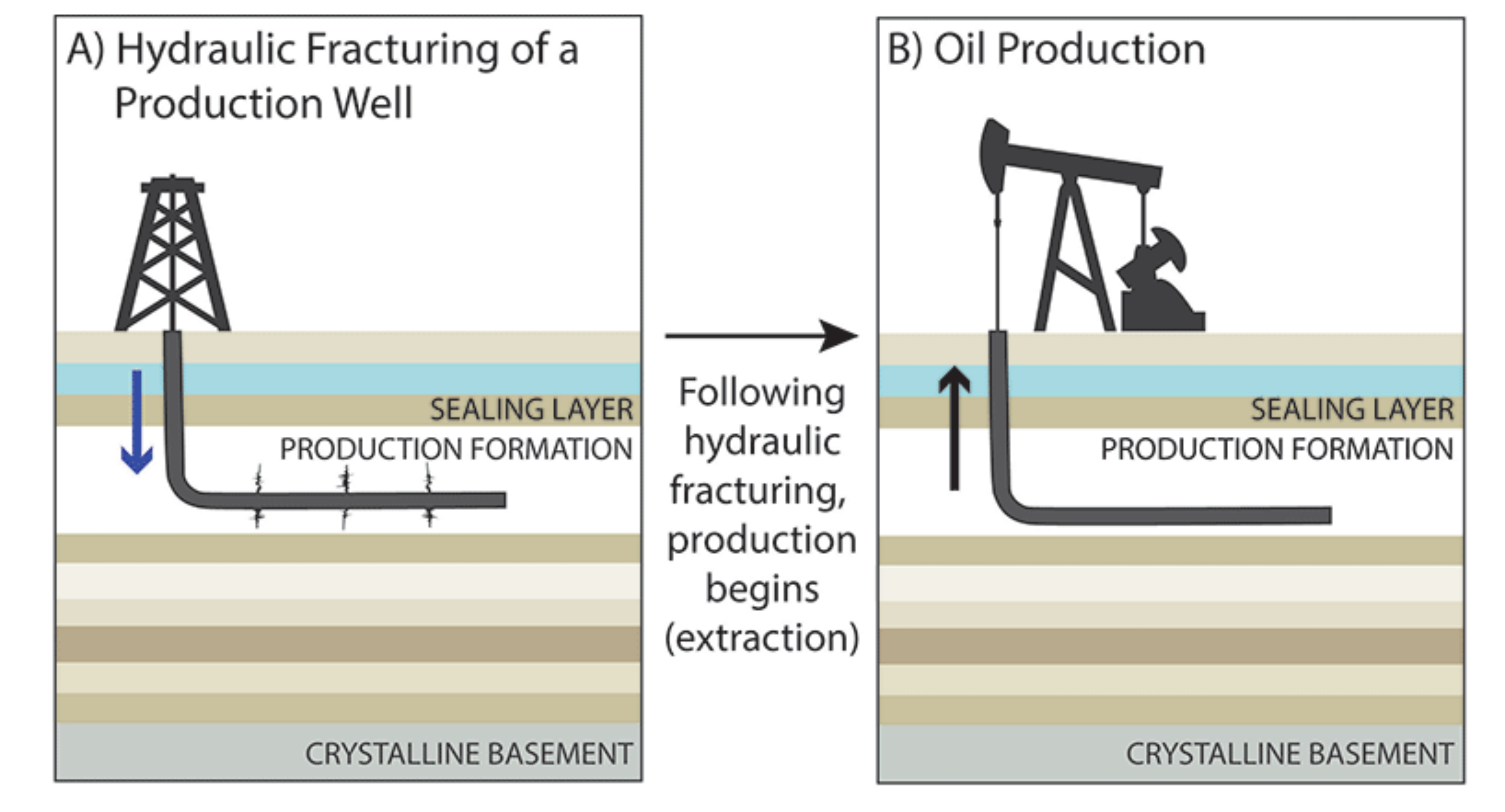
What is it and how does it work?

- A method of drilling wells that releases oil and gas from shale rock by using water and other fluids under pressure to fracture or crack the rock, thereby releasing the oil and gas.

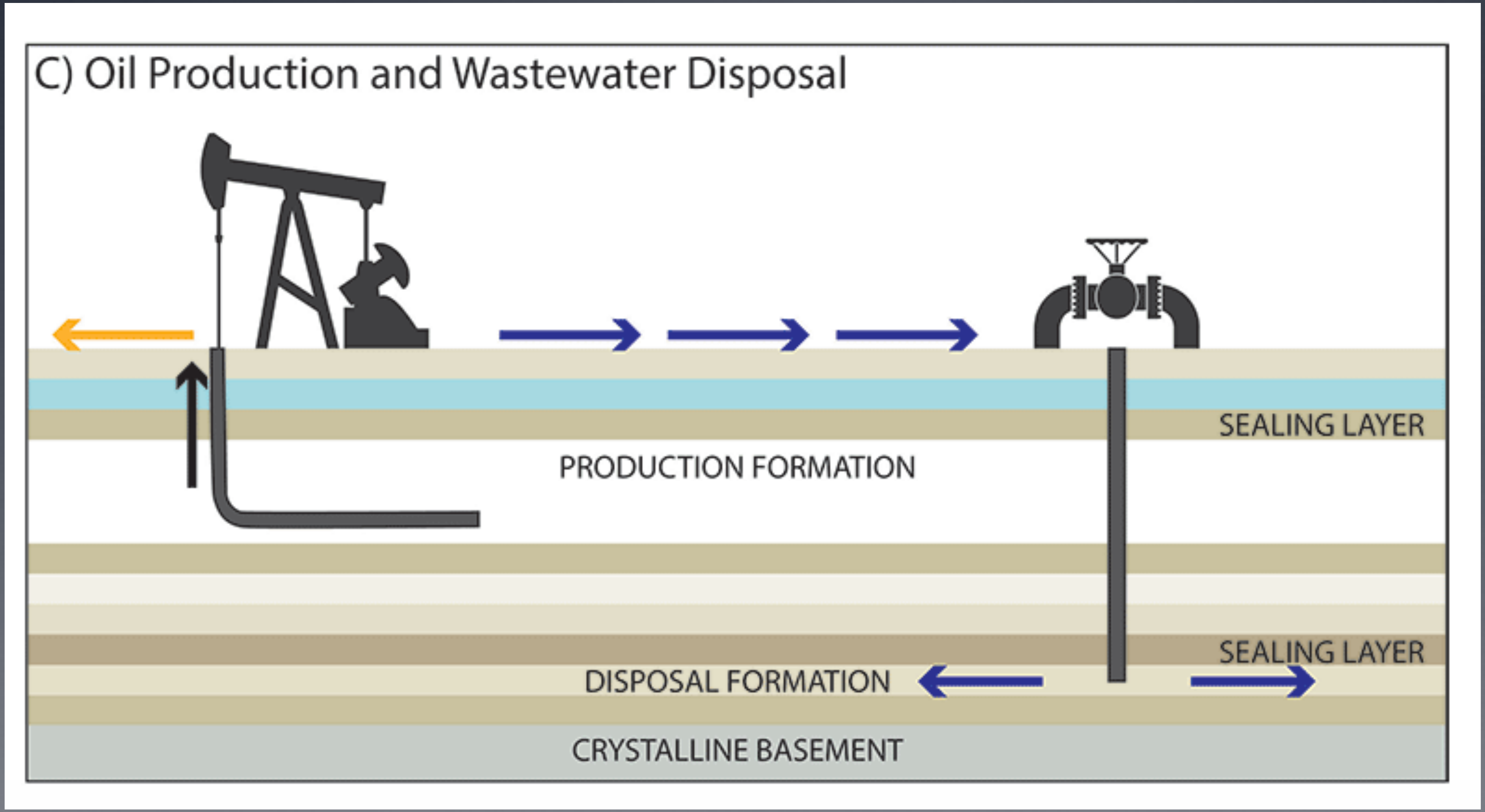
- Freshwater combined with chemical additives assist with the completion of a well.

- The average well requires between 2 and 9 million gallons of water for hydraulic fracturing.

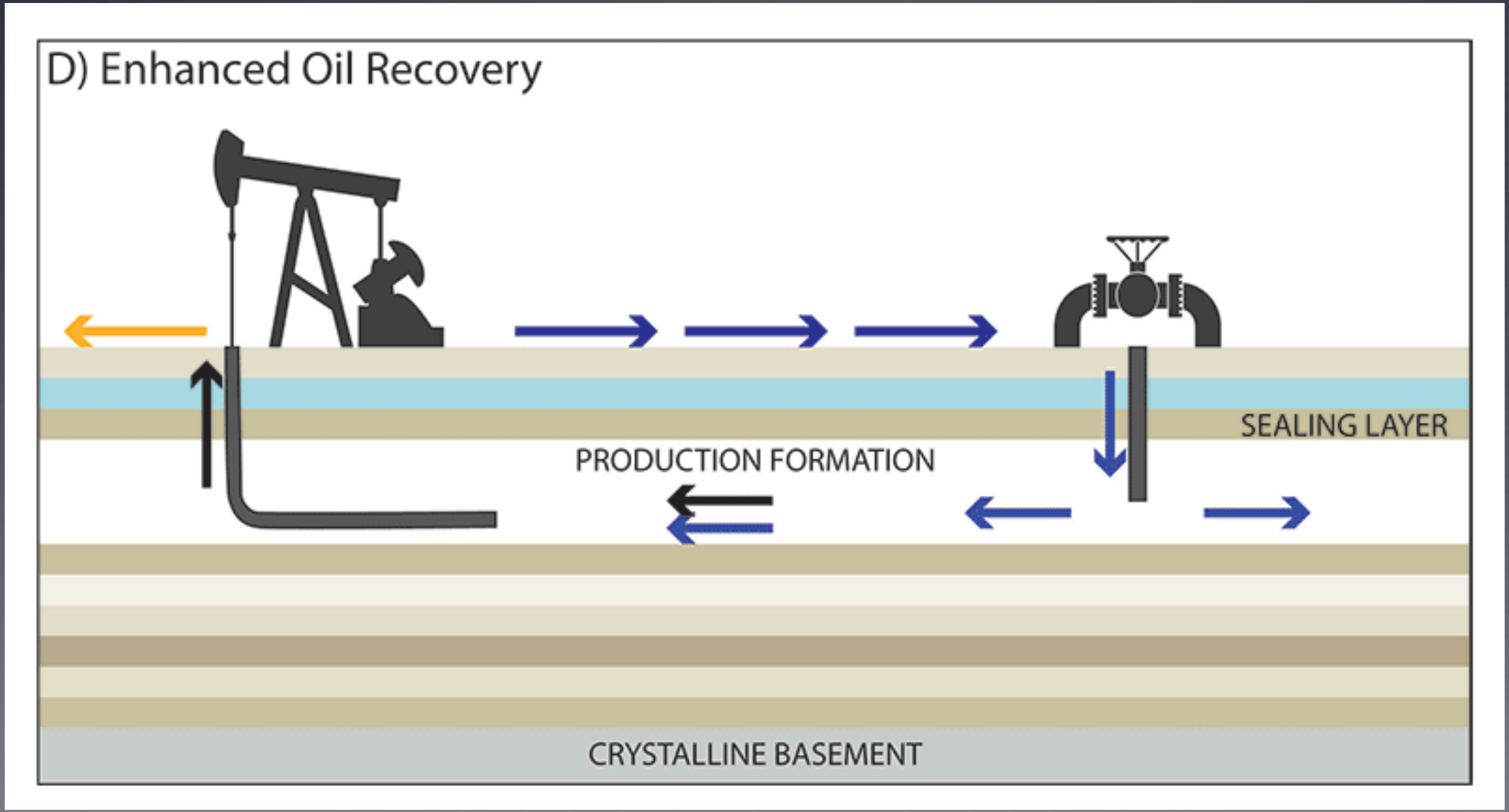
Hydraulic Fracturing and Oil Production



Oil Production and Wastewater Disposal



Enhanced Oil Recovery



Water Use in Perspective

- 65.8 billion gallons of water used for hydraulic fracturing for oil and gas development across the U.S. from Jan. 2011 through Sept. 2012
    - Enough Water to supply roughly 2.5 million Americans for one year

- Texas used a reported 25 billion gallons in 2012 for hydraulic fracturing
    - This represents less than 2 percent of total water usage in Texas
    - 47 percent of Texas shale gas wells are located in areas with high or extremely high water risk
    - High or extremely high risk means over 80 percent of available water for an area is being withdrawn for municipal, industrial, and agricultural purposes each year

Water Use by Type of Production

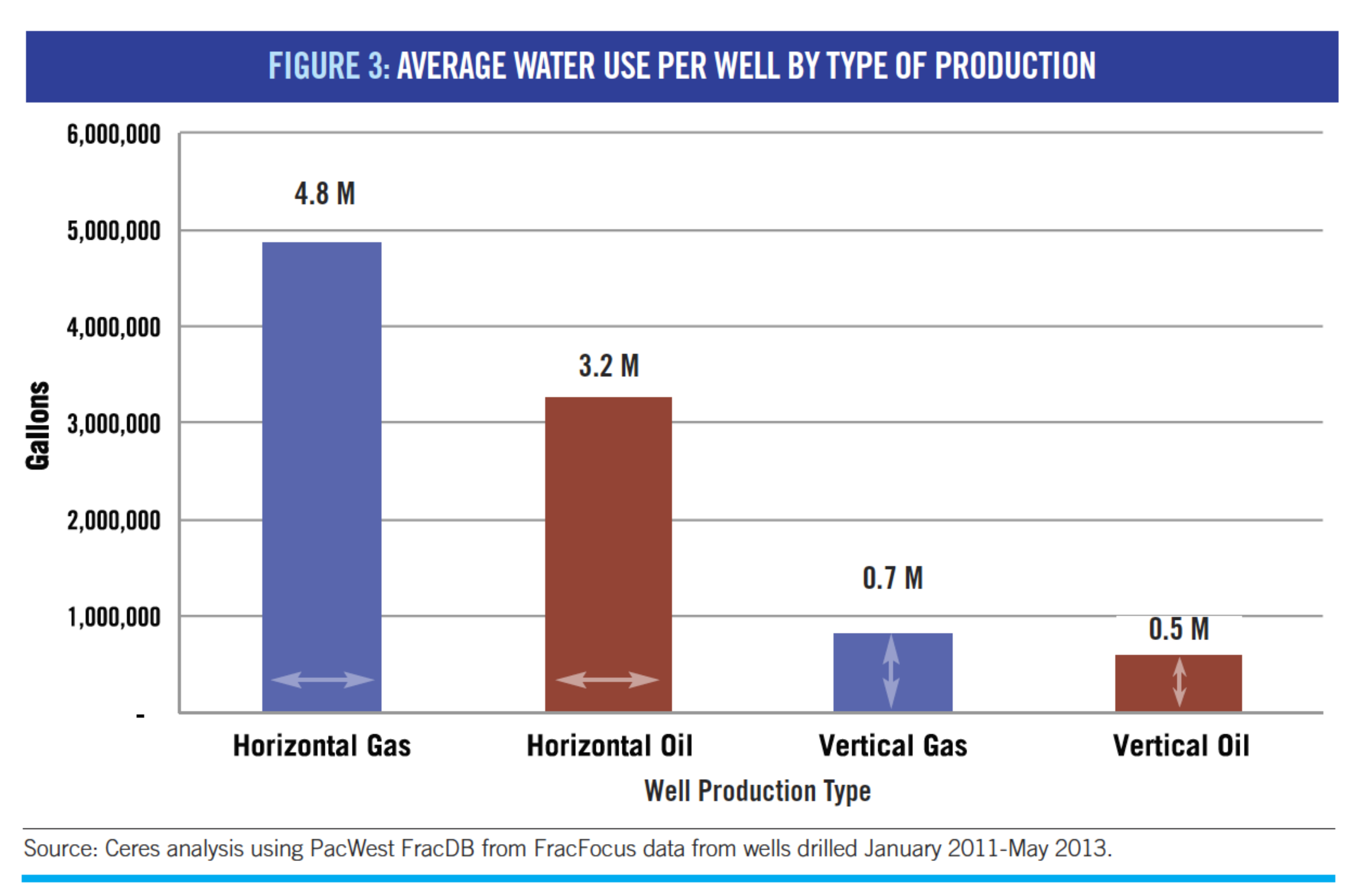
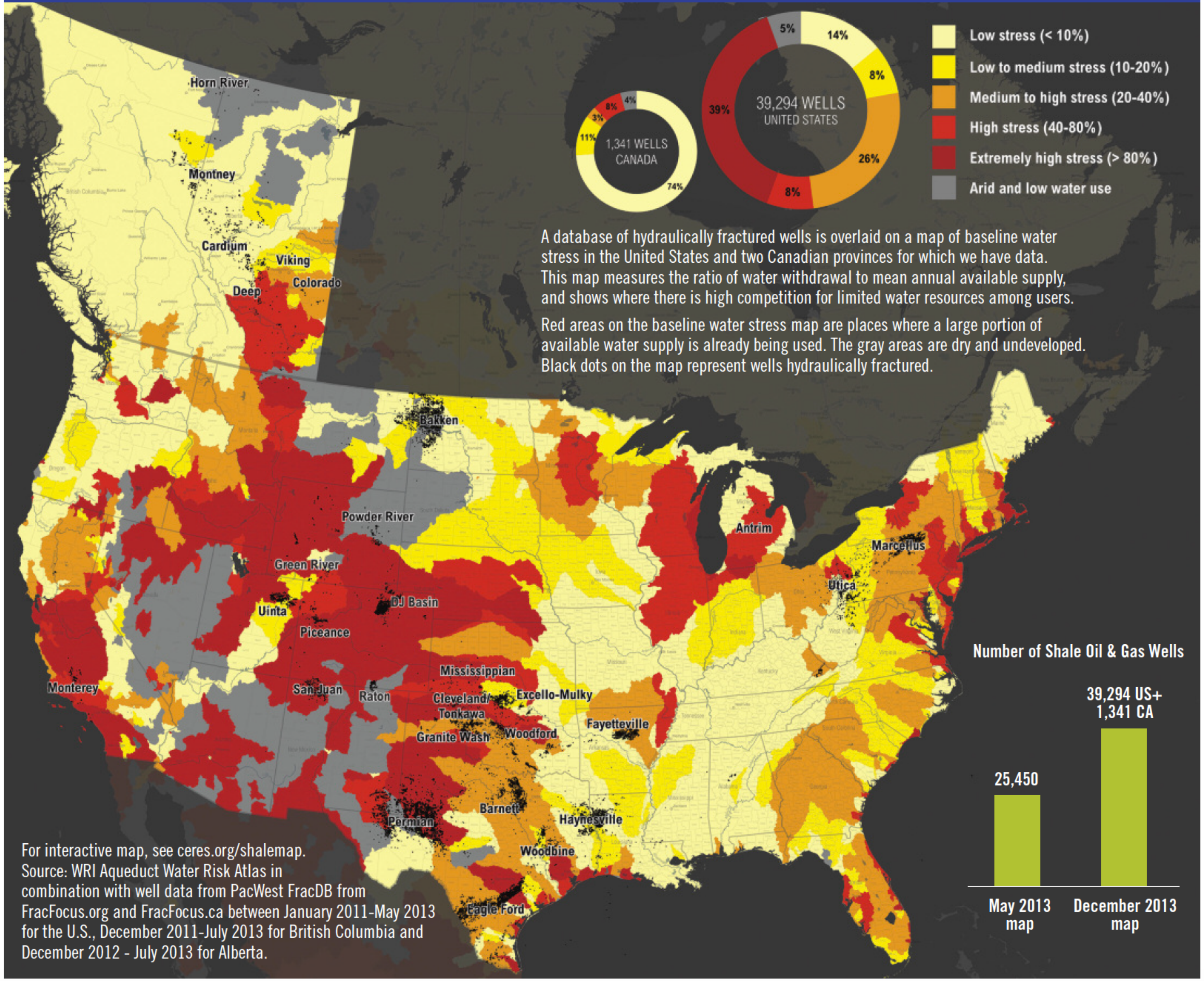
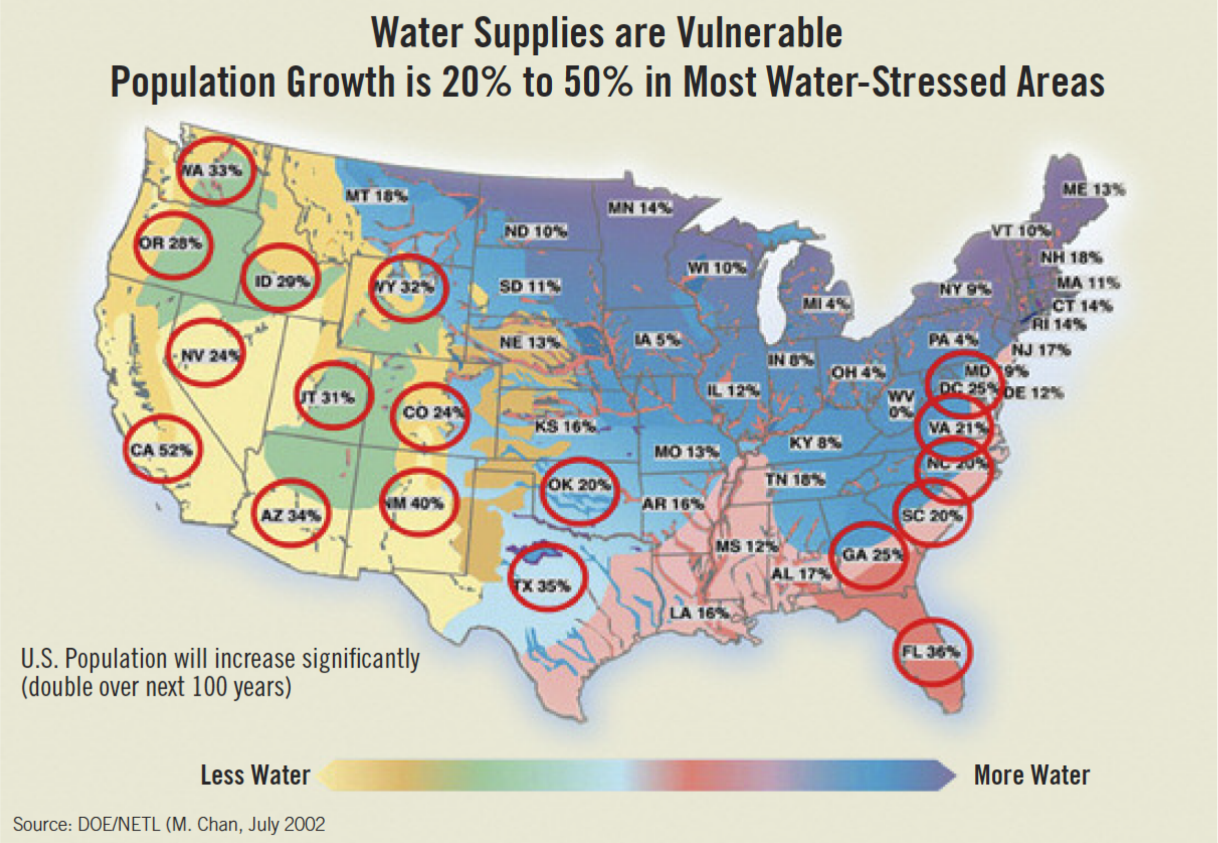


FIGURE 5: NORTH AMERICAN WATER STRESS & SHALE ENERGY DEVELOPMENT



Water Resources and Population Growth

FIGURE 11: WATER RESOURCE STRESS & POPULATION GROWTH, 2000-2020



Many areas of high water stress are also expected to see high population growth through 2020. Texas, Colorado, Wyoming, New Mexico, Oklahoma and California face expected population growth, water stress and shale energy development.

Source: Sandia National Labs, "Energy-Water Nexus Overview," http://www.sandia.gov/energy-water/nexus_overview.htm.

FIGURE 9: U.S. DROUGHT MONITOR MAP & SHALE ENERGY DEVELOPMENT

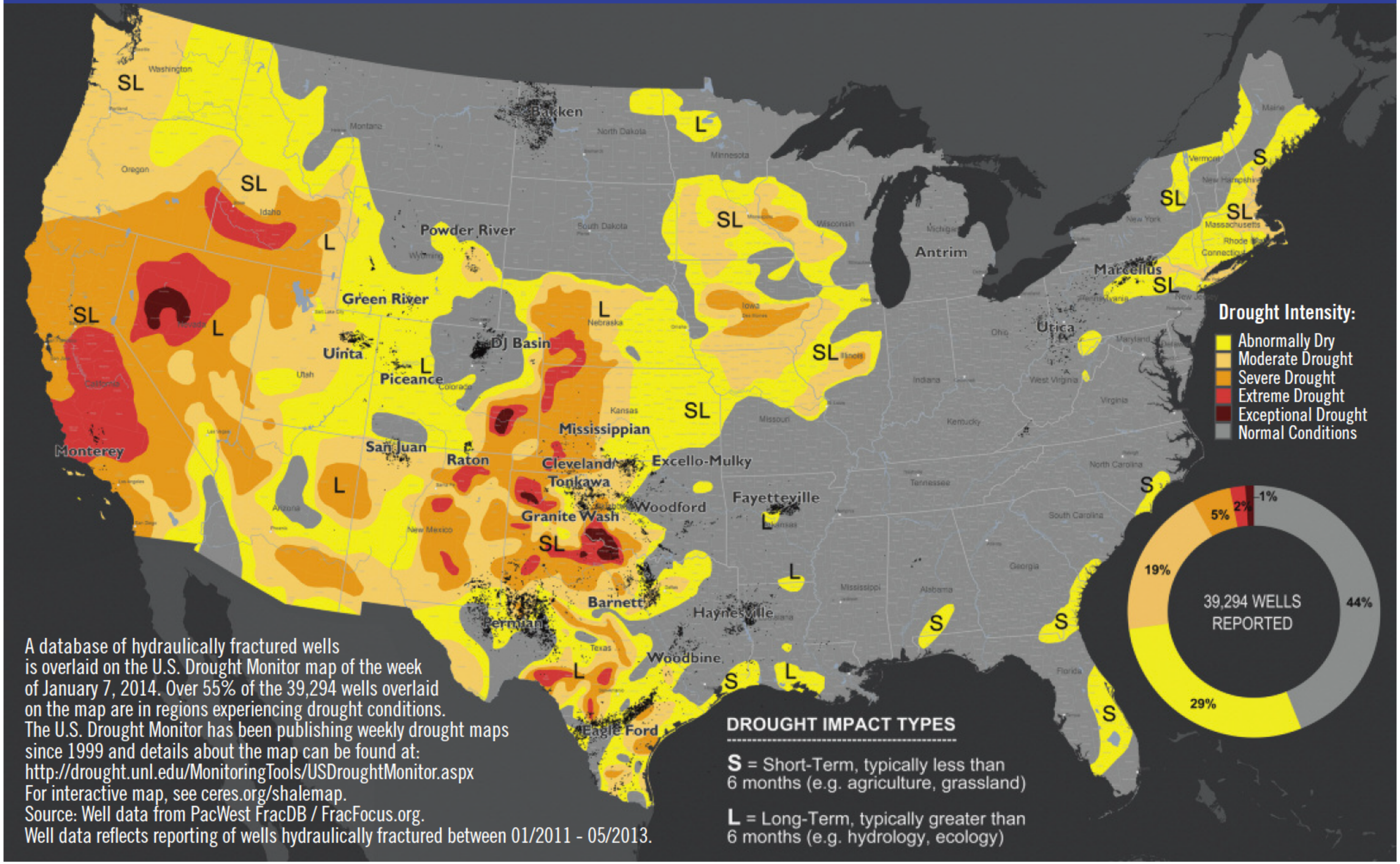
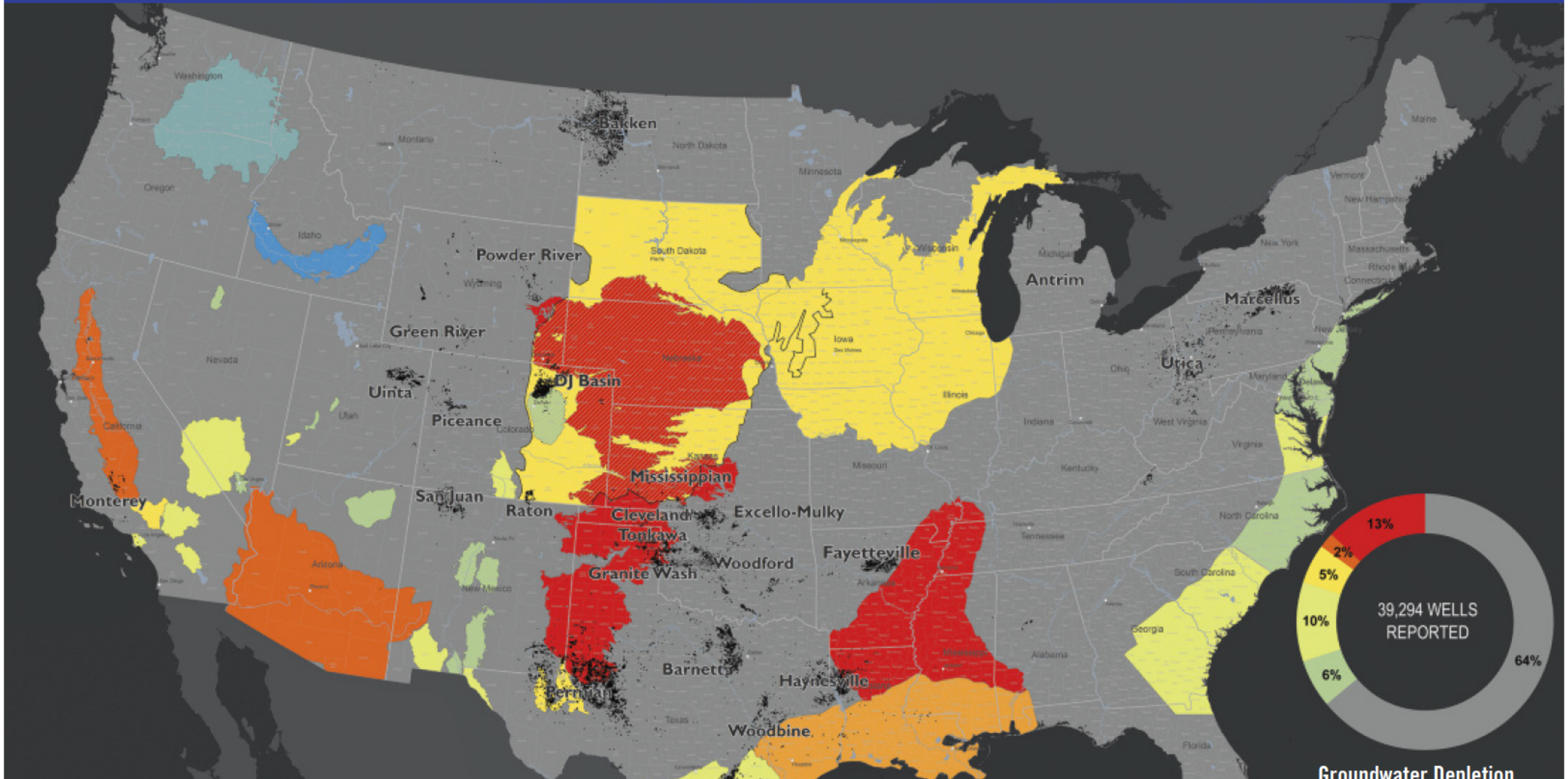


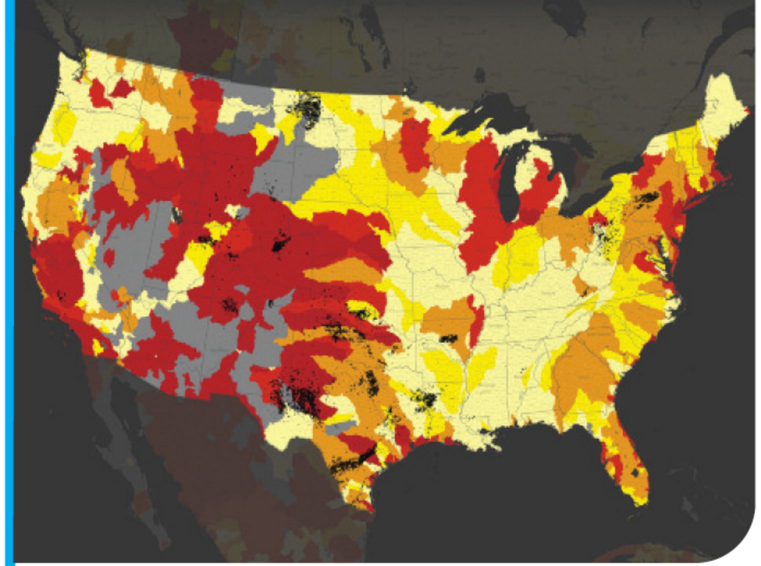
FIGURE ES2: GROUNDWATER DEPLETION & SHALE ENERGY DEVELOPMENT



A U.S. Geological Survey map of cumulative groundwater depletion, from 1900 - 2008, in 40 major aquifer systems overlaid by 39,294 hydraulically fractured oil and gas wells (black dots).
For interactive map, see ceres.org/shalemap.
Source: Well data from PacWest FracDB from FracFocus.org between January 2011-May 2013 and U.S. Geological Survey Scientific Investigations Report 2013-5079.

United States

Water Use Trends for Hydraulic Fracturing



U.S. Data Summary (January 1, 2011 - May 31, 2013) as reported by FracFocus

WATER USE TRENDS

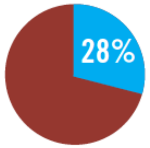
Number of Wells Used to Calculate Water Volume Data:	**39,294**
Total Water Use *(gallons)*:	**97.5 billion**
Average Water Use *(gallons/well)*:	**2.5 million**

EXPOSURE TO WATER RISKS

Proportion of Wells in **High or Extreme Water Stress:**	**48%**
Proportion of Wells in **Medium or Higher Water Stress:**	**73%**
Proportion of Wells in **Drought Regions** (as of Jan. 7, 2014):	**56%**

LOCAL WATER USE IMPACTS

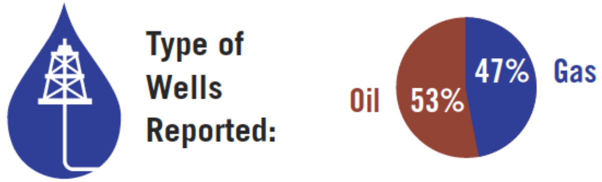
Water Use in Top 10 Counties
as Proportion of Water Use Nationally



Number of Counties with Hydraulic Fracturing Activity:	**402**
Highest Water Use by a County *(gallons)*: **Dimmit County, Texas**	**4 billion**

OPERATING TRENDS

Type of Wells Reported:



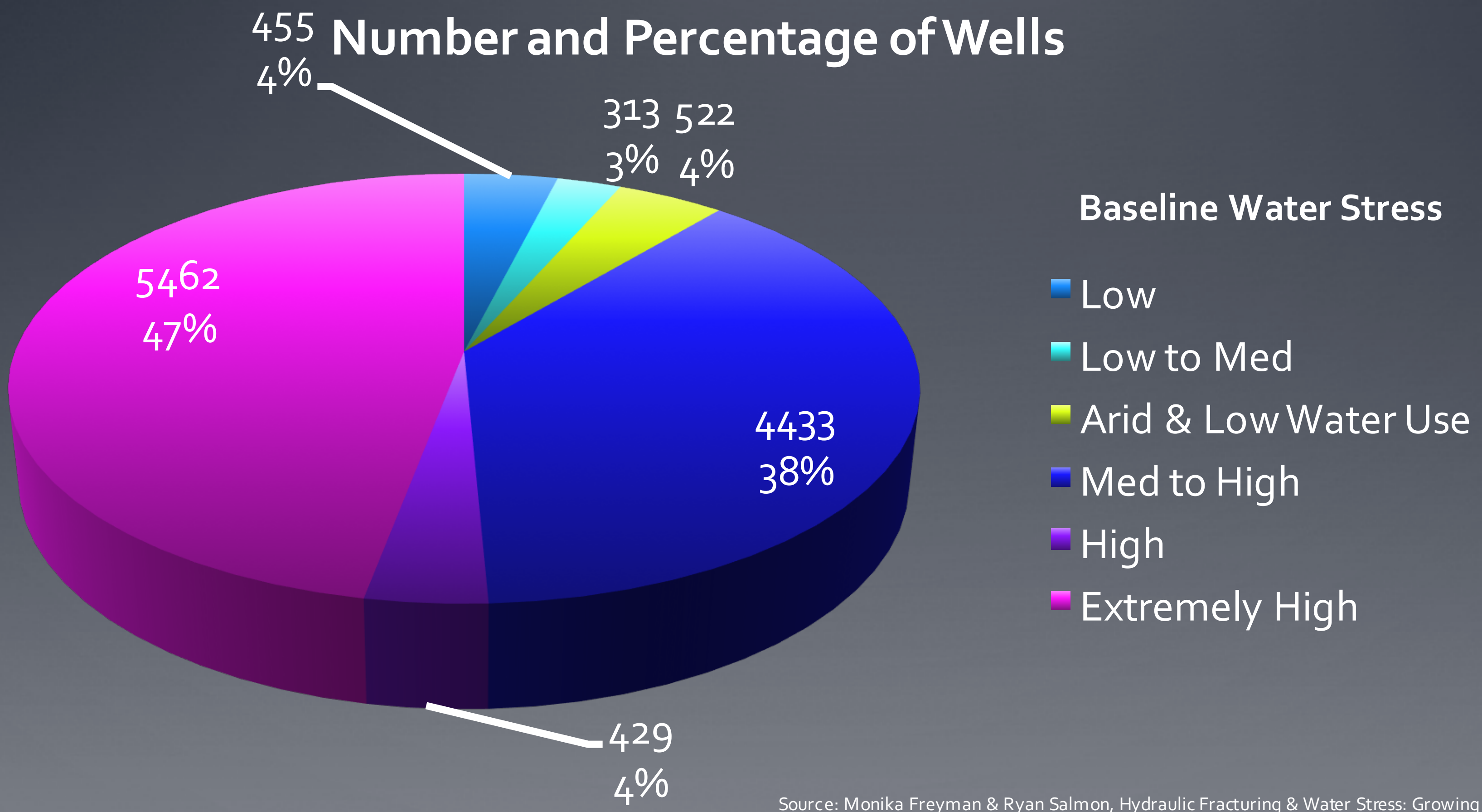
Number of Operators Reporting to FracFocus (1st Quarter 2013)

253

OPERATORS
Top Three in U.S. by Water Use:
- Chesapeake
- EOG
- XTO

SERVICE PROVIDERS
Top Three in U.S. by Water Use:
- Halliburton
- Schlumberger
- Baker Hughes

Texas Wells and Water Stress



Source: Monika Freyman & Ryan Salmon, Hydraulic Fracturing & Water Stress: Growing Competitive Pressures for Water 7 (May 2013).

Barnett Shale Annual Water Use

2000-2012

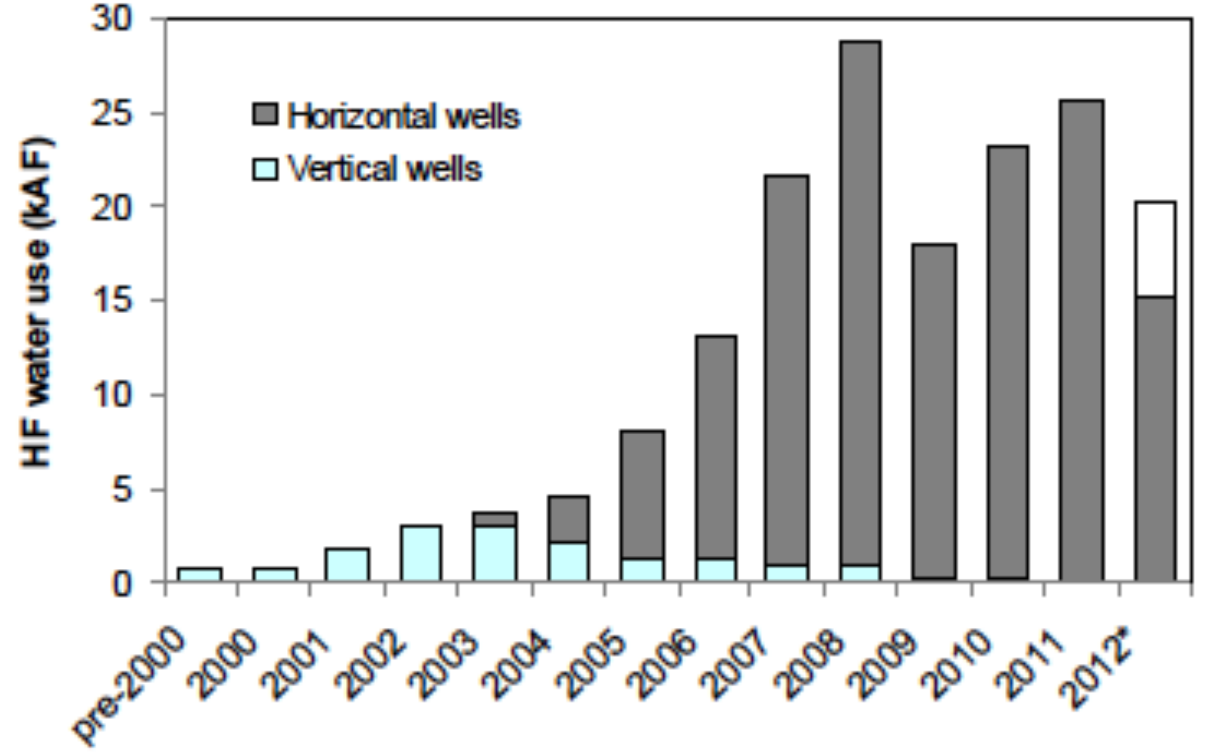
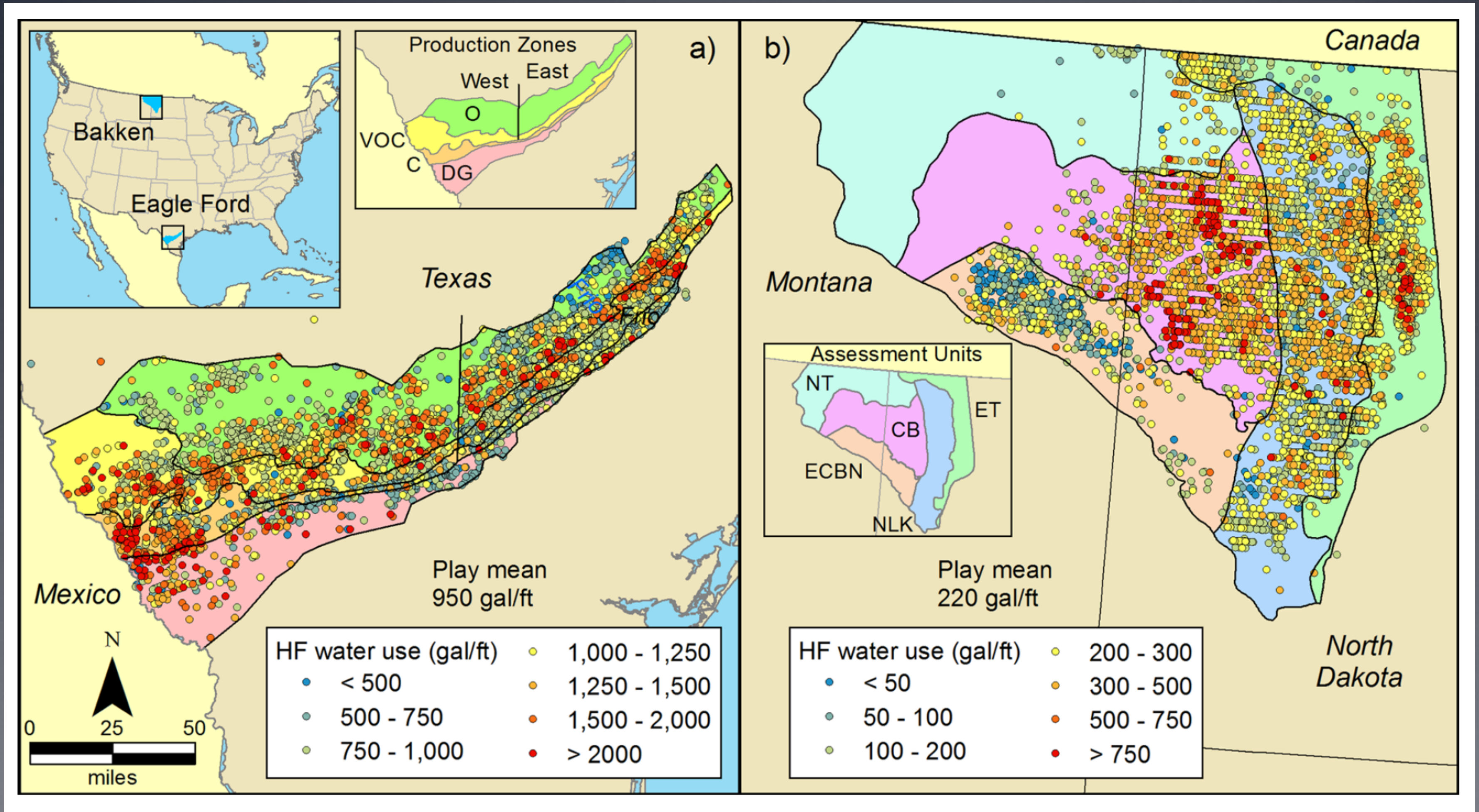


Figure S3. Annual HF water use; 2012 data not complete; 5 kAF, estimated additional 2012 water use not yet recorded in the database, is added to the plot.

Source: Jean-Philippe Nicot, Bridget R. Scanlon, Robert C. Reedy, and Ruth A. Costley, Source and Fate of Hydraulic Fracturing Water in the Barnett Shale: A Historical Perspective, S13 (Nov. 29, 2013).

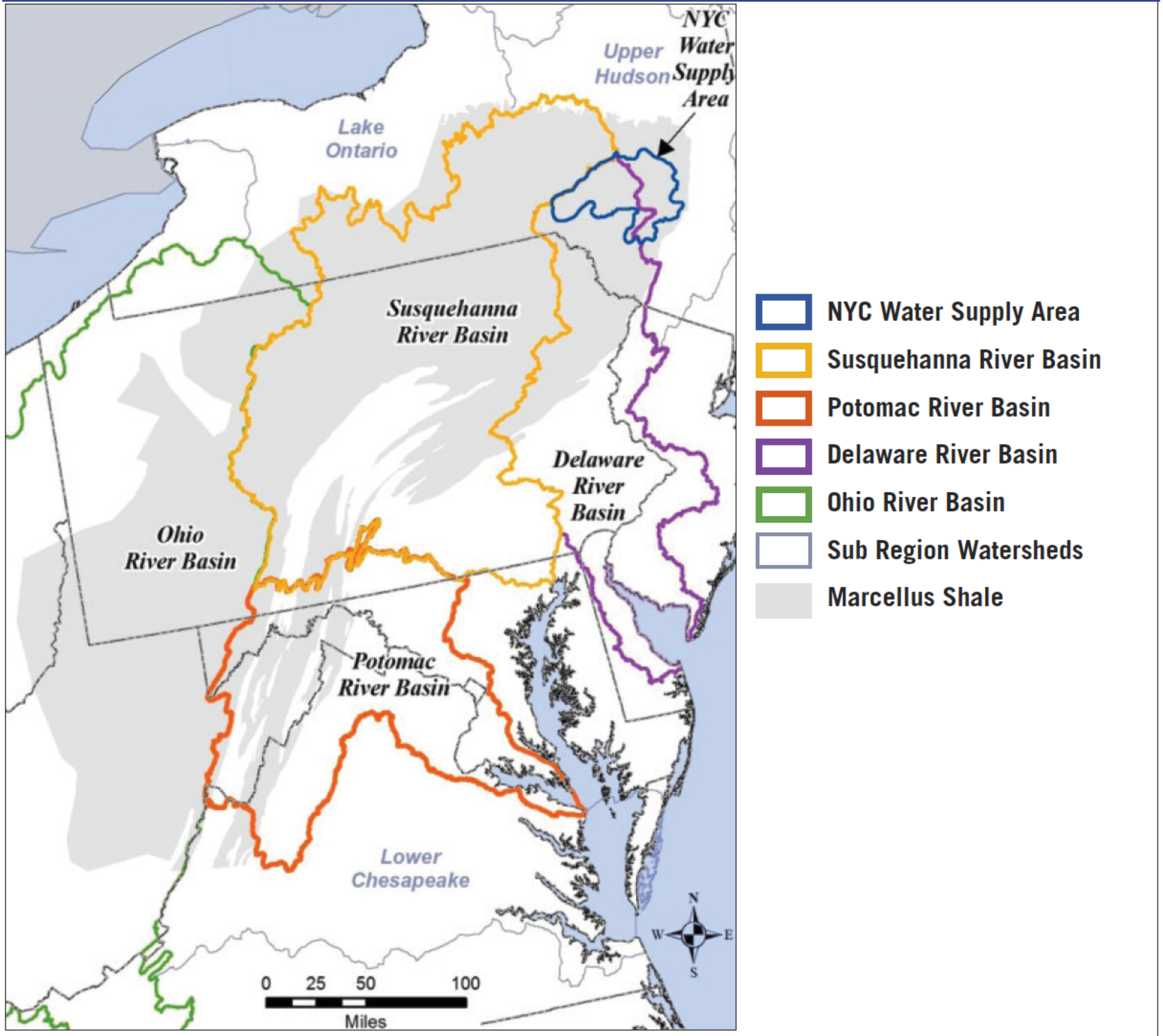
Water Use in Bakken and Eagle Ford Shale



Source: B. R. Scanlon, R. C. Reedy, & J.-P. Nicot, *Comparison of Water Use for Hydraulic Fracturing for Unconventional Oil and Gas Versus Conventional Oil*, 48 Environmental science & technology 12386 (2014).

Marcellus Shale and Water Resources

FIGURE 36: THE MAJOR RIVER BASINS OF THE MID-ATLANTIC AND EXTENT OF MARCELLUS SHALE



Source: J. Daniel Arthur et al, Water Resources and Use for Hydraulic Fracturing in the Marcellus Shale Region, ALL Consulting, LLC.

Alternatives to New Water

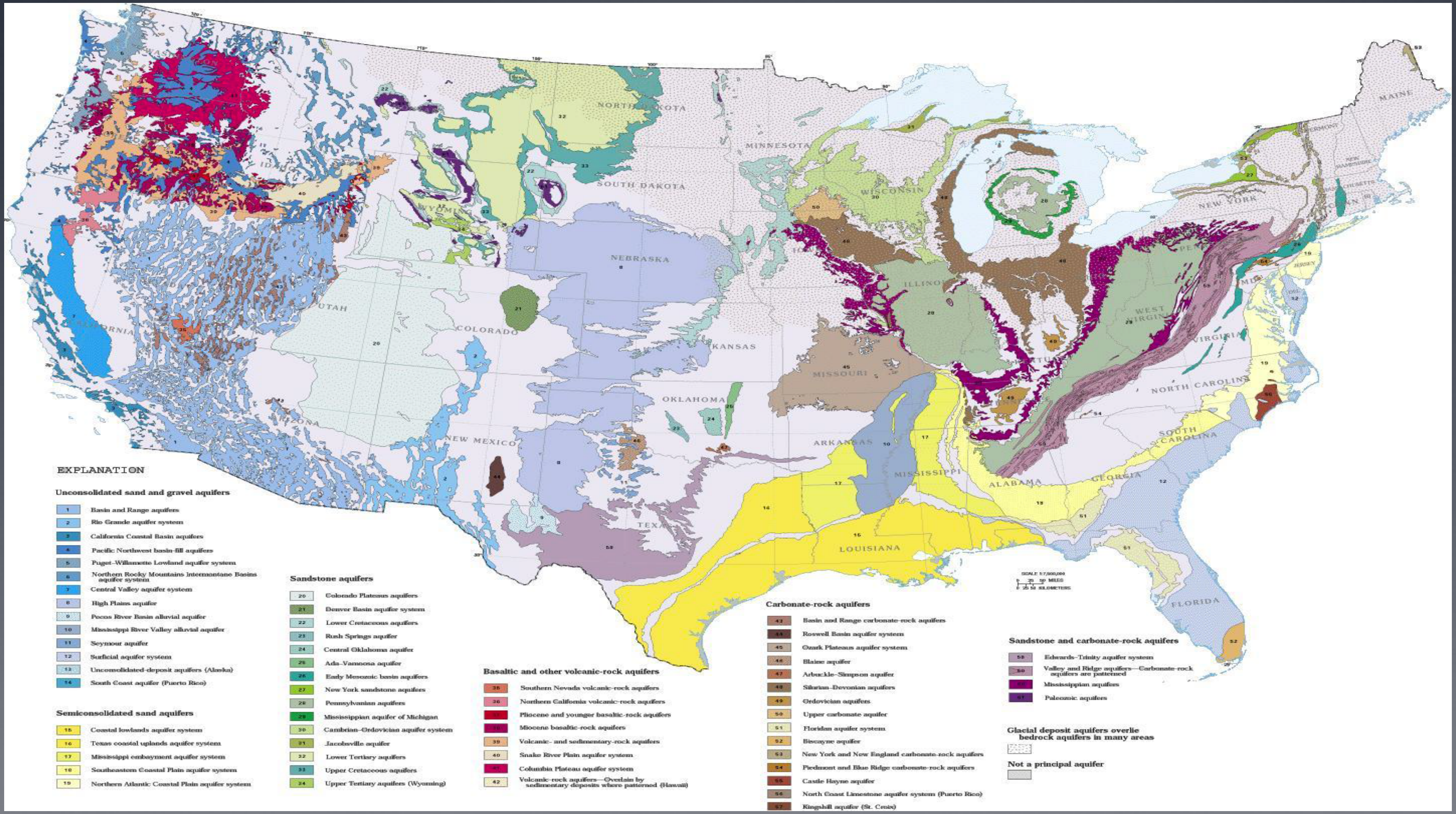
Brackish Water

- Abundant supply of brackish and sea water
- Nine legislative bills introduced in 2013 Session regarding brackish water
- Concerns remain over well corrosion, contamination, and regulation

Recycle/Reuse

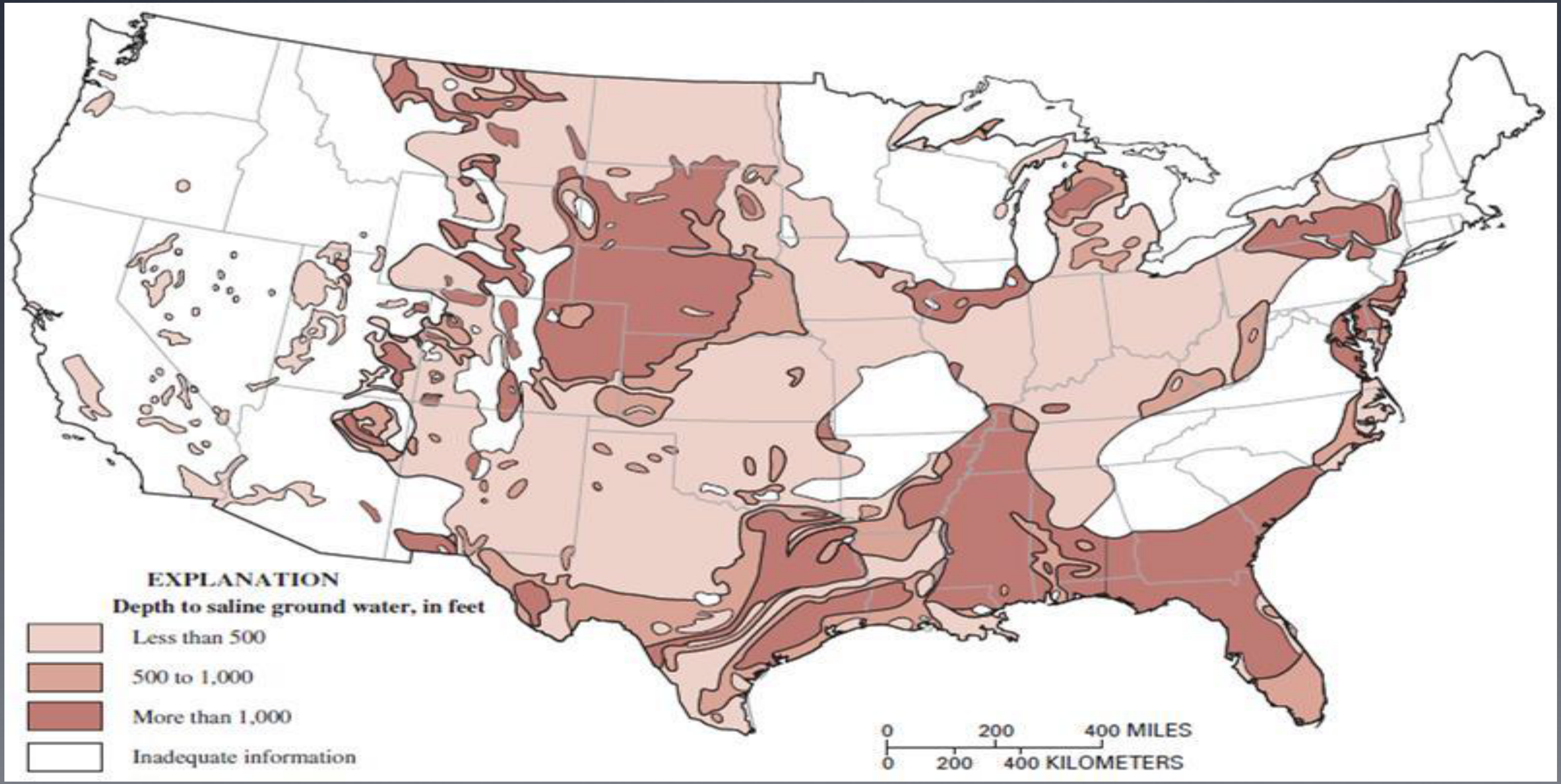
- Variety of methods on or off-site (microfiltration, vapor recompression, etc.)
- Trucking and disposal rates reduced 60%
- More expensive than current injection disposal
- 16 Tex. Admin. Code Ch. 4, Subch. B—Rules addressing recycling by oil and gas operators

US Fresh Water Aquifers



Source: William E. Godsey, Fresh, Brackish or Saline Water for Hydraulic Fracs: What are the Options?

US Saline Aquifers



Source: William E. Godsey, Fresh, Brackish or Saline Water for Hydraulic Fracs: What are the Options?

Recycling/Reuse by Shale

Barnett Shale

- Fresh Water: 92% (20% groundwater and 80% surface water)
- Brackish Water: 3%
- Recycled/Reused: 5%

Eagle Ford Shale

- Fresh Water: 80% (90% groundwater and 10% surface water)
- Brackish Water: 20%
- Recycled/Reused: 0%

Haynesville Shale/East Texas Basin

- Fresh Water: 95% (70% groundwater and 30% surface water)
- Brackish Water: 0%
- Recycled/Reused: 5%

Permian Basin

- Fresh Water: 20% in Far West and 68% in Midland (100% groundwater)
- Brackish Water: 80% in Far West and 30% in Midland
- Recycled/Reused: 0% in Far West and 2% in Midland

Anadarko Basin

- Fresh Water: 50% (80% groundwater and 20% surface water)
- Brackish Water: 30%
- Recycled/Reused: 20%

Source: Jean-Philippe Nicot, Robert C. Reedy, Ruth A. Costley, & Yun Huang, Oil and Gas Water Use in Texas: Update to the Mining Water Use Report 54 -56 (Sept. 2012).

Flow back/Produced Water Volume by Shale

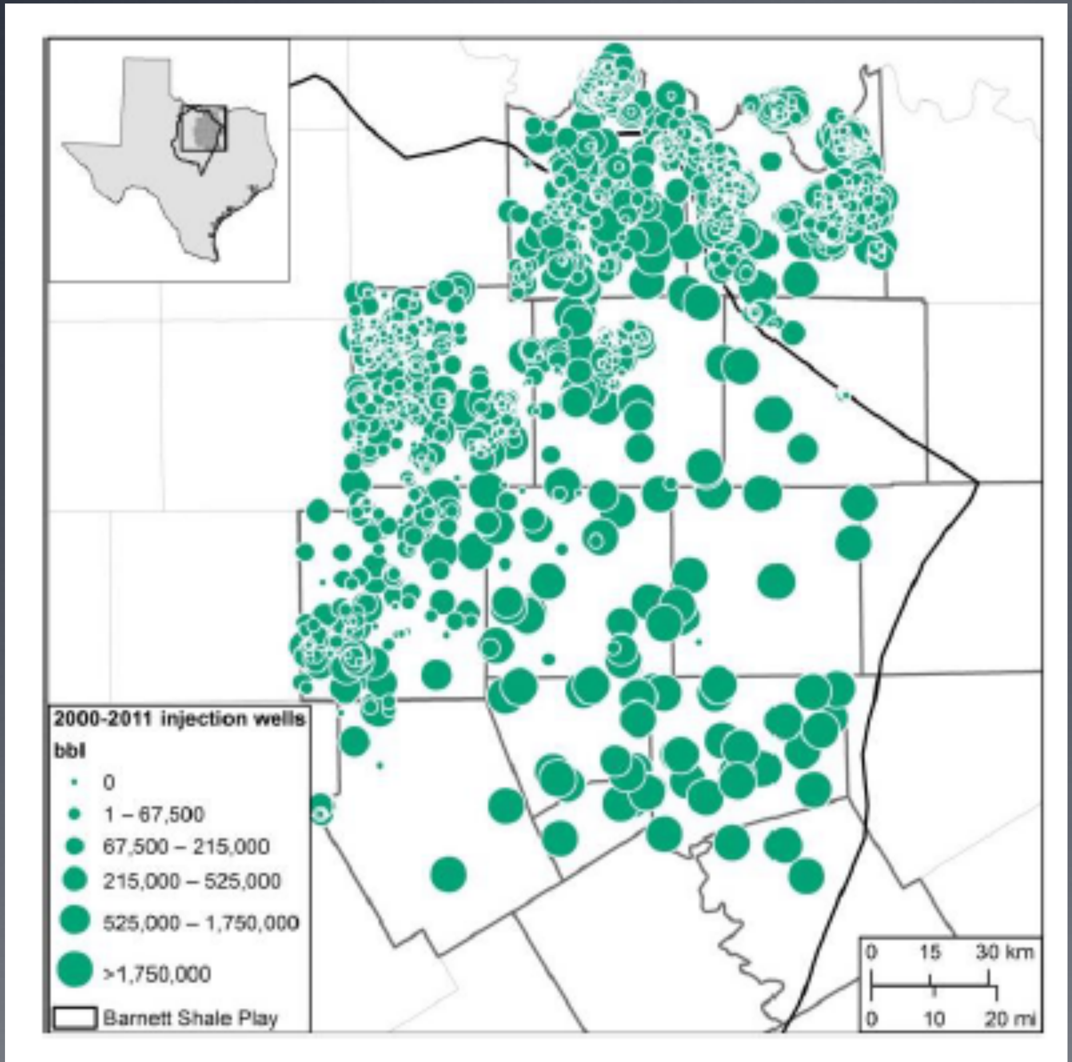
Estimated flow back/produced water volume relative to HF injected volume

Play / Region	Comment
Delaware Basin (Permian Basin)	Close to 100% in year 1, 150% well life >200% well life
Midland Basin (Permian Basin)	50%-100% in year 1
Anadarko Basin	~50% in month 1, 90% at month 6
Barnett Shale	10-20% month 1, 20-60% well life 70% year1; 150% in 5 years
Eagle Ford Shale	20% over life; 20% over life
Haynesville Shale	20% over life; 15% over life
Cotton Valley Fm.	60% month 1, >100% well life; 40% or 100% over life

Source: Jean-Philippe Nicot, Robert C. Reedy, Ruth A. Costley, & Yun Huang, Oil and Gas Water Use in Texas: Update to the Mining Water Use Report 70 (Sept. 2012).

Fluid Waste Disposal

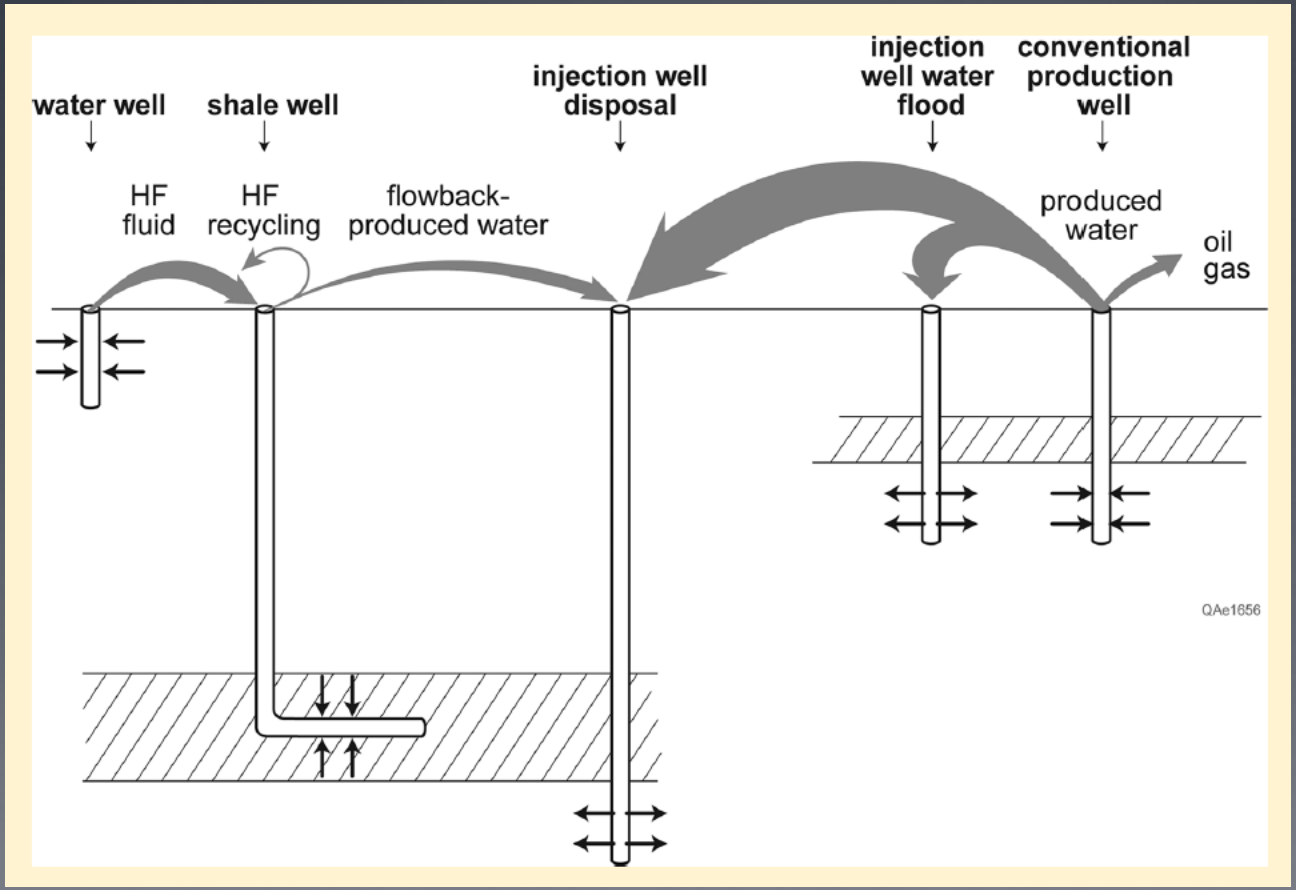
Map of Barnett Shale Injection Wells and Cumulative Injected Volume 2000-2011



Source: Jean-Philippe Nicot, Bridget R. Scanlon, Robert C. Reedy, and Ruth A. Costley, Source and Fate of Hydraulic Fracturing Water in the Barnett Shale: A Historical Perspective, S38 (Nov. 29, 2013).

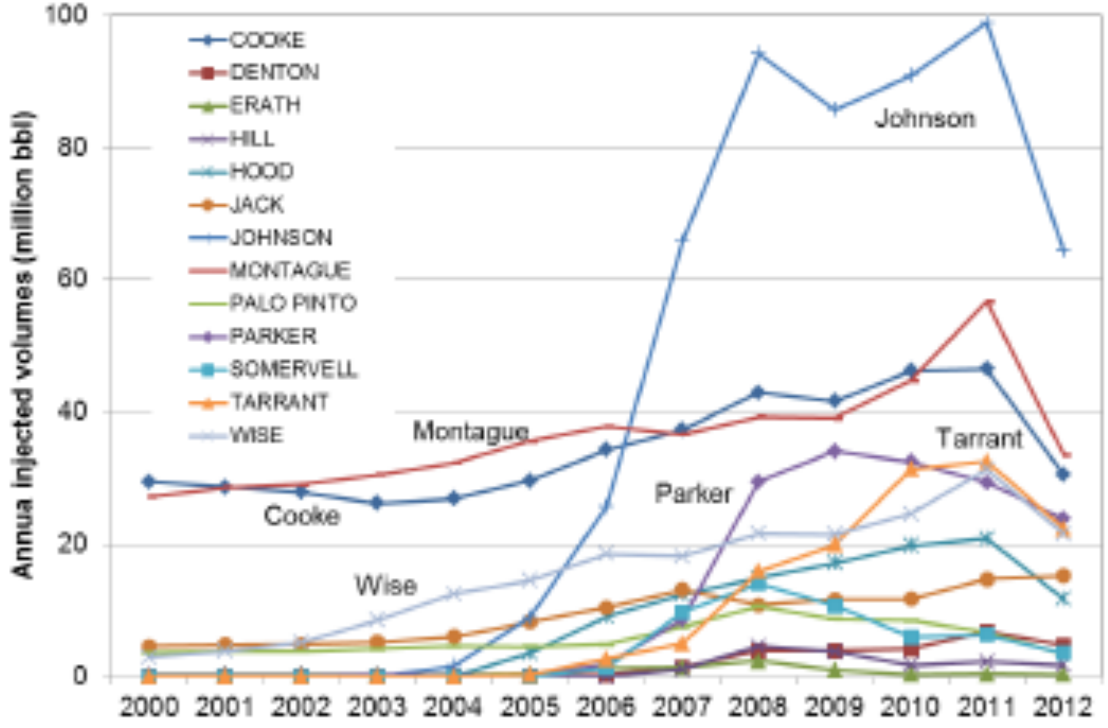
Injection Wells

Injection Well Disposal
Conventional vs Unconventional Production



Source: J.-P. Nicot, B. R. Scanlon, R. C. Reedy, R. A. Costley, *Source and Fate of Hydraulic Fracturing Water in the Barnett Shale: A Historical Perspective*, 48 Environmental science & technology 2464 (2014).

Barnett Shale
Yearly Injected Volumes by County
(including conventional oil and gas)

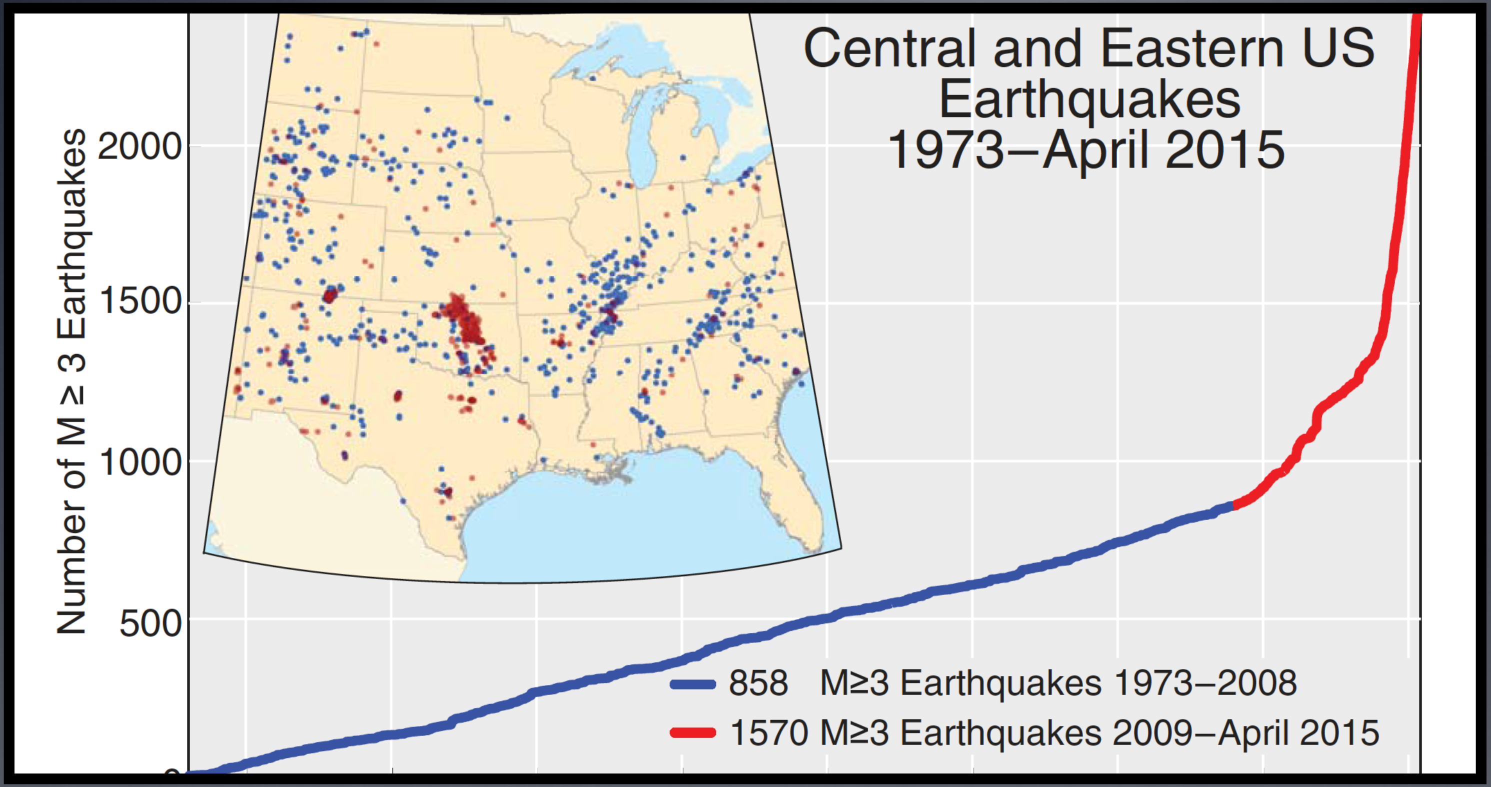


Note: no injection in Dallas and Bosque Counties.

Source: Jean-Philippe Nicot, Bridget R. Scanlon, Robert C. Reedy, and Ruth A. Costley, Source and Fate of Hydraulic Fracturing Water in the Bamett Shale: A Historical Perspective, S39 (Nov. 29, 2013).

Concerns with Disposal

- Increased pollution and damage to roads from truck traffic
- Potential for contamination of other water sources through soil migration or spills
- Impacts to naturally occurring fault lines causing earthquakes
- Water lost from hydrologic cycle



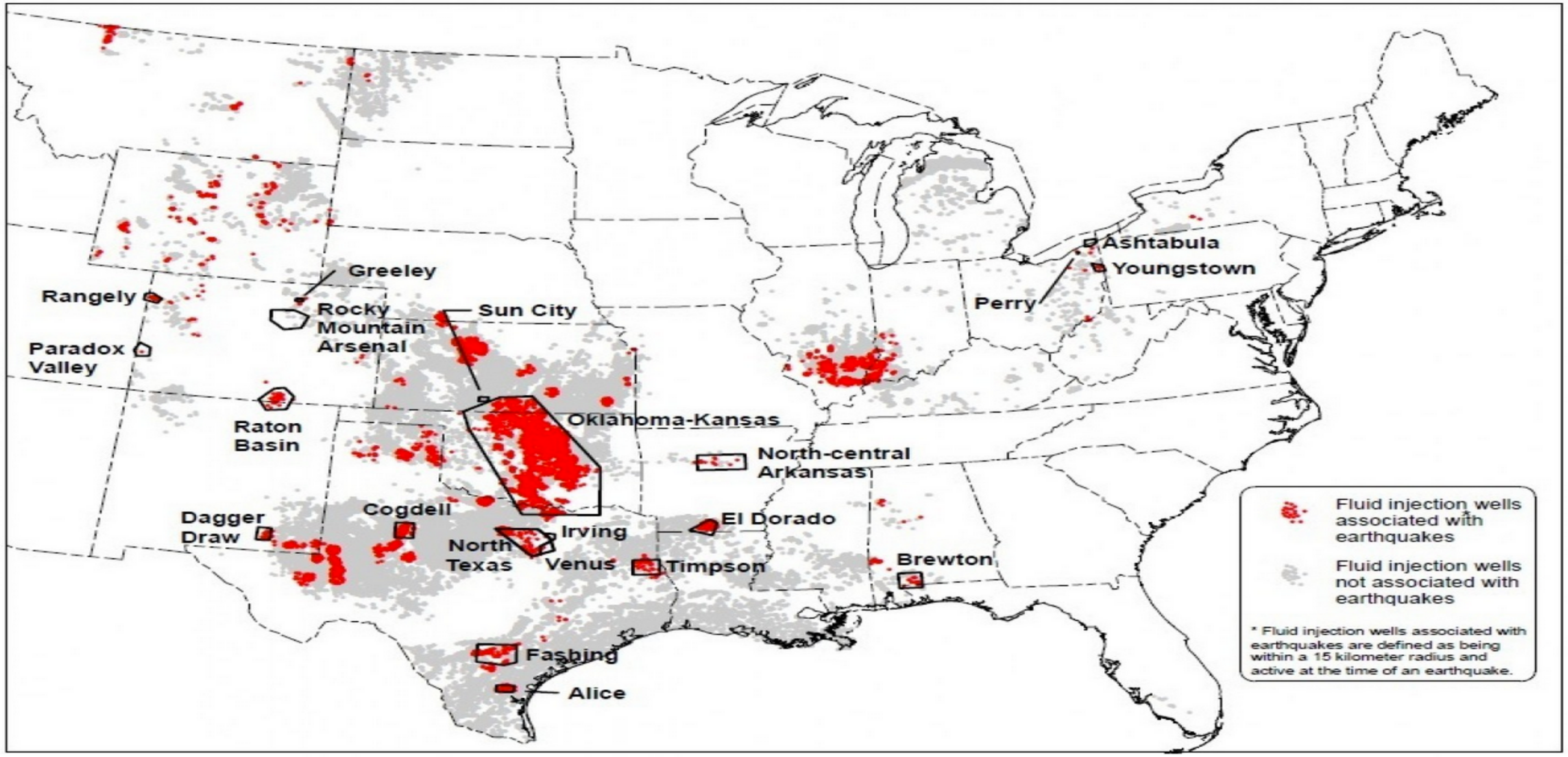
Induced Seismicity

Facts About Induced Seismicity

- Hydraulic fracturing, long-term wastewater injection, and enhanced oil recovery have all induced earthquakes in the United States and Canada in the past few years
- Factors that contribute to induced seismicity:
  - Duration of injection
  - Magnitude of fluid pressure increase
  - Size of region affected by injection
- Wastewater disposal into previously undisturbed formations more likely to induce earthquakes than hydraulic fracturing
- Seismicity can be induced 10 miles or more away from injection point and at significantly greater depths than the injection point

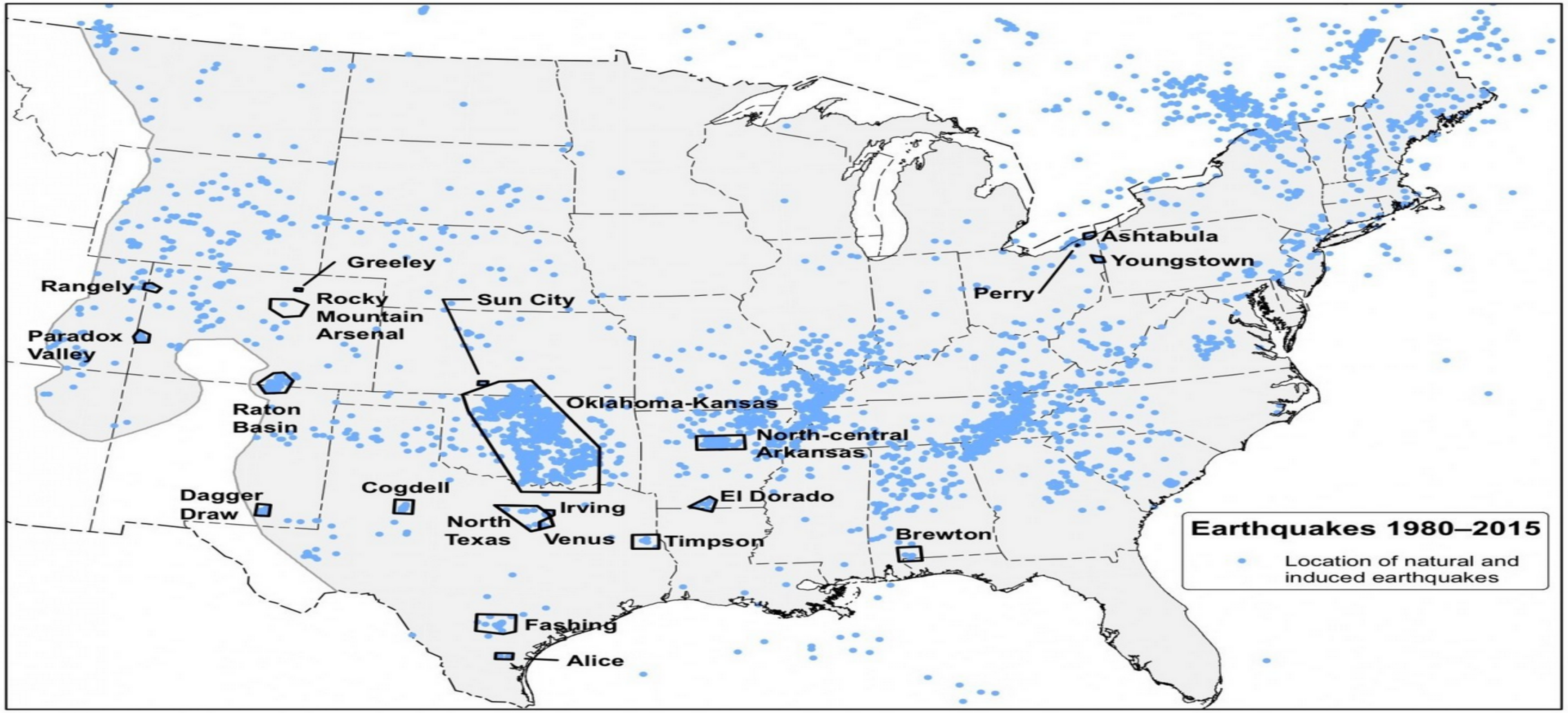
Source: Justin L. Rubinstein & Alireza Babaie Mahani, Myths and Facts on Wastewater Injection, Hydraulic Fracturing Enhanced Oil Recovery, and Induced Seismicity, 86 Seismological Research Letters No. 4 (2015).

Location of Injection Wells and Areas Impacted by Induced Earthquakes



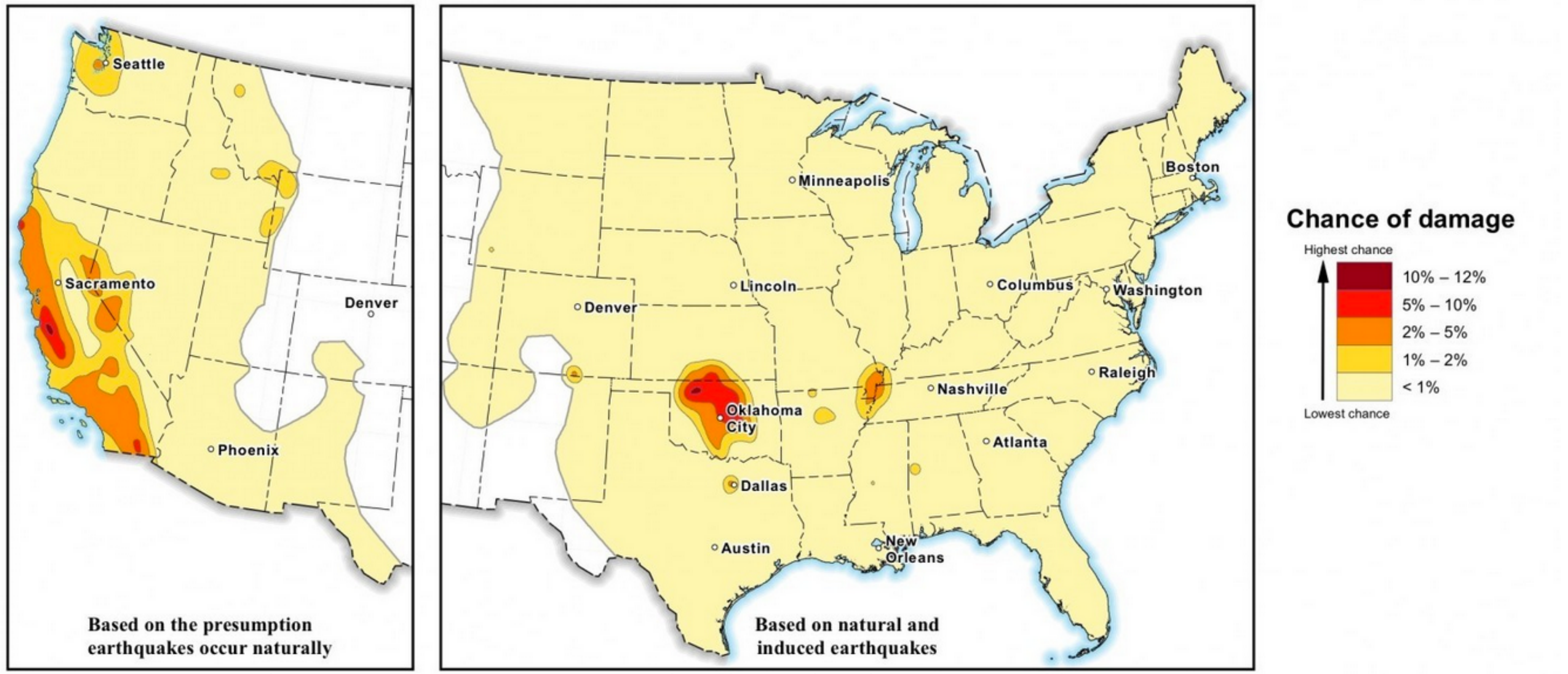
USGS map displaying 21 areas impacted by induced earthquakes as well as the location of the fluid injection wells that have and have not been associated with earthquakes. (Courtesy of USGS)

Areas of Wastewater Injection with Rapid Changes in Seismicity



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. (Courtesy of USGS)

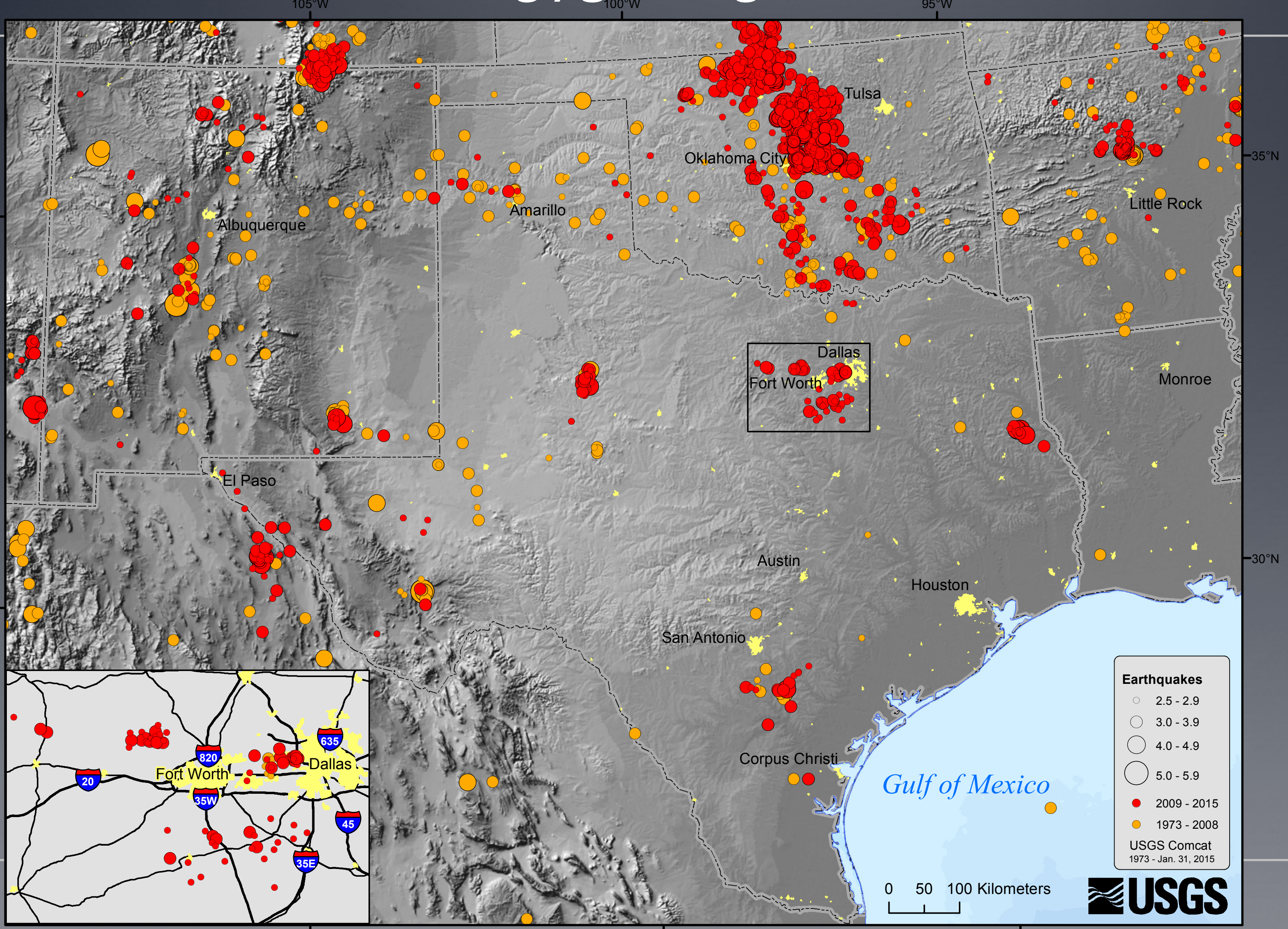
Potential for Damage from Earthquakes



U.S. Geological Survey map shows the potential for Americans to experience damage from natural or human-induced earthquakes in 2016. Changes range from less than 1 percent to 12 percent. (Courtesy of USGS)

Texas Seismicity

1973-2015



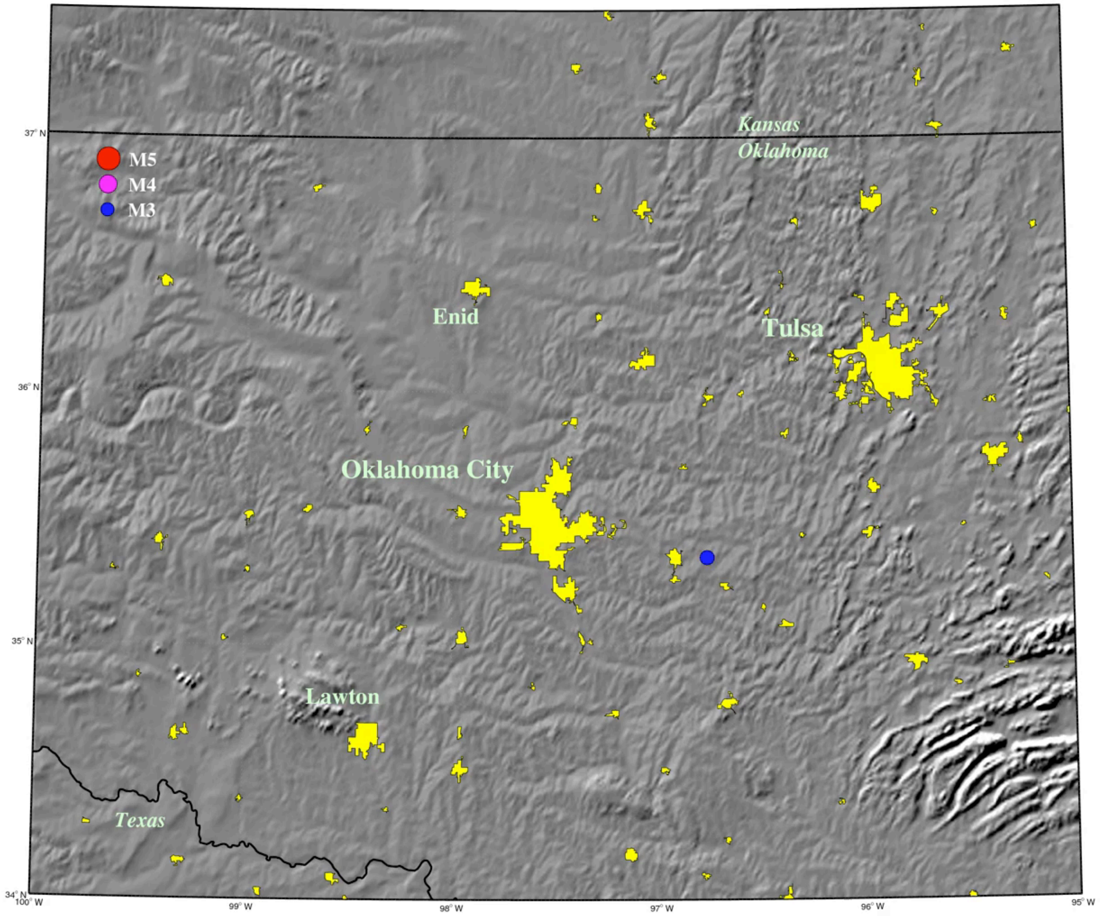
Animation of Oklahoma Seismicity

2008 - 2016

Earthquakes from:
09–Jun–2008 to: 03–Apr–2016

Earthquake Count: 1

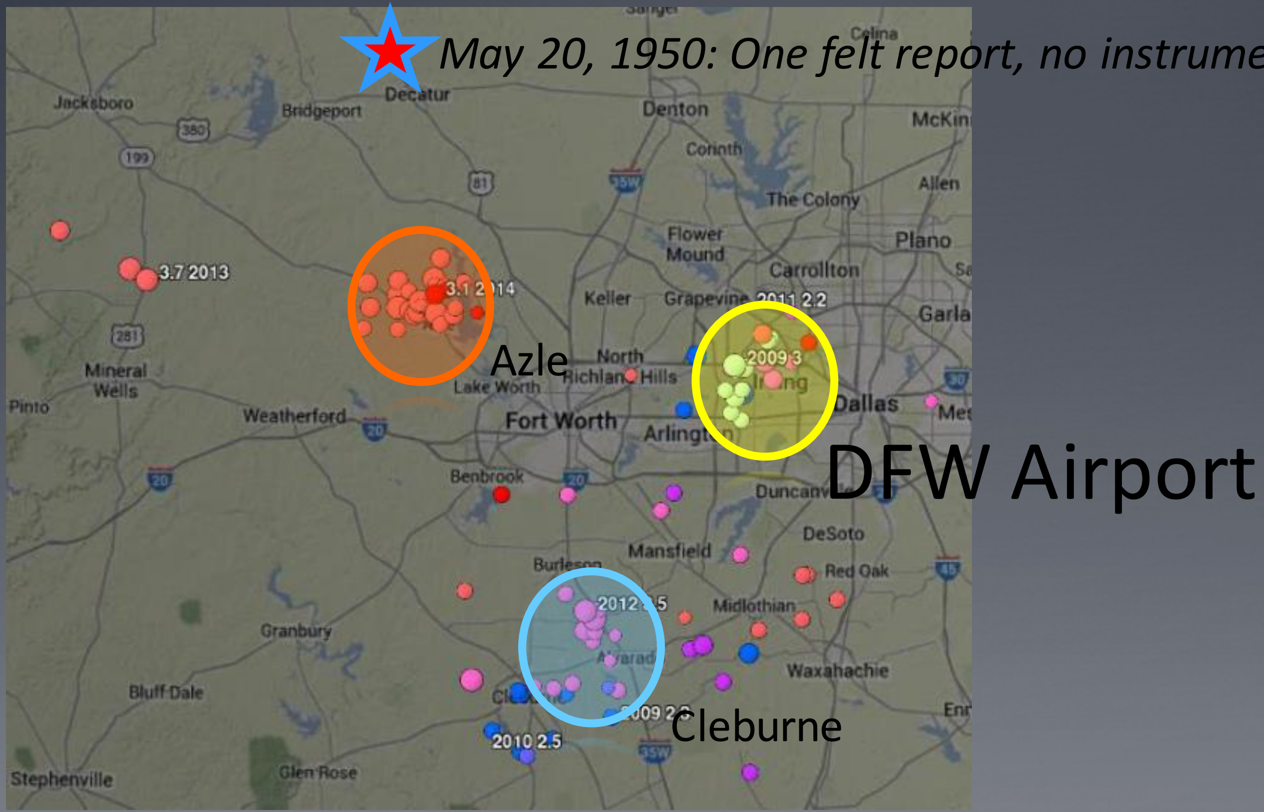
Date: 09–Jun–2008



Earthquakes are from the USGS ComCat web service. Earthquakes displayed have a minimum magnitude and are complete above magnitude 3.0.

USGS
science for a changing world

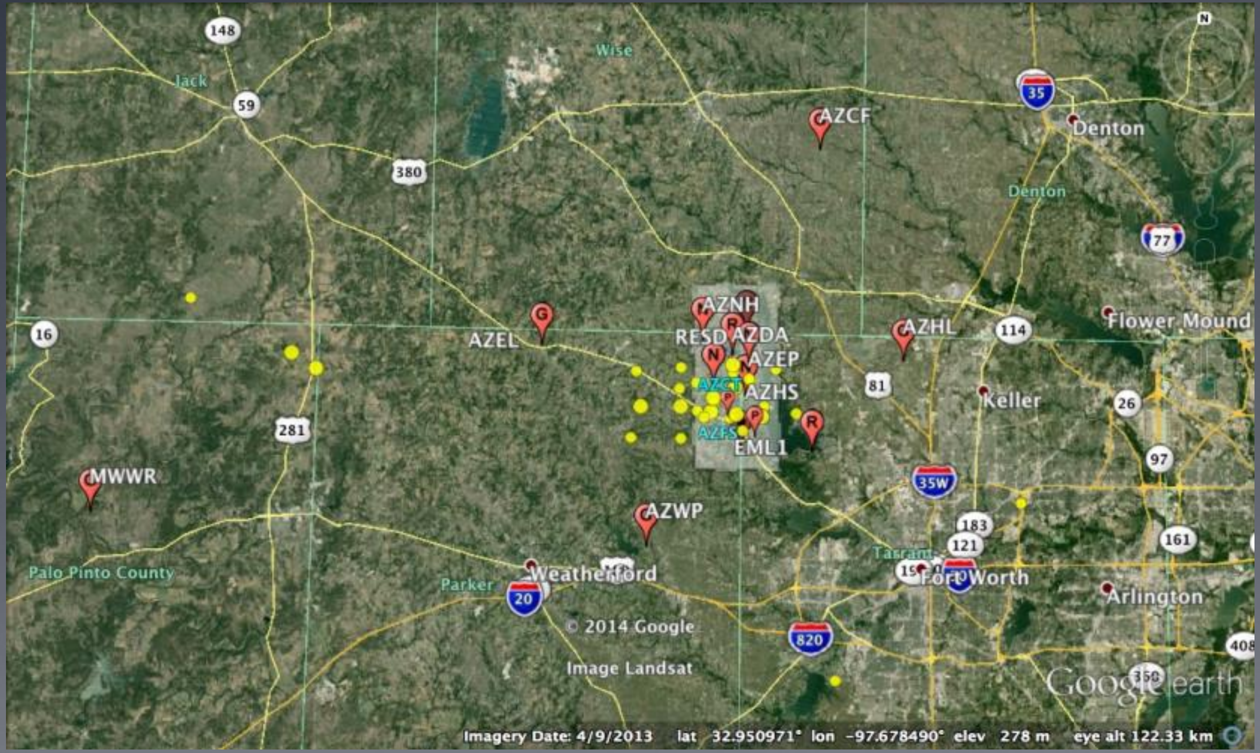
One Earthquake in Fort Worth Basin Prior to 2008 and over 70 Since



Earthquakes Report by National Earthquake Information Center since 2008 (2.0 – 3.5)

Source: Cliff Frohlich and the USGS Earthquake Hazards Program

Reno-Azle Earthquake Update

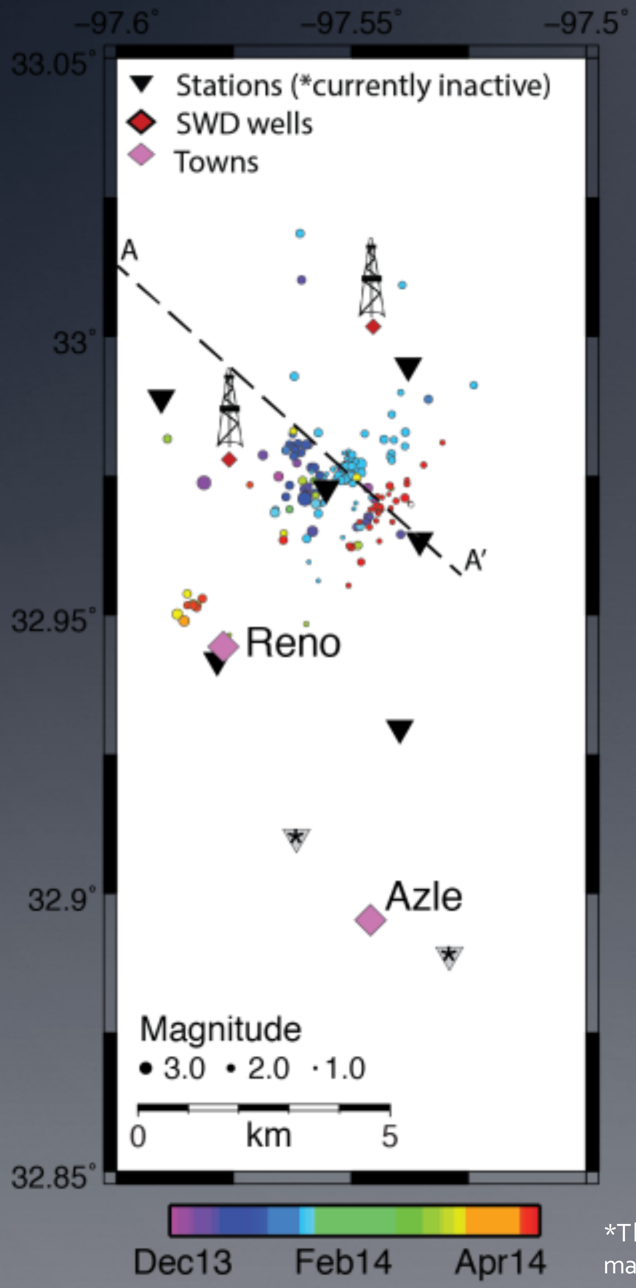


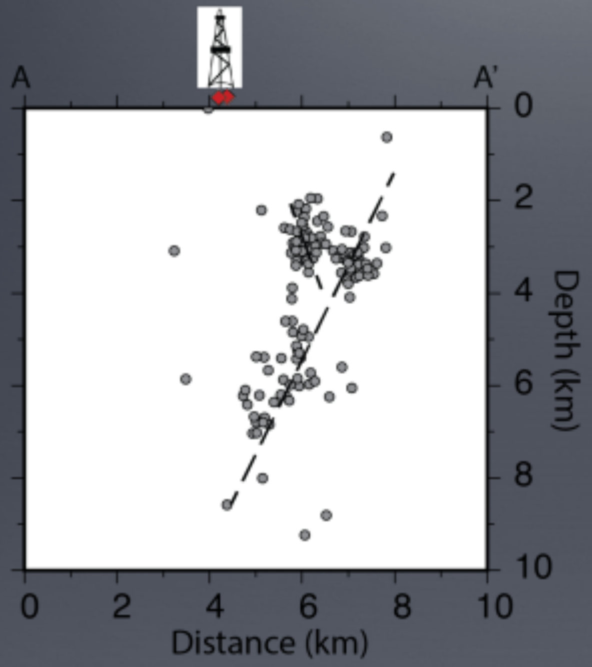
Station Map as of May 2014
12 active stations (G, R, N)

USGS NEIC Earthquakes
(11/01/2013 – present)

Source: Cliff Frohlich and the USGS Earthquake Hazards Program

Preliminary Earthquake Locations





- The Sequence is continuing, though there have been no felt events since Jan. 28th, 2014
- Seismicity rate has been highly variable
- Faulting appears complex

*These results have not been peer-reviewed and location and magnitude may change upon further analysis.

Source: Cliff Frohlich and the USGS Earthquake Hazards Program

Texas Railroad Commission Regulation

- Amendments to 16 TAC Sections 3.9 and 3.46 Regarding Disposal Wells and Injection of Fluid Waste
  - Designed to address disposal well operations in areas of historical or future seismic activity
- What do the Amendments Require?
  - Requires applicants for new disposal wells to conduct a search of the USGS seismic database for historical earthquakes within circular area of 100 square miles around a proposed, new disposal well
  - Clarifies RRC staff authority to modify or suspend or terminate a disposal well permit
  - RRC staff can require operators to disclose the current annually reported volumes and pressures on more frequent basis if RRC staff determines it is needed
  - RRC staff can require an applicant to provide additional information and to demonstrate disposal fluids will remain confined

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