Compared to the years 1976-2007, Oklahoma has experienced a 40-fold increase from 2008-2013\(^2\). These earthquakes are associated with Underground Injection Control (UIC) Class II wells, which inject chemically treated water into porous subsurface rock formations \(^1\). Oklahoma has been particularly affected by these dispositions: prior to 2008, OK experienced about one earthquake (M≥3) per year, however, after 2008, the state saw hundreds of earthquakes per year as a result of increased wastewater disposal \(^5\). Using logistic regression, we took a statistical approach, similar to hydrogeological modeling, to project a probabilistic output for earthquake occurrence.

### Model Parameters

| Parameter | Coefficient(s) | Std. Error | t-value | P(t>|z|) |
|-----------|----------------|------------|---------|---------|
| Intercept | 1.54937 | 0.10357 | 14.211 | <2e-16*** |
| BBLs/month | 0.07027 | 0.02910 | 2.411 | 0.015 |
| ED | -0.45268 | 0.14971 | -2.974 | <2e-16 |
| h/dist.to.basin | -7.81324 | 2.93060 | -2.660 | <2e-16 |
| Well depth | 0.000777 | 0.03867 | 0.111 | <2e-16 |
| Earthquake magnitude | 0.00209 | 0.00182 | 1.112 | <0.176 |
| Pressure | 0.00581 | 0.04942 | 0.112 | <0.905 |

### Conclusions and Future Work

- The Probability Output map shows much more clearly defined regions of high and low probability than the USGS Hazard Map.
- Of all the parameters, rate of wastewater injection (BBLs/month) correlated most strongly with causing earthquakes.
- Some parameters were left out of the model and will be investigated in the future. These include:
  - Cumulative volume (BBLs)
  - Spatial/Temporal Clustering of Past Earthquakes
  - Porosity and Permeability of Lithology

\(^{*}\) This model works under the assumptions of Binomial Distribution and Interpolation

### References


### Methodology

- **Injection Well Location**: High-rate injection wells are located to the north of the state, while low-rate wells are located to the east.
- **Earthquake Locations**: Earthquakes are located in similar areas to injection wells rather than on the fault lines. This indicates a correlation between the two.

### Figure

- **Figure 1**: High rate injection wells are located to the north of the state, while low rate wells are located to the east.
- **Figure 2**: Earthquakes are located in similar areas to injection wells rather than on the fault lines. This indicates a correlation between the two.
- **Figure 3**: Probability of Earthquake Occurrence
  - High: 100%
  - Low: 1%
- **Figure 4**: Model Validation
  - Random Points: Mean: 0.3834
  - Standard Error: 0.0161
  - P-value: 0.0001
  - The chance of seeing this difference in values is less than 0.01%
  - Test Date: Mean: 0.4679
  - Standard Error: 0.0118

### Table 1: List of parameters inputted into the model and a description of their effect on causing earthquakes.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High rate injection wells are more likely to be associated with induced seismicity than lower rate injection wells. (^6)</th>
<th>Pressure of injection</th>
<th>Similar to injection rate, high pressure injections cause more damage and are more likely to result in fatalities. (^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection well distance to basement</td>
<td>Seismic moments are strongly correlated with the proximity of injection to the crystalline basement. (^6)</td>
<td>Injection well drilled to basement</td>
<td>In wells drilled to the basement, wastewater is injected directly into the basin, reducing effective stress and possibly causing fault slip. (^6)</td>
</tr>
<tr>
<td>Well depth to faults</td>
<td>Earthquakes that occur near the fault are more likely to affect the earthquake. (^6)</td>
<td>Injection well drilled to basement</td>
<td>In wells drilled into the basin, wastewater is injected directly into the basin, reducing effective stress and possibly causing fault slip. (^6)</td>
</tr>
<tr>
<td>Earthquake distance to faults</td>
<td>Earthquakes that occur at close proximity to other fault lines are capable of reactivating faults and causing them to slip. (^6)</td>
<td>Injection well drilled to basin</td>
<td>In wells drilled into the basin, wastewater is injected directly into the basin, reducing effective stress and possibly causing fault slip. (^6)</td>
</tr>
</tbody>
</table>

### Output Equation:

\[ \text{Output} = 1.54937 - 0.45268 \times \text{ED} \times \text{h/dist.to.basin} - 0.000777 \times \text{Pressure} \times 0.07027 \times \text{BBLs.month} + 0.27404 \]

**Regression Analysis**

- \( \text{ED} \) = distance to fault, \( \text{h/dist.to.basin} \) = height/distance to basin, \( \text{Pressure} \) = Pressure, \( \text{BBLs.month} \) = BBLs/month.

**Table 2**: Parameters are ordered from greatest impact on earthquakes to least. EA, earthquake, to fault, \( r^2 \) not significant (is \( >0.05 \)).