



Title: Earthquakes and Gas Wells: Correlation vs. Causation	
Author: Charre Todd Crossett Middle School Crossett	
Course: Algebra 1 Environmental Science	Duration: 2-3 days
Grade: 9-12	
Objective: <ol style="list-style-type: none"> 1. Students will identify examples of correlation and causation. 2. Students will analyze examples of correlation and identify linking and lurking variables. 3. Students will analyze maps and other data to determine whether a correlation exists between Hydraulic Fracturing in natural gas wells and the number of earthquakes in Arkansas. 4. Students will analyze maps and other data to suggest a possible cause of the increased number of earthquakes in central Arkansas during 2011-2012. 	
Summary of Lesson: News headlines commonly suggest that one factor causes a change in another factor. Often these suggestions of correlation and causation are not only false but ridiculous. This lesson allows students to explore and practice the meaning of the terms correlation, causation, linking variables, and lurking variables. After developing a basic understanding of correlation and causation, students conduct a web quest to compile a set of data from maps and spreadsheets. Students are asked to analyze this data to determine if a correlation exists between the process of hydraulic fracturing to extract natural gas and the increase in Arkansas earthquakes in recent years.	
Standards: Common Core State Standards, Arkansas State Frameworks	
CODE	STANDARD
CCSS.Math.HSS-ID.C.9	Distinguish between correlation and causation.
Arkansas S.ID.9 (math)	Distinguish between correlation and causation.
DIP.5.AI.1 (Old Algebra frameworks)	Construct and use scatter plots and line of best fit to make inferences in real life situations
DIP.5.AI.10 (Old Algebra frameworks)	Communicate real world problems graphically, algebraically, numerically and



	verbally
DIP.5.AI.12 (Old Algebra frameworks)	Recognize when arguments based on data confuse correlation with causation
ESS3.C (A Framework for K-12 Science Education)	Human impacts on Earth Systems
SP.3.ES.1 (Arkansas Environmental Science Curriculum Framework)	Explain the reciprocal relationships between Earth's processes (natural disasters) and human activities
SP.3.ES.2 (Arkansas Environmental Science Curriculum Framework)	Investigate the relationships between human consumption of natural resources and the stewardship responsibility for reclamations including disposal of hazardous and non-hazardous waste
Teacher Excellence Support System: (TESS) Domain One: Planning and Preparation A. Knowledge of content and pedagogy Domain Three: Instruction C. Engaging students in learning	
Instructional Strategies and Practices: <ul style="list-style-type: none"> • Asking questions and defining problems • Planning and carrying out investigations • Analyzing and interpreting data • Using mathematics and computational thinking • Engaging in argument from evidence • Obtaining, evaluating, and communicating information • Real World applications 	
Bloom's Level: Highest Level Only Analysis	
Materials and Resources: <ul style="list-style-type: none"> • Student Handout 1 Earthquakes and Gas Wells: "Drilling might be culprit behind Texas earthquakes" • Student Handout 2: Earthquakes and Gas Wells: Correlation vs. Causation Practice Activity • Student Handout 3: Earthquakes and Gas Wells: Correlation vs. Causation Webquest Instructions • Student Handout 4: Earthquakes and Gas Wells: Correlation vs. Causation Webquest Research Results Sheet • Student Handout 5 Earthquakes and Gas Wells: Earthquakes_Archive2 (Excel spreadsheet) • Various websites listed with links in the body of the lesson 	

**Formative Assessment:**

Gallery Walk, Correlation vs. Causation Practice, Exit Slip, Webquest Research, Class Discussions

Notes to Teacher:

Background information on Hydraulic Fracturing may be found at:

<http://issuu.com/aipro/docs/arkansasoilandgasbook>

Key Vocabulary: correlation, causation, linking variable, lurking variable, hydraulic fracturing, injection well, earthquake magnitude.

If unable to secure computers and internet time, the teacher can project all the maps and data with a presentation machine or the teacher can print copies of the maps. Students may work alone or in pairs depending on the availability of computers. The lesson can be differentiated by allowing students to choose their own method for presenting their findings to the class (PowerPoint, Prezi, poster, etc.).

Depending on the prior knowledge of your students and lesson objectives, you may decide to go into detail on the use of the correlation coefficient; (r) or you may choose to just define the correlation coefficient in simple terms.

Student Activity:**Earthquakes and Gas Wells: Correlation vs. Causation—Part One****Bellwork:**

Give students the article “**Drilling might be culprit behind Texas earthquakes.**” (See Student Handout 1 Earthquakes and Gas Wells: “**Drilling might be culprit behind Texas earthquakes**”) Instruct them to read the article then answer the following questions:

1. Is there a correlation between the number of earthquakes and the number of natural gas wells?
2. Are earthquakes caused by drilling natural gas wells?

Discuss the article as a class:

1. Is the article true?
2. Are all news articles based on fact?
3. Define correlation and causation.

Body of Lesson:

1. Gallery Walk: Post the five statements below on the wall around the room. Divide the class into groups of 3-4. Give the groups 10 minutes to move from statement to statement. The students should discuss each statement, determine the factors involved in each scenario, and decide if the statement is always true, sometimes true, or never true. Each group should be ready to explain their conclusions.



- a. There is a higher number of drowning incidents when more people eat ice cream.
- b. The number of books read is related to the size of your shoe.
- c. The number of outfits purchased by a teenage girl is related to the size of the house she lives in.
- d. Worldwide, people who use tobacco live longer than people who do not.
- e. When the average water usage in a city increases, so does violent crime in the city
- f. There is a higher number of earthquakes in areas where there are natural gas wells.

Lead a class discussion about the gallery walk statements. Introduce the definitions of **correlation**, **causation**, **linking variable** and **lurking variable**.

Causation statement- is one that describes a cause/effect relationship. Typically, the statement can be written as an “If _____, then _____” statement. Outcome A causes outcome B.

Correlation- is an observed relationship between two variables. Two outcomes, A and B are seen at the same time.

Lurking Variable- an extraneous variable that may influence the interpretation of relationships among the variables A and B.

$A \leftarrow C \rightarrow B$; C is the lurking variable that causes a change in both variable A and variable B.

Linking Variable-an extraneous variable not mentioned in the correlation that causes the relationship between the variables A and B.

$A \rightarrow C \rightarrow B$; C is the linking variable. When variable A changes, variable C changes and this causes the change in Variable B.

2. Show the LearnZillion video lesson on Correlation and Causation -- <http://learnzillion.com/lessons/2873-differentiate-between-correlation-and-causation> -- (3.5 min.)
3. Show the Correlation vs. Causality: Freakonomics Movie – <http://freakonomics.com/videos/#originals> (Scroll down to the 4th **large** screen shot. The video is in the middle of the **second row of videos** under that screen shot)
 - Have students identify the correlation from the Freakonomics Movie: (Answer: The number of cases of polio increases with an increase in ice cream sales.)
 - Have students identify the lurking variable from the Freakonomics Movie: Correlation vs. Causality. (Answer: Polio cases spiked in the summer time. Ice cream sales increased in the summer time. Thus, summer is the lurking variable.)
 - Ask students to identify linking or lurking variables in the Gallery Walk statements at the beginning of the lesson. Suggested answers below.
 - The number of drownings and ice cream sales both increase in the summer. So these occurrences are correlated but do not cause each other.



- Age has a positive effect on both foot growth and reading ability.
 - Wealth determines both the ability to buy a larger home and a larger number of outfits.
 - Tobacco is an indicator of wealth. Those who are able to afford tobacco are also able to afford better health care. The poor world-wide are not able to afford either tobacco or health care. If the poor are not able to afford health care, they tend to live shorter lives.
 - Water usage increases in summer when people water lawns and use swimming pools. Violent crime tends to increase in summer possibly due to high temperatures causing more irritability and anger which result in more violent crime.
4. Practice: Assign **Student Handout 2: Correlation vs. Causation Practice Activity** for homework.
5. Exit Slip: Students answer the following question on an index card and submit it as they leave class.
1. A famous television doctor just reported that studies show eating dark chocolate lowers blood pressure. Is this statement an example of a correlation? Does dark chocolate actually lower blood pressure or is there some linking or lurking variable?
 - ✓ **(Answer:** Dark chocolate contains flavonoids which reduce inflammation and improve the elasticity of blood vessels which in turn may lower blood pressure.)

Earthquakes and Gas Wells: Correlation vs. Causation—Part Two

Bellwork:

Display the “**Three Centuries of Earthquakes in Arkansas From 1699 thru 2013**” poster. The poster can be found at: http://www.geology.ar.gov/maps_pdf/geohazards/Arkansas_Seismicity_Map.pdf

1. Zoom in so that students can read the dates of the earthquakes. Ask the students to suggest reasons for the recent concentration of earthquakes in Central Arkansas.
2. Discuss the map and allow students to share their ideas. Remind the students of the article, “**Drilling might be culprit behind Texas earthquakes (Student Handout 1),**” they read for Part One. Ask if the same might be true of earthquakes and hydraulic fracturing in Arkansas.

Body of Lesson:

1. Distribute **Student Handout 3: Webquest Instructions** and **Student Handout 4: Webquest Research Results. (Handouts and Teacher Answer Key follow this lesson.)**
2. Student groups will complete the web quest by examining maps, graphs, and spreadsheet data to determine if correlations exist between natural gas wells and earthquakes in Arkansas. Students will use the same data to determine possible causation of Arkansas earthquakes. Students will need access to the internet. This part of the lesson may take more than one class period.



Resource List:

http://www.eia.gov/dnav/ng/hist/na1170_sar_8a.htm

Arkansas Natural Gas Number of Gas and Gas condensate Wells

http://www.solarplan.org/Research/Well%20Production%20Profiles%20for%20the%20Fayetteville%20Shale%20Gas%20Play%20Revisited_Mason_9%20April%202012.pdf

Several graphs. Annual number of Wells Completed by County is on page 12.

<http://quake.ualr.edu/public/epicenters.htm>

Earthquake Epicenter Map

<http://www.aogc.state.ar.us/notices/Ex.%201B%20-Permanent%20Disposal%20Well%20Moratorium%20Area.pdf>

Permanent Disposal Well Moratorium Area

<http://www.aogc.state.ar.us/Maps.htm> link to Google Earth maps. Download Arkansas oil and Natural Gas Well Map and Drilling Fluid Disposal Sites Map.

<http://www.aogc2.state.ar.us/OnlineData/reports/ALL%20FayettevilleFrac%20FINAL.pdf> Well Locations in Fayetteville Shale of Arkansas on page 8

<http://oilshalegas.com/fayettevilleshale.html>

Lists counties in Fayetteville shale

<http://www.geo.mtu.edu/UPSeis/magnitude.html>

Information on Earthquake magnitude effects and number per year

<http://www.geology.ar.gov/geohazards/earthquakes.htm>

Scroll down and Download Arkansas Earthquake Archive This Excel file with additional worksheets is included on the Arkansas Energy Rocks web site with the other lesson materials. It is titled Student Handout 5 Earthquakes and Gas Wells: Earthquakes_Archive2 (In the Excel spreadsheet Open the "listsortable" sheet. Students can open the Data tab then sort by magnitude of quake, county etc.)

http://www.geology.ar.gov/maps_pdf/geohazards/Enola_Swarm_Map_Area.pdf

A sampling of seismic events recorded near the town of Enola in central Arkansas.



Earthquakes and Gas Wells: Correlation vs. Causation—Lesson Conclusion

Lesson Conclusion:

Conclude the lesson by having the students share their analysis with the class. Require the students to use the terms, correlation, causation, linking variable, and lurking variable, correctly in their presentations.

The students should make the following conclusions from the data:

1. There is a slight correlation between the number of natural gas wells and the number of earthquakes in Arkansas.
2. There is a strong correlation between the number of natural gas wells and the number of earthquakes in Faulkner County.
3. There is a strong correlation between the number of injection wells in the Fayetteville Shale Play and the number of earthquakes in Faulkner County. There is little or no correlation between the number of injection wells and the number of earthquakes in the South West Arkansas oil fields.
4. There is a strong correlation between the location of fault lines and the number of earthquakes in Faulkner County.
5. Based on the evidence there is a high probability that the injection wells in Faulkner County contributed to the earthquakes in the area because the wells were located on or near the previously undetected fault lines.

Student Handouts: (Printable copies of the handouts are available at:

<http://www.arkansasenergyrocks.com/educators/index.html>. (Select Curriculum, then 9-12 Lesson Plan – student handouts accompany each lesson plan.)

Earthquakes and Gas Wells Student Handout 1

Drilling might be culprit behind Texas earthquakes

<http://abcnews.go.com/topics/business/companies/chesapeake-energy-corp.htm>
By Jeff Carlton, Associated Press

CLEBURNE, Texas

The earth moved here on June 2. It was the first recorded earthquake in this Texas town's 140-year history — but not the last. There have been four small earthquakes since, none with a magnitude greater than 2.8. The most recent ones came Tuesday night, just as the City Council was meeting in an emergency session to discuss what to do about the ground moving.

The council's solution was to hire a geology consultant to try to answer the question on everyone's mind: Is natural gas drilling — which began in earnest here in 2001 and has brought great prosperity to Cleburne and



other towns across North Texas — causing the quakes?

"I think John Q. Public thinks there is a correlation with drilling," Mayor Ted Reynolds said. "We haven't had a quake in recorded history, and all the sudden you drill and there are earthquakes."

At issue is a drilling practice called "fracking," in which water is injected into the ground at high pressure to fracture the layers of shale and release natural gas trapped in the rock. There is no consensus among scientists about whether the practice is contributing to the quakes. But such seismic activity was once rare in Texas and seems to be increasing lately, lending support to the theory that drilling is having a destabilizing effect.

On May 16, three small quakes shook Bedford, a suburb of Dallas and Fort Worth. Two small earthquakes hit nearby Grand Prairie and Irving on Oct. 31, and again on Nov. 1. The towns sit upon the Barnett Shale, a geologic formation that is perhaps the nation's richest natural gas field. The area is estimated to have 30 trillion cubic feet of recoverable gas and provides about 7% of the country's supply.

The drilling's economic impact has been significant, because gas companies pay signing bonuses and royalties to property owners for the right to drill beneath their land. Signing bonuses climbed to around \$25,000 an acre at the boom's peak. Cleburne agreed to lease the mineral rights in the earliest stages of the frenzy, receiving a modest \$55 an acre for 3,500 acres of city land. There are about 200 drilling sites in Cleburne, and it is not unusual to see cattle chewing grass in the shadow of gas pipes. Cleburne has collected between \$20 million and \$25 million in royalties since 2001, about \$6 million in 2008 alone, Reynolds said. Such riches have allowed the building of parks and sports complexes in the city of 30,000, about 30 miles south of Fort Worth.

"That's a lot of libraries and police cars," the mayor said proudly. "It's enabled us to escape the worst part of the recession, enables us to keep tax rates low and lowered unemployment."

Landowners are also getting theirs. Locals call it "mailbox money," occasional royalty checks that arrive from the gas companies. The mayor, a contractor who owns three quarters of an acre, said his most recent check, for three months' worth of royalties, was nearly \$850. "It's better than a poke in the eye," he said.

Although many residents never felt the quakes, those who did have described them in different ways. When the first few hit, some ran outside to see if a house had exploded. The city manager said he thought his wife was closing the garage door. Picture frames and windows rattled. None of the quakes caused any damage or injuries, though city officials said they are keeping a close eye on the earthen dam at Lake Pat Cleburne. There seems to be little fear around town of any catastrophic damage, but the ground shaking is unnerving nonetheless. Townspeople want to find out at least what is causing it, even if it is unclear whether anything can be done about it.

The gas is extracted through a process known as horizontal drilling. A company will drill roughly 5,000 feet to 7,000 feet down and then go horizontally for as much as 4,000 feet or so. Then the fracking begins. A spokeswoman for Chesapeake Energy, which owns most of the mineral rights leases in the Cleburne area, said the company is "eager to get to the facts" and is working with the government and local researchers to determine whether there is a link.

"Drilling has occurred for more than a hundred years," Julie Wilson said in an e-mail. "Tens of thousands of wells have been drilled with no nearby earthquakes at all; hundreds of earthquakes have occurred with no drilling nearby."

Cliff Frohlich, a scientist at the University of Texas and author of "Texas Earthquakes," said he believes more than 20 Texas earthquakes in the past 100 years are related to drilling for petroleum and gas. But he added: "I would be surprised if a seriously damaging earthquake came out of this."

John Breyer, a petroleum geologist and professor at Texas Christian University, said drilling is absolutely not causing the earthquakes. "It's like the Great Wall of China," he said. "If you pull a brick out of the wall every half-mile, you are not going to affect the stability of the structure."

The mayor said he is open to any answer the city's geologist brings him.

"We are going to find out what's causing them and if it is something that we can deal with, I promise we will



deal with it," Reynolds said. "But it's like the dog that chases the car and catches the car: I don't know what you do then."

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**Correlation vs. Causation
Student Handout 2
Practice Activity**

Name: _____ Date: _____

For each of the following situations, decide whether there is a correlation or causation. Then identify any linking or lurking variables involved that affect correlation.

1. The older a car, the lower its resale value.

Correlation _____ Causation _____ Linking/Lurking variable _____

2. The more points a student earns in class the higher their final grade.

Correlation _____ Causation _____ Linking/Lurking variable _____

3. When students have a high number of cavities their math test scores will be lower.

Correlation _____ Causation _____ Linking/Lurking variable _____

4. The distance you drive and the number of gallons of gas burned.

Correlation _____ Causation _____ Linking/Lurking variable _____

5. The total amount of money spent on concessions at Phillies games and the number of wins the Phillies have.

Correlation _____ Causation _____ Linking/Lurking variable _____

6. Around the world, higher numbers of Nintendo games per person relate to longer life expectancy.

Correlation _____ Causation _____ Linking/Lurking variable _____

7. As ice cream sales increase, the rate of drowning deaths increases. Eating ice cream causes drowning.

Correlation _____ Causation _____ Linking/Lurking variable _____

8. A study found a relationship between air-conditioning bills and lemonade sales for a sample of households.

Correlation _____ Causation _____ Linking/Lurking variable _____



9. Fewer calories eaten results in more weight loss.

Correlation _____ Causation _____ Linking/Lurking variable _____

10. A study was done and the results showed that people who drove more expensive cars were better golfers.

Correlation _____ Causation _____ Linking/Lurking variable _____

11. Taller people tend to have more money than short people.

Correlation _____ Causation _____ Linking/Lurking variable _____

12. The more minutes a basketball player stays in the game the more points he will make.

Correlation _____ Causation _____ Linking/Lurking variable _____

13. The more firemen fighting a fire, the more damage there is going to be.

Correlation _____ Causation _____ Linking/Lurking variable _____

14. Students who use tutors have lower test scores than those students who do not use tutors.

Correlation _____ Causation _____ Linking/Lurking variable _____

Correlation vs. Causation

Student Handout 2

Practice Activity

Answer Key

Name: _____ Date: _____

For each of the following situations, decide whether there is a correlation or causation. Then identify any linking or lurking variables involved that affect correlation.

1. The older a car, the lower its resale value.

Correlation X Causation _____ Linking/Lurking variable number of repairs/mileage

2. The more points a student earns in class the higher their final grade.

Correlation _____ Causation X Linking/Lurking variable _____

3. When students have a high number of cavities their math test scores will be lower.

Correlation X Causation _____ Linking/Lurking variable Household income

4. The distance you drive and the number of gallons of gas burned.



- Correlation X Causation _____ Linking/Lurking variable type of car/traffic conditions
5. The total amount of money spent on concessions at Phillies games and the number of wins the Phillies have.
Correlation X Causation _____ Linking/Lurking variable attendance at games
6. Around the world, higher numbers of Nintendo games per person relate to longer life expectancy.
Correlation X Causation _____ Linking/Lurking variable wealth accounts for both
7. As ice cream sales increase, the rate of drowning deaths increases sharply. Ice cream causes drowning.
Correlation X Causation _____ Linking/Lurking variable warmer temperature causes both
8. A study found a relationship between air-conditioning bills and lemonade sales for a sample of households
Correlation X Causation _____ Linking/Lurking variable warmer temperature causes both
9. Fewer calories eaten results in more weight loss.
Correlation _____ Causation X Linking/Lurking variable _____
10. A study was done and the results showed that people who drove more expensive cars were better golfers.
Correlation X Causation _____ Linking/Lurking variable Wealth allows for both
11. Taller people tend to have more money than short people.
Correlation X Causation _____ Linking/Lurking variable older people are taller and have more money than younger people
12. The more minutes a basketball player stays in the game the more points he will make.
Correlation X Causation _____ Linking/Lurking variable Possession of the ball
13. The more firemen fighting a fire, the more damage there is going to be.
Correlation X Causation _____ Linking/Lurking variable _____
14. Students who use tutors have lower test scores than those students who do not use tutors.
Correlation _____ Causation _____ Linking/Lurking variable poor study habits cause both

Earthquakes and Gas Wells: Correlation vs. Causation

Student Handout 3

Webquest Instructions

Directions: Use the web or print resources provided to answer the following questions. You will record your findings on a separate research results sheet.

1. Natural Gas Wells and Earthquake Frequency---State data

Go to: http://www.eia.gov/dnav/ng/hist/na1170_sar_8a.htm



- A. Describe the trend in number of Natural Gas wells from 1990 to 2012.
- B. Identify two periods which saw a sharp increase in the total number of Natural Gas wells in Arkansas.

Go to: <http://www.geology.ar.gov/geohazards/earthquakes.htm> Scroll down and [Download Arkansas Earthquake Archive](#)

- C. Use the data to determine the number of magnitude 3 or greater earthquakes in Arkansas each even year period from 1990 to 2012 and 2011. You may want to create a graph for ease of comparison.
- D. Compare the earthquake data to the number of gas wells.
- E. Does the evidence show an overall correlation between the natural gas wells and the number of earthquakes in Arkansas? Look specifically at the two periods of sharp increase in total numbers of wells. Was there a correlation between increased drilling and earthquakes?
- F. What county accounted for the largest number of earthquakes from 2011 to 2012?
- G. Does this data prove that natural gas wells are the cause of increased earthquake activity in Arkansas? Explain.

2. Natural Gas Wells and Earthquake Frequency---County data

Go to:

http://www.solarplan.org/Research/Well%20Production%20Profiles%20for%20the%20Fayetteville%20Shale%20Gas%20Play%20Revisited_Mason_9%20April%202012.pdf Find the graph entitled “Annual number of Wells Completed by County” on page 12.

<http://quake.ualr.edu/public/epicenters.htm> Earthquake Epicenter Map

<http://oilshalegas.com/fayettevilleshale.html> List of counties in the Fayetteville Shale Play.

The Fayetteville Shale Play is a reservoir of natural gas 50-550 feet below the surface. Hydraulic fracturing is used to access the natural gas and bring it to the surface. Hydraulic fracturing is a process which pumps millions of gallons of water, sand and chemicals underground to make tiny fissures (cracks) in the rock to release the gas.

- A. Compare the bar graph showing the number of wells by county and the Earthquake Epicenter Map.
- B. Describe the relationship between the number of wells and the number of earthquakes on a county by county basis?
- C. Do these graphs and maps suggest a correlation between hydraulic fracturing in the Fayetteville Shale Play and the concentration of earthquakes in the area? Explain.

3. Injection wells in Fayetteville Shale Play and South West Arkansas Oil Fields

Go to: <http://www.aogc.state.ar.us/Maps.htm> link to Google Earth maps.

(If you do not have Google Earth you will need to conduct the free download. From this site **download** [Arkansas oil and Natural Gas Well Map and Drilling Fluid Disposal Sites Map](#). Injection wells are labeled as SWD for well type. Look at the cluster of gas wells in central Arkansas and the cluster of oil wells in Southwest Arkansas. With Google Earth you will be able to zoom in on individual wells and obtain data as to which are oil, gas, or injection wells.)



Go to: <http://www.geology.ar.gov/geohazards/earthquakes.htm> Scroll down and [Download Arkansas Earthquake Archive](#)

Some of the water used during the hydraulic fracturing process is recycled, some is returned to its original location, but a large amount of the water is disposed of permanently in injection wells. This waste water is pumped into underground rock formations far below freshwater supplies. Injection wells are also used to store waste water from oil wells underground.

- A. Determine the number of injection wells by county in both the Fayetteville Shale Play and the South West Arkansas oil fields.
- B. Determine the number of magnitude 3 or greater earthquakes (from 2002 to 2011) in the counties where injection wells are located.
- C. Have all counties with injection wells had the same number of earthquakes?
- D. Do these maps and earthquake data suggest a correlation between the number of injection wells and the occurrence of earthquakes? Explain.

4. Earthquakes and Fault lines in the Fayetteville Shale Play

Go to:

<http://www.aogc.state.ar.us/notices/Ex.%201B%20-Permanent%20Disposal%20Well%20Moratorium%20Area.pdf> Permanent Disposal Well Moratorium Area

http://www.geology.ar.gov/maps_pdf/geohazards/Arkansas_Seismicity_Map.pdf Three Centuries of Earthquakes in Arkansas

- A. Record the number of injection wells located on the map outlining the permanent disposal well moratorium.
- B. Name the injection wells located closest to the concentration of earthquake activity.
- C. What do the yellow circles on the “Three Centuries of Earthquakes in Arkansas” map represent?
- D. In which Fayetteville Shale Play county are the yellow circles located? Does this agree with data discovered in step 1 of this web quest?
- E. Consider only the earthquakes in the central part of the state. Record the number of 4.0-4.9 earthquakes by year.
- F. What do these maps and data tell you about the age of the faults found in the Fayetteville Shale Play?
- G. Do these maps and data show a correlation between injection wells and earthquakes?
- H. Do these maps and data show a correlation between faults and earthquakes?
- I. Do these maps and data indicate a cause for the increase in earthquakes in the Fayetteville Shale Play?

The cluster of earthquakes between Holland and Mount Vernon on the Disposal Well Moratorium Area map is located at Enola, Arkansas.

Go to:

http://www.geology.ar.gov/maps_pdf/geohazards/Enola_Swarm_Map_Area.pdf



- J. What was the Enola Swarm and when did it occur?
- K. Based on all the evidence you have collected, is the Enola Swarm correlated to the increase in natural gas wells drilled between 2010 and 2012? Explain.
- L. L. How does the map of the Enola Swarm area help you determine the cause of the drastic increase in earthquakes in Faulkner County (middle of the Fayetteville shale play) during the years 2010-2012?

5. Analysis: The data you have examined show several correlations. These correlations do not necessarily indicate causation. After examining the data, what is the most likely cause of the increased number of earthquakes in the Fayetteville Shale Play during 2011? Support your claim with evidence. Be prepared to share your conclusions with the class.

**Earthquakes and Gas Wells: Correlation vs. Causation
Student Handout 4
Webquest
Research Results**

Directions: Use the following outline to record data from your research.

1. Natural Gas Wells and Earthquake Frequency---State data

A. Trend in number of Natural Gas wells from 1990 to 2012.

B. Periods of sharp increase in Natural Gas wells in Arkansas.

C. Number of 3.0 earthquakes per even year

	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	2010	2011	2012
No. of Earthquakes													

D. Compare earthquake data/ number of gas wells.



E. Correlation?

F. County with largest number of earthquakes? _____

G. Causation?

2. Natural Gas Wells and Earthquake Frequency---County data

A. Compare the number of wells by county and the Earthquake Epicenter Map

B. Number of wells and the number of earthquakes on a county by county basis?

County	Number of Wells	Earthquake Frequency
Van Buren		
White		
Conway		
Cleburne		
Faulkner		
Independence		

C. Correlation? _____



3. Injection wells in Fayetteville Shale Play and South West Arkansas Oil Fields

A.

County (Fayetteville Play)	Number of Injection Wells
Van Buren	
White	
Conway	
Cleburne	
Faulkner	
Independence	

County (South West oil fields)	Number of Injection Wells
Lafayette	
Columbia	
Union	

B. Magnitude 3 or greater earthquakes (from 2002 to 2011) in counties with injection wells.

County (Fayetteville Play)	Number of 3.0 or greater earthquakes
Van Buren	
White	
Conway	
Cleburne	
Faulkner	
Independence	

County (South West oil fields)	Number of 3.0 or greater earthquakes
Lafayette	
Columbia	
Union	

C. Have all counties with injection wells had the same number of earthquakes? _____

D. Correlation?



4. Earthquakes and Fault lines in the Fayetteville Shale Play

A. Number of injection wells in permanent disposal well moratorium area _____

B. Injection wells closest to the concentration of earthquake activity

C. Yellow circles on “Three Centuries of Earthquakes in Arkansas” map represent _____

D. Fayetteville Shale Play county containing yellow circles: _____

E. Record the number of 4.0-4.9 earthquakes by year:

Year	Number of 4.0-4.9 Earthquakes
1982	
2001	
2010	
2011	

F. Age of faults found in the Fayetteville Shale Play:

G. Correlation between injection wells and earthquakes?

H. Correlation between faults and earthquakes?

I. Causation for the increase in earthquakes in the Fayetteville Shale Play?

J. What was the Enola Swarm and when did it occur?



K. Correlation between the Enola Swarm and Natural Gas Wells?

L. Enola Swarm and causation of earthquakes in Faulkner County?

5. Conclusion:

The data you have examined show several correlations. These correlations do not necessarily indicate causation. After examining the data, what is the most likely cause of the increased number of earthquakes in the Fayetteville Shale Play during 2011? Support your claim with evidence. Be prepared to share your conclusions with the class.

Student Handout 5 Earthquakes _Archive2 is an Excel file. Go to:

<http://www.arkansasenergyrocks.com/educators/index.html>. Select Curriculum; 9-12 Lesson; go to the lesson plan, then select the student handout.