Induced Seismicity

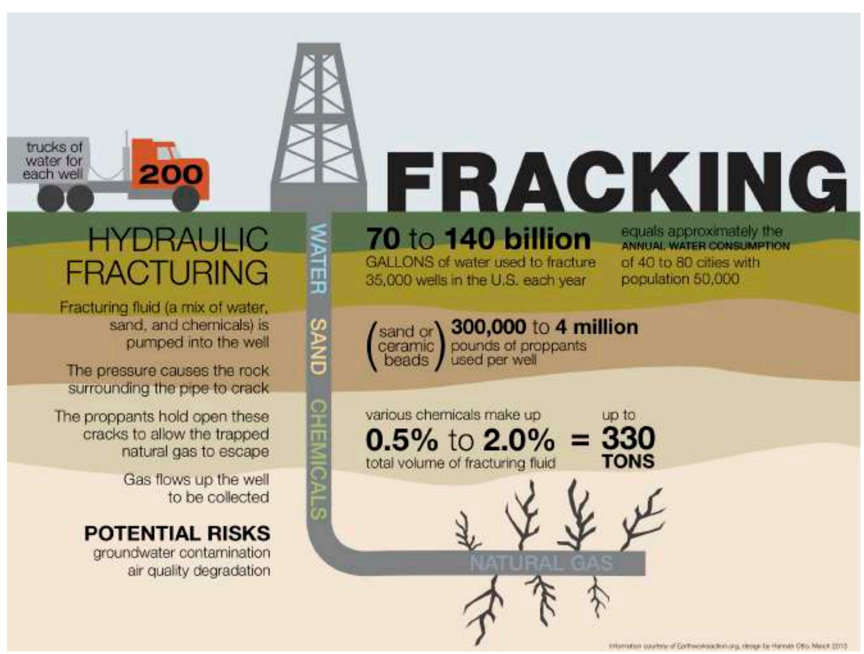
Student Sheet

The process of removing hydrocarbons from Earth's crust has become an essential activity for humankind. However, major challenges arise during oil and gas production that have the potential to affect the natural and built environments in a variety of ways.

One particularly challenging approach is known as the production of ***unconventional gas resources***, through a process known as hydraulic fracturing ("***hydrofracking***"). Hydrofracking involves injecting large volumes of water, sand and chemicals into the rock under high pressure to create cracks through which the gas may escape the rock formation and then be collected. Hydrofracking most commonly takes place in gas fields found in shales.

In addition, water is also trapped in the same pore space as oil and natural gas and is recovered during conventional oil and gas production. The disposal of naturally produced water and/or hydraulic fracture fluid presents major challenges, since the wastewater is frequently injected back into Earth's crust. Some states, such as Oklahoma and Ohio, allow hydrofracking and wastewater injection, while other states such as Pennsylvania, allow hydrofracking but require wastewater to be transported out of state for disposal. In Oklahoma, hydrofrac fluid represents only 10% or less of the fluids disposed of in wastewater injection wells.

In some cases, the stress generated from hydrofracking and wastewater disposal can cause increased levels of earthquake activity ("***induced seismicity***"). By its very nature, hydraulic fracturing causes very small earthquakes, which are normally not felt. However, the causal relationship between fluid injection and induced seismicity is an active topic of scientific research and debate, as the largest earthquake ever thought correlated with injection is a M5.7 earthquake in Oklahoma that occurred in November 2011.



In addition, the complexity of unknown subsurface geologic structures can make drawing direct correlations between hydrofracking or wastewater injection with nearby earthquakes difficult.

The purpose of this activity is to explore the processes involved in unconventional gas resource exploration and production (hydraulic fracturing), how we monitor seismic activity and draw correlations between fluid injection (related to hydrofracking or from wastewater disposal) and earthquake activity, and ways that we might establish a better understanding of correlations between the two.

Part I: Unconventional gas resource exploration: Process and effects

Let's first start with understanding a bit about the hydrofracking process…
Watch: What is Fracking? – How Stuff Works (3:00): https://youtu.be/Io8o2nTXhb0
Watch: Fracking explained: opportunity or danger (5:03): https://youtu.be/Uti2niW2BRA

Now, let's consider the stresses experienced by the rock during the hydrofracking process.

1) *What kinds of stresses would be generated when fluids are injected into shales during hydrofracking? Sketch the stress directions you think the hydrofracking process would create.*

2) *Sketch a fault in the area of wastewater disposal, and how you think that changes in stresses generated by fluid injection might cause changes in fault stresses.*

Part II: Hydrofracking, wastewater injection, and seismic activity - general

Let's start our examination of regions with active fluid injection operations, and how the injection may or may not relate to regional seismic activity.

Let's begin by exploring areas in the United States with significant hydrofracking and/or wastewater injection activity.

- Go to http://www.fractracker.org/map/national/us-oil-gas/.
- Click on the map that you see, which will bring up a much larger map with layers that you can overlay or remove.
- Simplify the map by pressing the Layers tab at the top of the screen, and deselecting all the layers except the layer on "Oil and Gas Wells (generalized)"

3) *List two (2) areas/regions where you expected oil and gas wells to exist. Why?*

4) *List two (2) areas/regions that you were surprised that oil and gas wells exist. Why?*

5) *Do you think that regions of oil and gas drilling end abruptly at state boundaries, such as Texas? Why or why not?*

6) *Explore the "Shale Plays" and "Shale Basins" layers to examine the relationship between where the wells occur and the geologic formations. Does this change your answer to the above questions?*

<u>Now let's explore more specific information related to fluid injection activity.</u>

Injection wells related to oil and gas activities are Underground Injection Control (UIC) Class II wells, and are regulated by the EPA (http://water.epa.gov/type/groundwater/uic/). The Class II wells related to our purposes include ***enhanced recovery wells***, which include wells used in the hydrofracking process, and ***disposal wells***, which are used to dispose of fluids used in the production of oil and natural gas (http://water.epa.gov/type/groundwater/uic/class2/index.cfm).

- Go to http://www.fractracker.org/map/us/
- Explore a few states that have horizontal wells. (Try KS first)
- The Layers tab can be used again to examine where the horizontal wells are located, and in which counties the wells are situated.
- To do this, only select "Horizontal Slant Wells" & "Counties"
- Furthermore, you can take a look at the shale plays and basins and learn about their names.
- Click on a county that has Horizontal Wells.
- When you click on a horizontal well, information about the well permit and the well type may be included.

7) What information can you obtain relatively quickly and efficiently regarding details of well permits?

<u>Now let's examine seismicity in the United States using the IRIS earthquake browser (www.iris.edu/ieb).</u>

- Zoom in on the United States (see icons on the left of the screen, and 'Zoom to Region' button), and choose a time range from 2008 to present (options on right).
- For best results, after zooming in, select a "Max Quakes" value of 2,500
- Besides looking at the seismicity in map view, you can also view a table of earthquakes using the "Open as:" feature in the bottom right corner

8) Compare and contrast the earthquake activity in California with the rest of the continental United States. California has many active faults, like the San Andreas Fault. Are there other states that have earthquake activity? If so, which ones stand out to you?

- Now shift the map to exclude California, and select a "Max Quakes" value of 2,500

9) Compare the well maps you examined earlier to the seismicity maps, and describe at least two (2) regions that appear to contain both wells and significant concentrations of seismic activity. Describe the type of geology in the region, the extent of well activity, and the time and magnitude range of seismic activity.

Part III: Hydrofracking, wastewater injection, and seismic activity – Oklahoma case study

Here we will investigate potential connections between fluid injection and seismicity to test the hypothesis that wastewater fluid injection causes earthquakes.

As alluded to in the previous portions of this exercise, there is no comprehensive publicly available dataset that documents injection well activities. In lieu of actual well activity data, we will utilize a dataset of well completion dates, combined with a high-resolution catalog of seismicity for the state of Oklahoma.

- Go to the Google Earth KMZ file: **OK_Earthquakes_Wells_2010-2012.kmz**.
- Detailed information for each of the datasets is included in the "Places" tab to the left under "Temporary Places."
    - Yellow circles: Earthquakes located by the Oklahoma Geological Survey
    - White circles: Hydrofracking wells completed between 2010 and mid-2012
    - Red circles: UIC Class II injection wells active as of January 2013

- A time slider should appear in the top left corner once the data file is loaded in Google Earth.
- The injection wells are set to display for the entire time period and may or may not have operated during the entire time frame.
- The length of time for the time window in view can be adjusted using either the wrench on the time slider popup, or adjusting the time slider manually.
- First, take some time to familiarize yourself with the operation of Google Earth and the time slider bar. For instance, make sure that the 'Borders and Labels' layer is selected (can be found under 'Layers' tab) and that the 'Scale Legend' is on under the 'View' tab to answer the following questions.
- Next, visually inspect the dataset over time to probe for earthquake swarms.

10) Where did you find earthquake swarm activity? Remember that swarms are earthquakes that are clustered in time and space, and usually have similar magnitudes or size. To answer this question, you may need to zoom in and out on different regions in Oklahoma. Include the following in your answer:

a. Town nearest the swarm

b. Central latitude and longitude of the swarm

c. Time window in which you observe swarm activity

d. Approximate radius (in mi) that the swarm spans from the answer to (b)

e. Approximate total number of earthquakes in the swarm (i.e. tens or hundreds)

11) Does the observed swarm activity correlate with the location of nearby wastewater injection wells, the time of completion of nearby hydrofracking wells, neither, or both?

Most induced seismicity occurs within a few kilometers of an active injection well, but due to diffusion of stresses in rock, induced seismicity has been observed to occur up to ~35 km away from injection.

12) *What is the smallest distance you can find between an active wastewater injection well and an earthquake?*

13) *Based on your data and analysis, is there a causal link between wastewater disposal and increased seismicity? That is, do you have evidence to support the hypothesis that fluid injection induces seismicity in your study area? Explain!*

14) *What additional evidence would help you support your claim? Why is it necessary?*