Another Case History of Large Volume Water Injection

With Implications for Pure Carbon Capture and Storage

May 2023

Background (1)

- Intensive Horizontal Drilling Activity is Underway in the Permian Basin
- Increasing Lateral Lengths in the Last Few Years have Greatly Improved Well Economics and Drilling Continues at a High Pace
- Oil and Gas Production Rates are High*
- Produced Water Volumes are also High with an Average of Approximately 3x the Oil Volumes

** The Best Wells will Make More than 1,000 barrels of oil per day for several Months and return the cost of the well in less than a year*

Background (2)

- Increasing Levels of Produced Water Reuse in Hydrofracs of New Wells are Occurring
- Otherwise, Produced Water **Disposal** Must be Accomplished in Reservoirs other than the Producing Ones*
- The Produced Water Volume Disposal has Become an Industry in Itself, Involves Large Volumes of Barrels, and is Providing, Perhaps, the Best Analogue for Certain Large Volume Carbon Capture & Storage (CCS) Projects

* *The Horizontal Well Plays Require Reservoir Depressurization to Produce the Oil & Gas; Reinjection of the Co-produced Water Must go into Formations Other than the Producing Ones*

With this as Background, Let's Look at an AoR: 10-Mile Radial Area in SW U.S.

1. The AoR was Effectively Inactive of Any Large Injection Prior to 2010
2. It Now Possesses Accelerating Drilling Activity Since 2016
3. The "Associated" Produced Water is Requiring Shallow & Deeper Disposal
4. Disposed Water Disposal Rates have Reached 340,000 Bbls/Day in Dec '22
5. Equivalent Disposed Mass is 22 million Metric Tons/Year and Climbing
6. Both Shallow and Deep Disposal is Underway with Deep @ ~75% of Total
   a) Deep is Into a Thick Carbonate Formation Just Above Crustal Rocks
   b) Shallow is Into a Thick Series of Basinal Turbidite Sandstones Above Current Producing, Depressuring Zones
7. Is a Valuable Analogue to Certain Large CCS Injection Projects

* Touches 9 Townships; 18x18 miles

Case History Assumptions

- Water Disposal is a Proxy for CO_2 Disposal (CCS) – i.e., no fluid withdrawals, no mass balancing of reservoir fluids in and out
- Deep Disposal has no pressure "Dissipation" above to the producing intervals
- Deep Disposal may have pressure "Dissipation" below to a thin deeper zone or into fractured crustal rocks
- Water & Dense Phase CO_2 Pressure Mass Reservoir Responses are ~ Equal

AoR Monitored/Measured Data

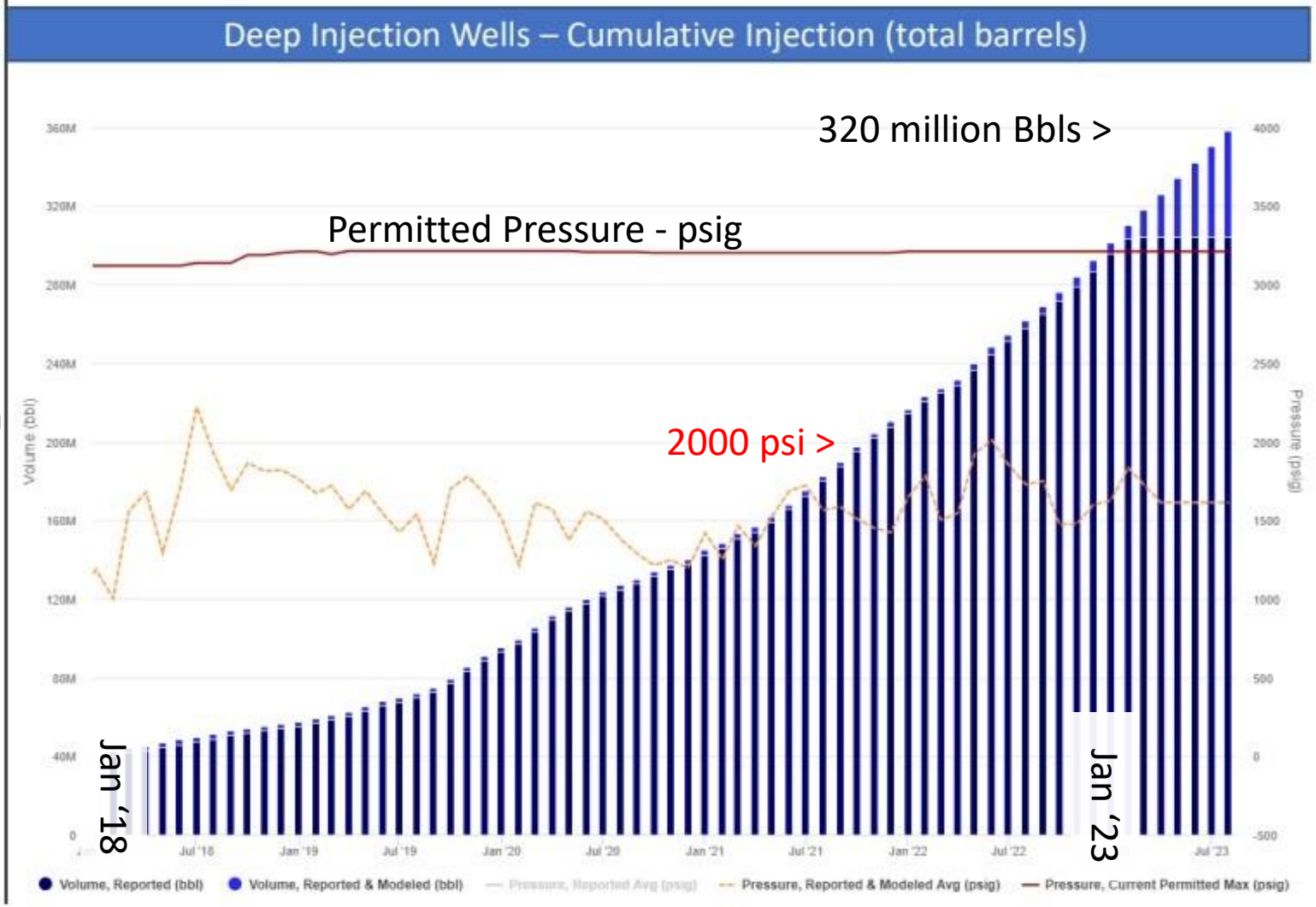
- Mass Injections to Date
  - Deep - 830 million tons (1/2 in last 6 years)
  - Shallow - 310 million tons (90% in last 6 years)
- Current Mass Injection Rates
  - Deep – 17.7 million tons/yr (280,000 bwpd)
  - Shallow – 3.8 million tons/yr (60,000 bwpd)
- Current Surface Injection Pressures
  - Deep - 1500-2000 psig
  - Shallow – 600-700 psig

Case Study AoR
(15 Deep Injection Wells)

Cumulative Injection Volumes and Surface Pressures
(Permitted and Actual)

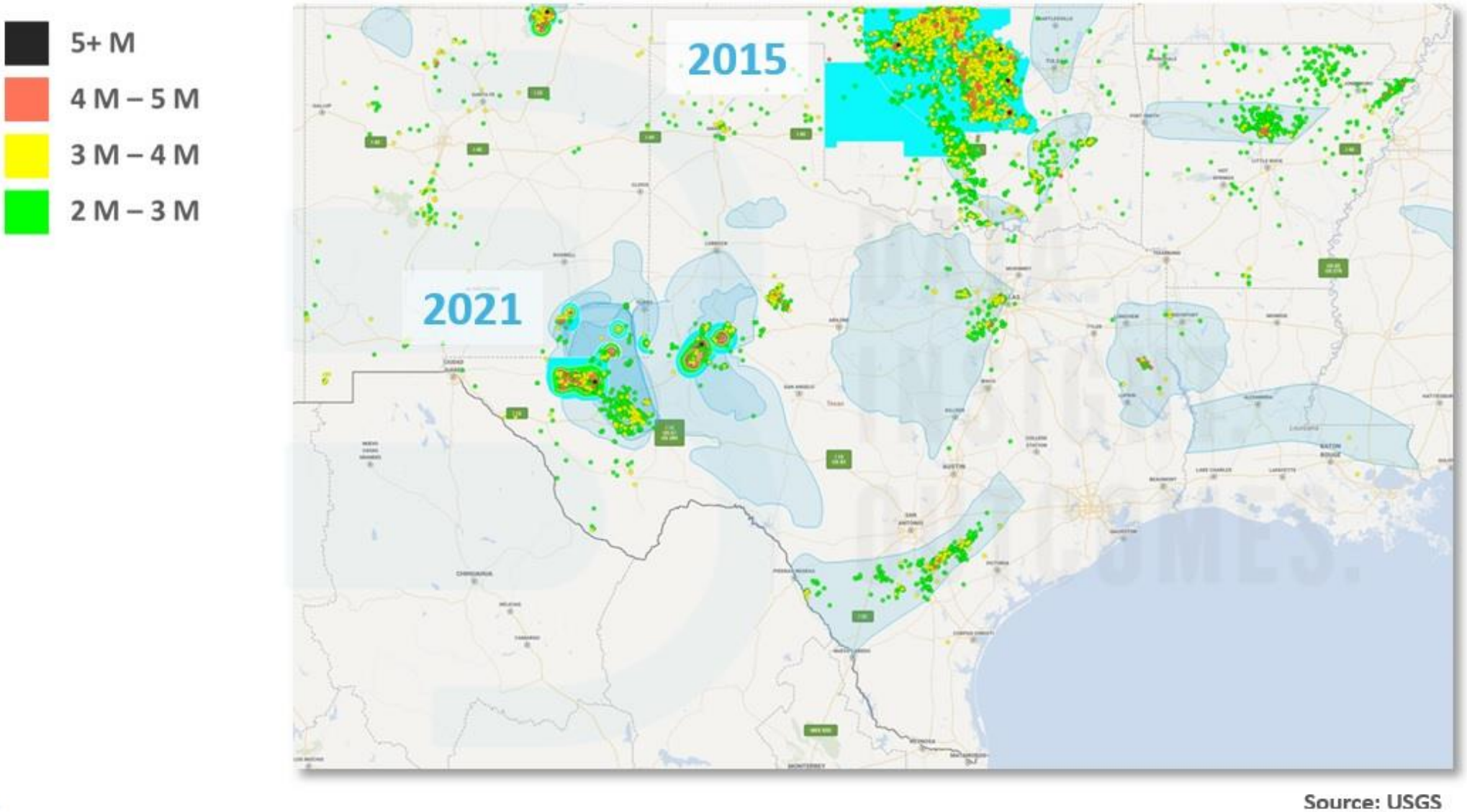
35 million Tons >

- **15 deep injection wells, cumulative injection of roughly 320M barrels of water**
- **Deep injection zones range from depths of 14,906' to 17,920'**
- **Average Top Injection Zone = 14,919'**
- **Average Bottom Injection Zone = 17,124'**



Are There Impacts of the Water Disposal?

A Regional Look
Four State Regional Seismicity Response



Source: USGS

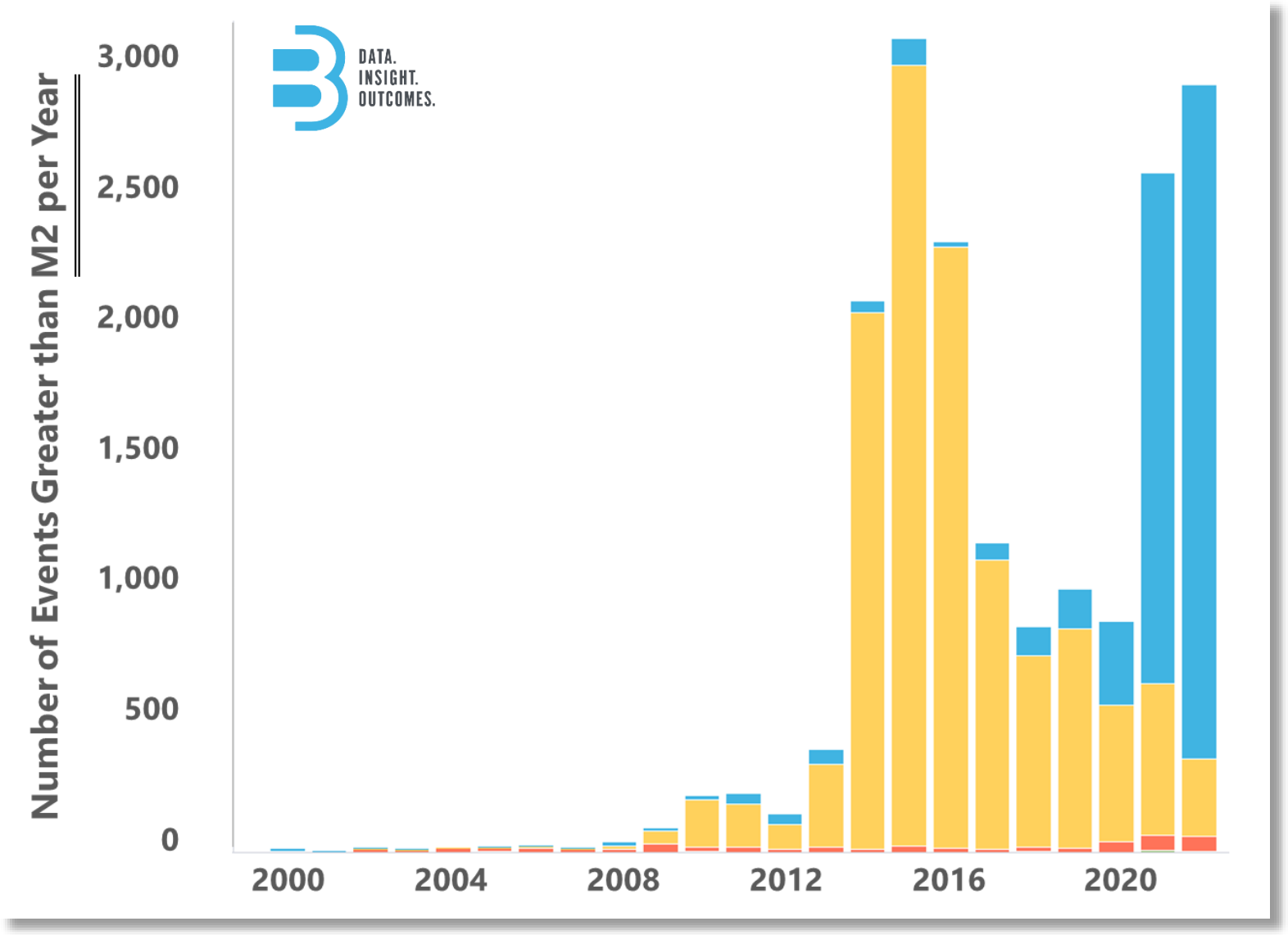
One Impact Example: Induced Seismicity (USGS)

At what magnitude does damage begin to occur in an earthquake?

It isn't that simple. There is not one magnitude above which damage will occur. It depends on other variables, such as the distance from the earthquake, what type of soil you are on, building construction, etc. That being said, damage does not usually occur until the earthquake magnitude reaches somewhere above 4 or 5.

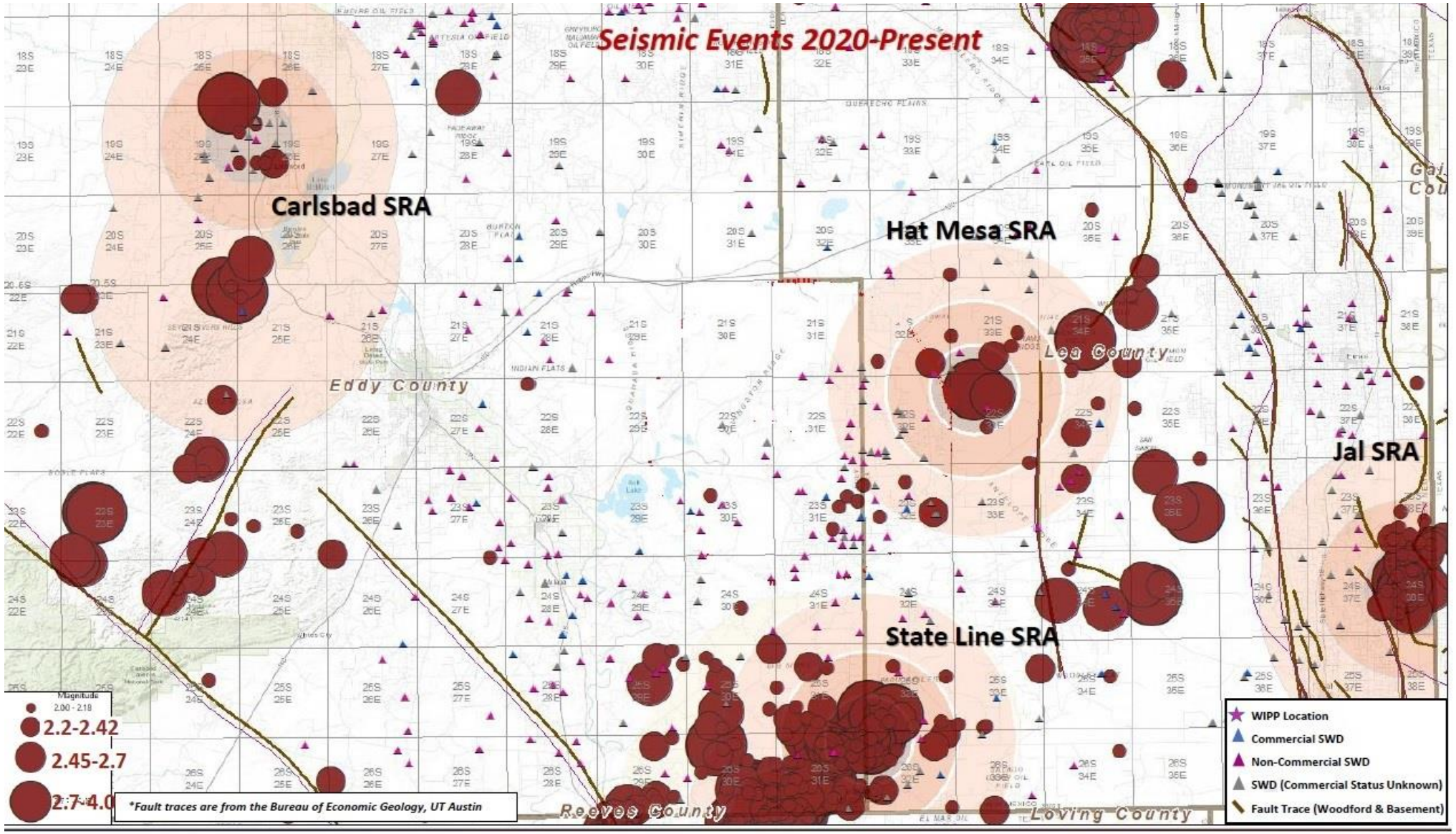
Let's Look First Outside the AoR for a Baseline

Regional Four States Seismicity: 2000 - Present



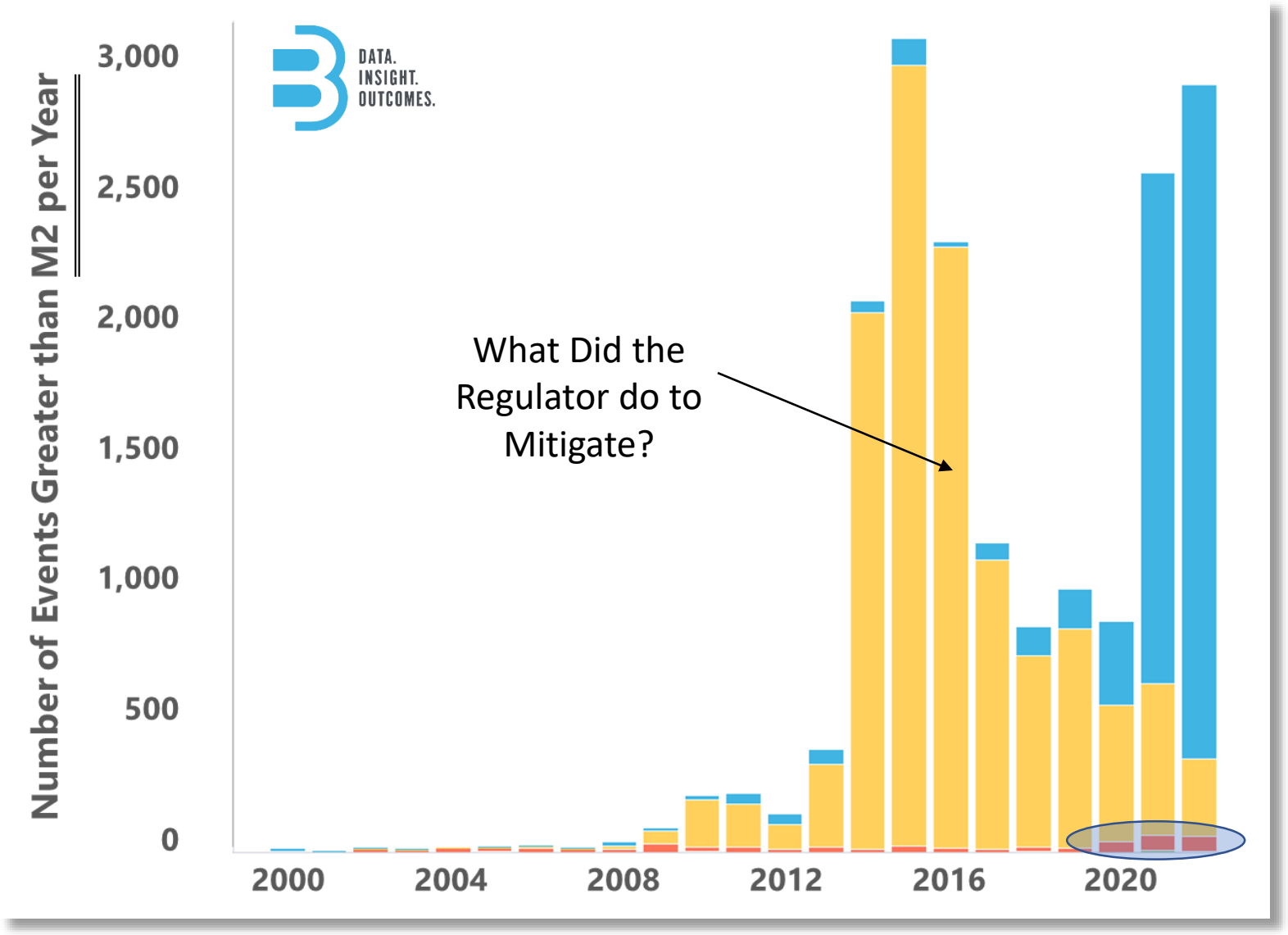
Source: USGS

Back to the AoR: SE NM Induced Recent Seismicity



DATA. INSIGHT. OUTCOMES.

Regional Four States Seismicity: 2000 - Present



Source: USGS

In Response to Large Magnitude Seismic Events and Increased Event Frequency, the NM OCD Copied some of the Mitigation Approach Used in OK and Instituted Seismic Response Areas (SRAs) to Try and Mitigate Earthquakes by Curtailing Injection (Nov 2021)

November 23, 2021 Notice to Operators Regarding SRAs →

Justification for SRAs →

State of New Mexico
Energy, Minerals and Natural Resources Department

Michelle Lujan Grisham
Governor

Sarah Cottrell Propst
Cabinet Secretary

Todd E. Leahy, JD, PhD
Deputy Secretary

Adrienne Sandoval, Division Director
Oil Conservation Division

NOTICE TO OPERATORS

IMMEDIATE RESPONSE PLAN FOR SEISMIC EVENTS RELATED TO CLASS II UNDERGROUND INJECTION CONTROL WELLS

November 23, 2021

The New Mexico Energy, Minerals and Natural Resources Department, Oil Conservation Division ("OCD") has the authority under the Oil and Gas Act (Section 70-1-1 *et seq.*, NMSA 1978) and pursuant to delegated authority from the U.S. Environmental Protection Agency under the Safe Drinking Water Act (42 U.S.C. 300f *et seq.*) to regulate all aspects of Underground Injection Control ("UIC") Class II well development and operation, and decommissioning, including their contribution to induced seismic activity. See 19.15.26 NMAC. This Notice sets forth OCD's framework for responding to seismicity related to UIC Class II injection well operations wherever it may occur across New Mexico.

The USGS and New Mexico Bureau of Geology has detected increasing seismic activity over the last two years in the vicinity of several UIC wells located across New Mexico, including:

- Seven earthquakes of magnitude from M2.5 to M4.0 between March 2021 and September 2021, in an area known as the County Line Seismic Response Area ("County Line SRA") located approximately 35 miles east southeast of Malaga, NM;
- Thirteen earthquake events ranging from M1.8 to M2.7 in a location approximately six miles northeast of Jal, NM, that started in August 2020 and have occurred periodically to the present;
- A swarm of 21 earthquakes ranging between M2.3 and M3.3 over a three-day period in June 2020 located in an area approximately 12 miles southwest of Lovington, NM; and,
- A collection of earthquakes in the last month, including:
  - A M3.2 event in an area approximately 24 miles southwest of Monument, NM;
  - A M4.0 event in an area approximately 15 miles North of Cimarron, NM; and,
  - A M2.5 event in an area approximately 15 miles north northeast of Ute Park, NM.

OCD has actively engaged with UIC well operators in these areas to gather data on the seismic events and to understand their causes. Based on the available data, the location of the seismic activity, and its proximity to existing UIC injection activities, as well as the experience of other states managing oil and gas related induced seismicity, OCD believes that these seismic events are directly related to UIC injection activities. These seismic events demonstrate the need for OCD to marshal available tools and data to mitigate induced seismicity and ensure that appropriate measures are established to manage it going forward.

To that end, the OCD announces the following statewide induced seismicity mitigation and response framework (see Attachment A). The framework incorporates requirements that will be implemented either through voluntary actions by operators and/or orders issued by the OCD. The OCD has the authority to institute the framework under the Oil and Gas Act, including 19.15.26.11 NMAC, which provides for:

1) "more comprehensive testing of [an] ...injection well when deemed advisable, including the use of tracer surveys, noise logs, temperature logs or other test procedures or devices;" and,
2) "special tests [of an injection well] ...if the division believes conditions so warrant."

Testing under this authority may include but is not limited to: (1) operational curtailment of injection volumes and shut-ins,[1] (2) pressure monitoring, (3) well communication testing, and (4) phased-in reinstatement of operational activities. Consistent with this authority, the OCD expects the following actions in response to seismic events depending on the timing and magnitude of the observed event:

1. Following the occurrence of two seismic events equal to or greater than M2.5 within a 30-day period and within a 10-mile radius, OCD expects all UIC well operators within 10 miles of the epicenter of the seismic events (the "Seismic AOI") to:
   a. comply with the Category 1 Seismicity Response Protocols identified in Attachment A to this notice until such time as OCD determines appropriate mitigation actions in response to the observed seismic events have occurred.
2. Following the occurrence of one seismic event equal to or greater than M3.0, OCD expects all UIC well operators within the Seismic AOI to:
   a. Implement all the monitoring and reporting requirements in the Category 1 Seismicity Response Protocols set forth in Attachment A, plus
   b. The additional operational controls in the Category 2 Seismicity Response Protocols set forth in Attachment A.
3. OCD expects the duration the of any measures identified above will be until such time as OCD determines, in its sole discretion, that appropriate mitigation actions in response to the observed seismic events have occurred. Factors the OCD will consider, without limitation, including the lack of additional seismic activity for 6 months after the triggering event and/or approval of an operator/industry response plan to the seismic activity.
4. Attachment B contains OCD's Seismicity Response Protocol Information Form, which OCD in its discretion may convert into an online form.

OCD may add additional requirements in any order issued in response to a seismic event as it deems necessary and appropriate to address the specific circumstances.

Finally, OCD will consider an operator's voluntary implementation of the measures outlined in this Notice when deciding whether and when to issue an order. For additional information, contact OCD.Engineer@state.nm.us.

Attachments:
Attachment A: OCD, Seismicity Response Protocol
Attachment B: OCD, Seismicity Response Protocol Information Form (*form shall be submitted using OCD's e-permitting system*)

[1] Operational controls are intended to test the geologic response to reductions in disposal volumes.

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Case History Observations/Conclusions that Can Inform CCS Injection Sites

- Small Volume Injection Pilots are not very Helpful Guides to Large Volume Injections
- We are Fortunate to be Witnessing the Analog of Large Volume Water Injection
- We are also Realizing Mass Balancing is Critical in a Lot of Geologies
- Producing Fluids to Accompany Large Volume Injection will be Necessary in Most Geologies
  - For Mass Balancing of Formation Overpressures
  - For Plume Management

Further Thinking:
Perhaps We Should Reframe the 45Q Tax Credit Rules

- It was a Bipartisan Effort that Got it Passed
  - Blue Folks Wanted to Reduce GhG Emissions & Move to Environmental Sustainability
  - Red Folks Wanted Energy Security and Economic Sustainability
- Mass Balanced CO_2 Injections for Geological Storage are Proving to be Critical
- Let's Reframe so that $85/ton is Appropriate for Utilization of the CO_2 Regardless of the Product Sold and all Mass Balanced Projects
- Should Lead to CO_2 Utilization on a Large Scale and Assist in Paying for the Reservoir Mass Balancing Required